THE STABILITY AND RECOVERY OF RIB FABRICS PRODUCED FROM BULKED NYLON YARNS

by

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THESIS

submitted to the

UNIVERSITY OF GLASGOW

in accordance with the regulations

governing the award of

the DEGREE of

DOCTOR of PHILOSOPHY

in the Faculty of Science

Fibre Science Department,

The University of Strathclyde,

GLASGOW.

AUGUST 1966

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ACKNOWLEDGEMENT

The author wishes to express his sincere gratitude to Professor R. Meredith for the interest he has shown in the present investigation; to Mr. A.W. Marvin for his guidance and encouragement throughout the present work, to Messrs. I.C.I. (Fibres) Ltd. for the courtesy and co-operation in supplying and processing the yarns used in the present study.

Thanks are also due to Dr. N. Peacock, Dr. H.M. Elder, Dr. J. Ferguson and Mr. Z. Grosicki for their help, and to all colleagues for their friendly co-operation at all times.

Finally, the author is indebted to I.C.I. (Fibres) Ltd., for the financial assistance which made this work possible.

ABSTRACT

With the introduction of bulked synthetic yarns, investigations into the dimensional properties of plain fabrics knitted from those yarns have been made and a certain amount of information obtained. In the present work an attempt has been made to extend that investigation to the 1 x 1 rib structure, which in addition to being of considerable commercial importance, is also the basic knitted ribbed structure.

For fabrics knitted from bulked yarns, it is not sufficient that they should be only dimensionally stable but that they should possess also the properties of ease of extensibility and subsequent recovery from that extension. Therefore, the work was designed so as to cover the broad aspect of the properties and performance of rib fabrics.

The first part of this thesis is concerned with the dimensional properties of 1 x 1 rib fabrics, whereas the second part deals with the load-strain and elastic recovery characteristics of those fabrics. All the fabrics used in this work were knitted on a Universal Power Flat Machine without employing any positive feeding device. The influence of various yarn and machine variables such as yarn denier, crimp rigidity, filament denier, method of yarn bulking and alteration of stitch cam setting on the dimensional and elastic recovery properties of 1 x 1 rib fabrics have been investigated. The work is concerned with the properties of fabrics knitted from bulked nylon yarns which were processed by false twist crimping and

stuffer box bulking methods. The influence of three relaxation processes, steam relaxation, wet relaxation and dry tumbling, upon the dimensional stability of fabrics has been investigated.

A detailed assessment has been made of the various methods of measuring yarn collapsing properties of the bulked yarns used in this work. Explanations have been given for different results obtained when the measurements were made in air after the yarns were given relaxation treatments and those obtained when the measurements were made in water by the standard H.A.T.R.A. crimp rigidity test.

The yarn collapsing results have been compared with the performance of these yarns when knitted into fabrics. It has been found that a number of methods used in this work for measuring yarn collapsing properties predict reasonably well the behaviour of yarns comprised of lower denier filaments when in fabric form, but none of these methods appear suitable to predict the performance of yarns composed of higher denier filaments when knitted into fabrics. For such yarns, therefore, a method is required to measure their collapsing properties which would correlate with the actual collapse of these yarns in fabric form.

From the geometry of plain knitted fabrics it is known that the length of yarn in a loop and the number of loops per unit area in the fabric are the predominant factors which affect the dimensions of a fully relaxed fabric. The effect of yarn and knitting variables on the loop length and stitch density of 1 x 1 rib fabrics is discussed in the first part of this thesis, which also deals with other fabric properties such as fabric length to width ratio, area shrinkage, thickness, fabric bulk and fabric air permeability measurements. The limited use of the air permeability test as a measure of fabric bulk is shown.

In order to calculate the relationship between relaxed and measured stitch length for 1 x 1 rib fabric, the same method has been used as that for plain knitted fabric and it is observed that the theory developed for the latter fabric is also generally applicable to 1 x 1 rib fabric.

From the measurements of various fabric properties, it has been found that dry tumbling causes maximum collapse of the fabric and that steam relaxation is an ineffective process in this respect. Heat energy in itself does not seem capable of causing adequate fabric relaxation and as such, mechanical agitation of the fabric during a relaxation process seems highly desirable.

In the second part of this thesis, explanations have been offered for the differences obtained in the elastic recovery and load-strain characteristics of fabrics knitted from false twist crimped and stuffer box bulked nylon yarns. It has been observed that when the fabrics are finished by dry tumbling, various differences such as those due to the method of yarn bulking are diminished.

Comparisons have also been made between load-strain and elastic recovery characteristics of 1 x 1 rib fabrics with those of the half cardigan structure and the results obtained are discussed in terms of the geometric arrangement of yarn in those fabrics.

Elastic recovery characteristics of 1 x 1 rib and half cardigan fabrics made from wool yarns have been compared with those obtained from fabrics produced from bulked nylon yarns and it is found that the former fabrics possess superior recovery properties. It is suggested that the high flexural and torsional rigidities of wool fibres in relation to those of nylon may be responsible for the superior elastic recovery performance of wool fabrics. Thus, if the elastic recovery properties of fabrics made from bulked nylon yarns are required to simulate those of fabrics made from wool yarns, the properties of the bulked nylon yarn must be improved, either by improving the basic fibre properties or by producing a yarn structure having improved properties, or by a combination of both.

PART 1

DIMENSIONAL PROPERTIES OF 1 x 1 RIB FABRICS PRODUCED FROM BULKED NYLON YARNS

GENERAL INTRODUCTION AND SURVEY OF LITERATURE

CONTENTS

1. 1 General Introduction

In the last fifty years there have been many developments in yarn production techniques particularly in the field of man-made fibres. Various types of synthetic fibres have been produced having differing physical and chemical properties. Synthetic fibres are usually available in two yarn states:

(a) as continuous filaments, and (b) as staple fibres.

In staple form the fibres may be blended with wool, cotton or other staple forms and spun on the woollen, worsted or cotton systems giving greater variety of yarns.

Garments or fabrics knitted from staple fibre yarns have the disadvantage of pilling in places where the garment or fabric is subjected to a rubbing action. This pilling appears as small balls or neps of fibres on the surface of these fabrics, the balls or neps adhering more so to the surface of fabrics produced from nylon and Terylene due to the greater tensile strength of these fibres compared to the strength of wool fibres.

Pilling does not generally appear in fabrics made from continuous filament yarns but these fabrics lack many of the properties of fabrics produced from staple fibre yarns, these properties being handle, thermal insulation, moisture absorption and wear comfort. The bulked or textured yarns can be said to be tied to man's search for a suitable substitute for staple fibre yarns.

The bulking process imparts a permanent curl, loop or crimp to the individual filaments, these filaments in their relaxed state having the ability to bulk and stretch to predetermined extent. Bulked yarns have the advantage that they do not have free fibre ends to pull out, roll-up and cause pilling. Bulked nylon yarns are more opaque, have a different appearance and feel, are warmer, more absorbent and have a better covering power than the corresponding regular nylon filament yarns. Thus bulked yarns have bridged the gap between the two basic types of yarns - continuous filament yarns and staple fibre yarns.

The idea of modifying continuous filament man-made yarn was suggested by Heberlein and others but production of these yarns in quantity was not started until about 1952. Since that time a number of modified filament yarns have been marketed and a guide to stretch and bulked yarns has been published by the Hosiery and Allied Trade Research Association.[1]

1.11 Definition of Terms

Textured Filament Yarns

In the broadest sense, any continuous filament yarn which differs from the uniform appearance and smooth texture normally associated with filament yarns might be called a textured yarn.[2]

A certain amount of controversy exists as to the exact definition of the types of yarn now made, but according to the Textile Institute Terms and Definition Committee[3], these at the present time are:

Bulked yarn

Yarns which have been treated physically or chemically so as to have a notably greater apparent volume or bulk sufficiently stable to withstand yarn processing tensions and the normal forces exerted on garments during wear.

Note: The increased bulk is obtained in one method, for example, by the introduction of randomly spaced loops into the individual filaments of the yarn.

Bulky Yarn

1. Yarn in which the apparent density of the filaments is much lower than the real density.

Note: Examples are man-made fibres which are hollow along part or all of their length and fibres which have cross-sectional shapes of such gross irregularity that close packing is impossible.

2. Spun yarns made from staple fibres having a high degree of resiliency.

Note: Such fibres resist the twist imposed upon them during processing and so produce a voluminous yarn, e.g. protein fibres acrylics.

Stretch Yarns

Yarn made from thermo-plastic fibre, usually in the form of continuous filaments, which is capable of a pronounced degree of stretch and rapid recovery. This property is conferred on yarn (having one or more filaments) which has been subjected to an appropriate combination of deforming, heat-setting and developing treatments.

Note 1: The yarns so produced may also have a greater bulk in the unstretched form.

Note 2: It is desirable to be able to distinguish between two broad classes of stretch yarns. These are

a) those produced by crimping, and

b) those produced by twisting and heat-setting.

The former is characterised by wave-like deformation whereas in the latter the deformation is produced by a combination of heat-setting and twisting.

The terms "Torque yarns" and "Non-torque yarns" are also often used for twist stretch and crimped stretch yarns respectively.

Existing methods with the exception of air-jet texturing are confined to modifications of the man-made thermoplastic continuous filament yarns, though the production of the textured yarns is not of necessity confined to thermoplastic materials only.

Normally any yarn which may be set in a compact condition such that the set is permanent to any chemical or physical action that the yarn may encounter in its normal usage could be made into stretch or bulked yarns. This procedure has been shown to be possible with woollen or worsted yarn[4]. Therefore, since it is the thermoplastic nature of most synthetic fibres which is exploited by the texturing processes, it is appropriate to consider the effect of heat on thermoplastic materials in general and on thermoplastic fibres in particular.

1.12 Thermoplastic Properties of Synthetic Fibres

Any substance which is capable of being repeatedly softened on heating so that it can be reshaped by mechanical forces in its plasticised form is known as thermoplastic material. On cooling, it sets in whatever shape it has been caused to assume, and if reheated to a suitable temperature it may be further shaped as required.

Many of the synthetic fibres are thermoplastic and they generally soften at higher temperatures than they are likely to be subjected in their end-uses and this enables them to be heat-set in either yarn form or fabric form. It is this property which makes the synthetic fibres ideally suited for the manufacture of heat-set bulked yarns.

When substances undergo changes of state on heating, such as from solid to liquid, and liquid to vapour, such changes are accompanied by the intake of latent heat and by sharp volumetric change and are generally known as "First Order Transitions".

With polymorphous substances, a sharp melting point temperature exists, this being the temperature at which both the solid and liquid states can exist, and corresponds to the breakdown of the crystal lattice. When most fibre forming polymers are considered, it is known that they are partially crystalline, and therefore their melting point is preceded by a softening of the substance due to the melting of the non-crystalline regions. It is therefore a normal practice to quote a softening temperature for such polymers and this is usually 20° to 40° C below the melting point and corresponds to the beginning of the transition from the solid to the liquid state.

Besides "First Order Transition", there are also transitions of lower orders such as "Second Order", "Third Order" etc., transitions. The second order transition temperature is not accompanied by the intake of latent heat and sharp volumetric changes, but there is a marked change in physical properties such as co-efficient of expansion, its specific heat and modulus of elasticity[5].

This phenomenon can be readily observed with amorphous polymers such as rubber and polystyrene, where the effect of second order transition is very pronounced. At room temperature, rubber is soft and elastic but on cooling down to approximately -70° C it assumes hard, brittle and "glassy" characteristics. Similarly, polystyrene at low temperatures is a glassy, hard and rigid substance but on heating through its second order transition temperature, it changes to an extensible rubber-like material. On cooling it returns to its original rigid form.

In both forms, the molecules of such non-crystalline polymers are dispersed in an irregular configuration, each molecule having a randomly kinked form. However, at temperatures below the second order transition point, the molecules have a high resisting power against any imposed deformation because of the strong inter-molecular forces of attraction. When heated above the second order transition temperature, the molecules attain a greater degree of flexibility by virtue of the reduction of the inter-molecular forces, and therefore the structure is less rigid.

Thermoplastic continuous filament yarns are generally mechanically deformed into the desired shape and heat-set to temperatures between the second order transition and softening point in bulking or texturing processes.

At this juncture it is appropriate to outline the various methods employed to produce heat-set textured yarns.

1.2 Methods of Producing Heat-set Bulked Yarns

In the manufacture of bulked yarns from thermoplastic filaments, the following techniques are known to be in commercial use and will be considered in some detail.

1) Bulked yarns produced by twisting, heat-setting and untwisting (multi-step process)
2) Bulked yarns produced by the false twist method (continuous process)
3) Bulked yarns produced by the modified false twist method
4) Bulked yarns produced by the stuffer box method
5) Bulked yarns produced by the edge crimping process
6) Bulked yarns produced by air texturing
7) Bulked yarns produced by other methods

1.21 Bulked Yarns Produced by Twisting, Heat-setting and Untwisting

Since this is one of the first methods which was used for the production of heat-set bulked yarns, it is interesting to know the origins of this process, which is a development of crêpe yarn processes.

The first crêpe yarns were made from real silk[6]. A very high twist was inserted, the exact amount being dependent on yarn denier, the finer the denier, the higher the twist inserted. These yarns with high twist were generally woven as weft in a plain warp and when the fabric was wetted, the filaments were swollen and because of their high twisting they tended to snarl or distort resulting in "pebble" or "figure" to the fabric. When this technique was borrowed from the silk industry for use with regenerated cellulosic fibres it was found that viscose rayon was eminently suitable for crêpe fabrics and indeed was used in tremendous quantities. Cellulose acetate when twisted to form a crêpe yarn did not shrink when finished in fabric form as did viscose. Eventually it was observed that if the cellulose acetate yarn was twisted in a steam filled atmosphere, preferably under a little pressure, the resultant crêpe would cause the fabric into which it was woven to shrink and to exhibit a good crêpe figure on finishing. The refusal of the cellulose acetate yarn, twisted normally (in the absence of steam) to crêpe, was partly due to its low swelling capacity in water and partly due to its plastic and easily deformable nature. The steam twisting made no difference to the low water imbibition, but this setting orientated the structure of the yarn and gave it rigidity, so that the cellulose acetate crêpe yarn then behaved as a highly twisted yarn, the thermoplastic nature of cellulose acetate permitting its conversion into crêpe yarn. A further development of this method, using synthetic continuous filament yarns led to the production of yarns having bulking properties produced by separate twisting, heat-setting and untwisting stages.

The first step in the conventional multi-step Helanca[7,8] (a trade mark owned by the Heberlein Patent Corporation) process consists of highly twisting the yarn as it is wound under tension upon a bobbin. The stresses are of such magnitude that care must be exercised to prevent the bobbin collapsing. These stresses are utilised functionally to enable fabrics produced from bulked yarns to relax during finishing operations.

The second step is accomplished by subjecting the wound bobbins of highly twisted yarns to steaming under pressure for several hours. The temperature of the steam and the moisture plasticises the thermoplastic material and consequently all the stresses come to equilibrium through a shifting or re-orientation of the molecules of the fibre in its then plastic condition.

Finally, the yarn is cooled to stabilise the molecules to their new position and rewound on to a spinner bobbin, the yarn being highly twisted but this time in the opposite direction. This is the finished product with its capacity to relax. This force of relaxation is made use of in various ways e.g:

a) One right twist yarn is plied with one left twist yarn so that opposing forces balance each other. The balancing of the opposing forces helps to prevent bias in knitted or woven fabrics, but the torsional forces that continue to fight each other to bring about balance give rise to many desirable characteristics in fabrics such as handle, resilience, stretch, recovery from stretch, crease resistance, dimensional stability etc.

b) A single yarn may be used as a crêpe yarn is used to create fabric effects. If not held taut, the strong torsional forces tend to separate the individual filaments of a multi-filament yarn or fabric causing the yarn or fabric to shorten as the yarn attains greater bulk. Fortunately, in yarn or fabric form, the degree of bulking and shortening can be controlled by subjecting the yarn or fabric to heat-setting while under stress.

1.22 Bulked Yarns Produced by False Twist Processes

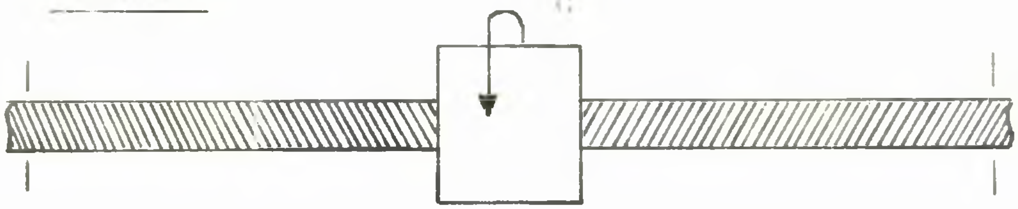
The low production capacity typical of the conventional, multi-step crimping process soon led to attempts to devise continuous methods. The first patents which date back to 1933 were registered in England and were meant to be used on artificial silk[9]. The processes now employed to crimp synthetic fibres are mostly based on Swiss and French patents granted in 1953[10] and 1954[11].

The operating principle of all types of false twist crimped yarn machines is very simple and interesting. To understand the principle consider a length of multi-filament yarn held at two points A and B as shown in Figure (1) and made to rotate at an intermediate point C, twist being inserted in one direction in portion AC and in the opposite direction in the portion CB. However, although if either half of the yarn is considered separately it would be observed that the twist is real, the algebraic sum of twists throughout the length of the yarn as a whole is zero, this process being known as "false twisting". With the false twisting tube rotating continuously but with the yarn passing forward, the system reaches a state of equilibrium whereby little or no twist exists in the yarn state after that yarn has passed through the tube because of the cancelling out of the twist on the delivery side of the tube[12]. Thus when equilibrium is reached, there is constantly twisted yarn on the intake side of the rotating tube and untwisted yarn on the output side.

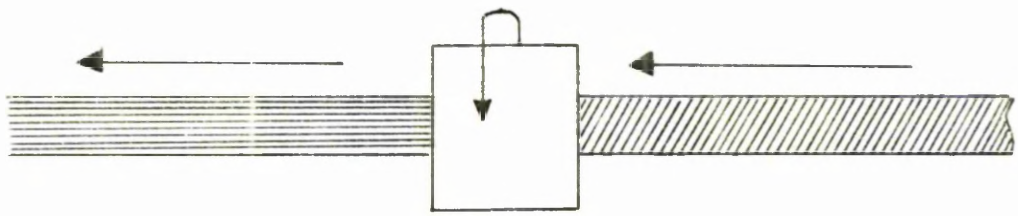
Numerous machines are marketed for the production of bulked yarns by false twist methods. However, the basic features of any false twisting process are shown schematically in Figure (2).

By interposing a heater on the intake side and allowing enough space for cooling of the yarn to take place before the

Figure.1.

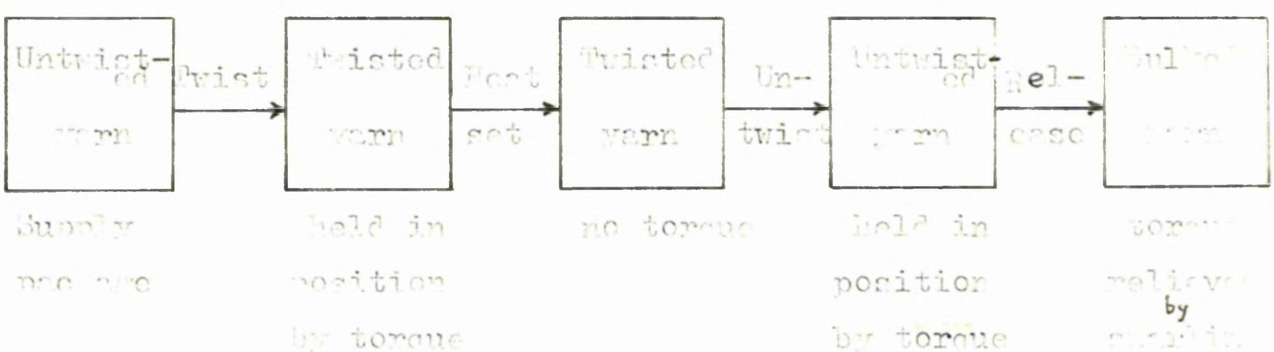


Insertion of False Twist in a stationary yarn.



Insertion of False Twist in a moving yarn.

Figure.2.



twisted yarn passes through the rotating tube, the three basic stages of twisting, heat-setting and untwisting are carried out continuously on one machine as illustrated in Figure (3). The yarn is taken from the supply package and fed at a controlled tension over the heater, through the false twister and then wound on to a take-up package with twist between the twister tube and the feed rollers set into the yarn by heating and subsequent cooling before it passes through the twister.

Heating is usually done by conduction, or radiation or a combination of the two, usually using electrically heated devices. Other methods of heating such as circulating hot fluid systems may be used and steam has also been tried[13]. The modern dry heat-setting methods are much superior to the steam method. If the quality of the steam varies, this will have a pronounced effect on the characteristics of the resultant crimped yarn.

Having considered the basic principles and stages involved in the manufacture of false twist crimped yarns, it must be stressed that there are five important variables in the process. These are

a) Type of yarn used

b) Yarn speed through the machine

c) Processing tension

d) Temperature to which the yarn is heated

e) Amount of false twist inserted

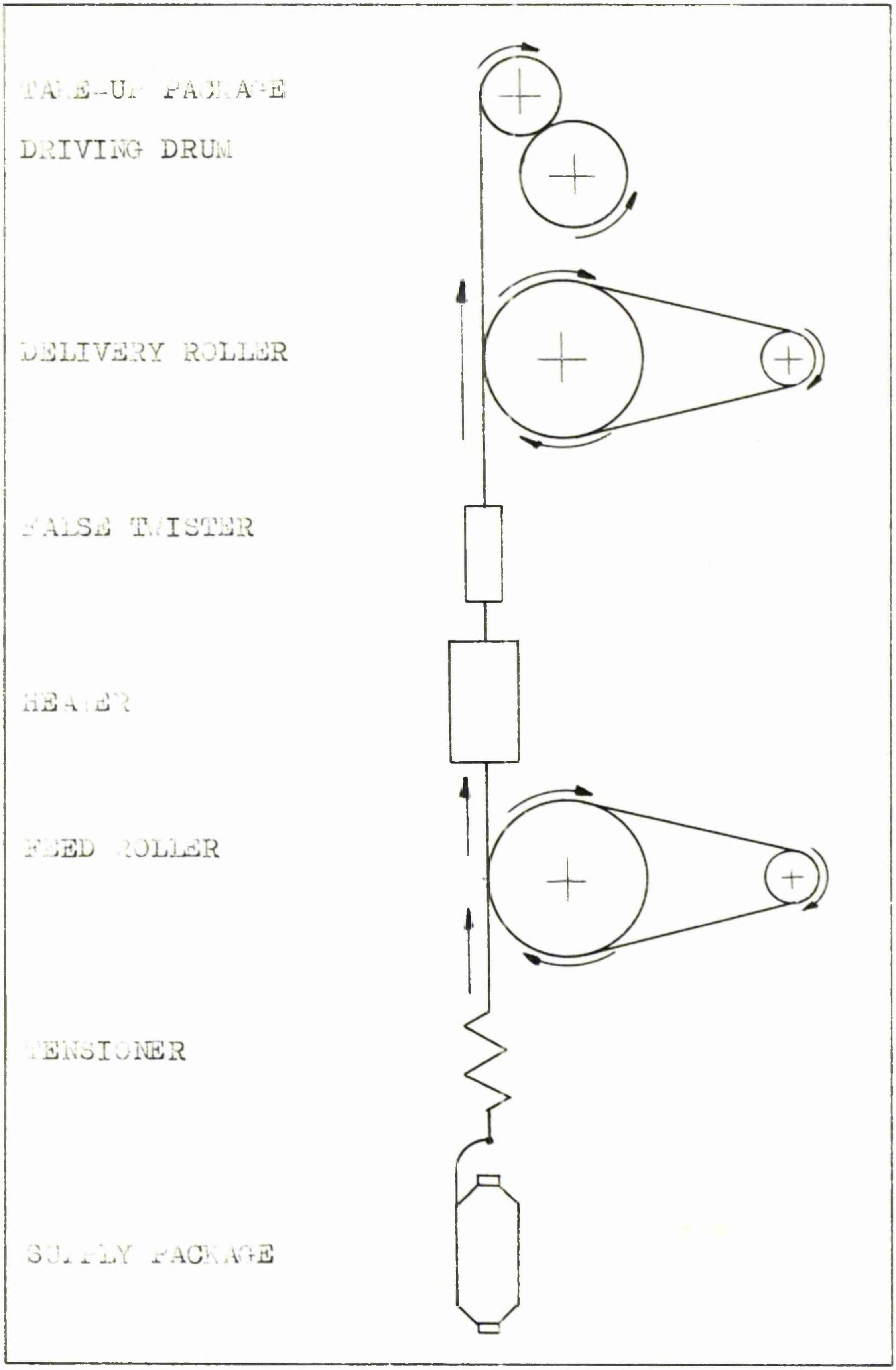


Fig.3. Illustration of the principle of the manufacture of bulked yarns by the false twist method.

The speed of processing is obviously of commercial importance and is generally limited by the rate at which false twist can be inserted. With more recent high speed methods such as friction twisting, heating of the yarn may become the limiting factor. However, speed appears to have very little effect on the quality of yarn produced, except perhaps at very high speeds when there may not be sufficient time for the molecules in the fibres to rearrange themselves as desired.

The quality of the yarn is greatly influenced by the last three mentioned variables, viz; tension, temperature and twist. The influence of these factors on yarn quality will be considered in some detail when the properties of these crimped yarns are considered later. At the moment it is sufficient to say, that the throwster by varying three T's i.e. tension, temperature and twist has the scope of producing a wide variety of textured yarns. Bulleid[14] has given typical details for the relationship between the variables for the production of 60/20 nylon yarn by false twist process as follows:

Twist head speed	30,000 r.p.m.
Amount of twist	75 per inch
Yarn speed	30-40 feet per minute
Heater temperature	430 ± 5° F
Yarn tension	2.5 - 5 g
Over-feed	5%

It is also important to realise that false twist crimped yarns exhibit torque in their singles form. To prevent spirality occurring in fabrics knitted from them, S and Z twisted singles yarns are folded together to give a balanced effect.

False twisting of yarn does not retain as much lustre as certain other types of bulking[15].

1.23 Bulked Yarns Produced by the Modified False Twist Process

When bulked thermoplastic yarns were introduced, it was soon appreciated that the inherent collapse and stretch properties of these yarns could be usefully exploited in the production of hose to add to the natural high extensibility of the knitted structure. The important advantage was that the range of hose sizes necessary to cover all shapes and sizes of legs could be reduced, and it was optimistically expected that the collapse of the hose would remove for ever the problem of length variation in the finished hose. As stretch yarns began to be applied to other types of garments such as men's and children's socks and underwear, this increased extensibility was of less advantage. Ultimately when these yarns came to be considered for outerwear, their stretch properties were an embarrassment rather than an advantage. For this application, modified textured yarns were required having lower stretch characteristics but retaining their bulk properties.

The development of these new yarns having bulk with reduced stretch has been the major commercial development in the last few years. All the methods are based on the same simple principle illustrated in Figure (4). The yarn is processed in the normal thermal manner at the first stage of the process by passage over the heater and through the false twister. This produces the yarn with normal collapse and extensibility. This yarn is then allowed to collapse to a fixed degree by overfeeding the crimped yarn to a known amount into a second heat treatment zone, so designed that the temperature the yarn attains on this heater is in excess of the temperature attained at the first heater. Thus the crimped yarn is reset in its partially extended condition and its elasticity considerably reduced for only a slight loss of bulkiness.

It should be noted that the re-heat-setting of false twist crimped thermoplastic yarns under controlled conditions makes it possible to produce a wide variety of modified false twist crimped yarns having properties that make them of special interest in many cases. Post-heat treatment of false twist crimped yarns may be used to eliminate shrinkage in yarns and fabrics or to reduce shrinkage and stretch to a predetermined extent. This elimination of shrinkage is of special value in certain woven fabrics where texture, softness and drape are the primary requirements.

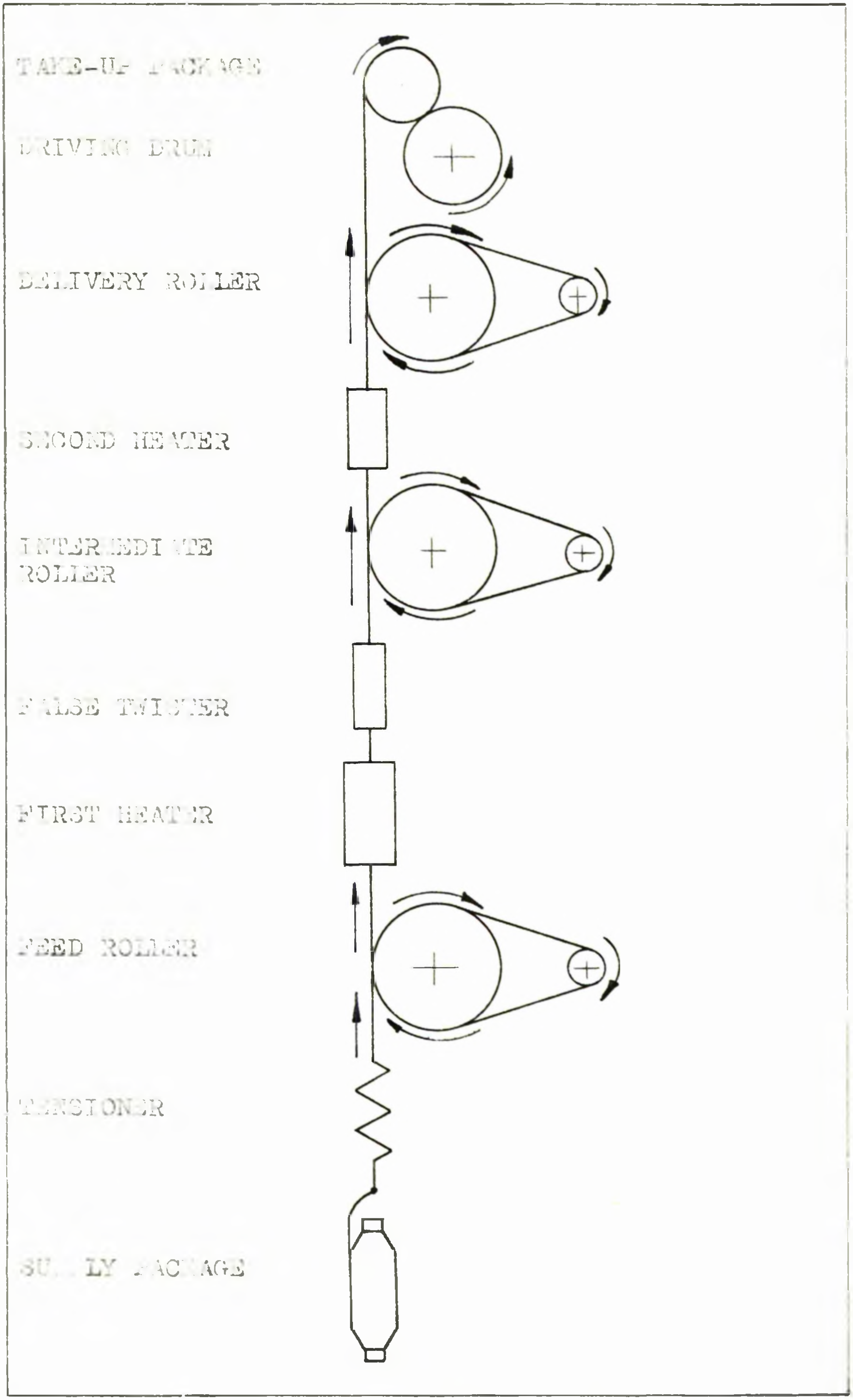


Fig.4. Illustration of the principle of manufacture of modified false twist crimped yarns.

1.24 Bulked Yarns Produced by the Stuffer Box Process

This method was adapted to nylon processing in the crimping of nylon tow for staple production. It has been used for wool for many years to put an extra crimp into the already naturally crimped fibre for making wool more suitable for use in the manufacture of carpets,[16] and also for the crimping of horse-hair used in mattress production. The principle of the process is based on buckling the fibre by end load compression.

The stuffer box method of crimping was developed by Joseph Bancroft and Sons Co. of U.S.A. Yarns are made by this process in many countries under license from the company and sold under the trade name Banlon. The first patent [17] was applied for in the United States in 1934 and number of further patent applications were made, the last patent being published in 1957[18].

The principal features of the process are shown in Figure (5). Thermoplastic yarns are continuously drawn into a tubular stuffer box by a pair of feed rollers operating at linear speeds ranging from 100 to 2000 yards per minute depending on the machine, the yarn processed, the denier used and the results desired. This yarn is compressed against a mass of existing yarns by means of a sliding lid on the upper end of the tube. As a consequence, the yarn buckles producing a characteristic zig-zag crimp and a great degree of bulk and stretch. The crimp in the yarn is heat-set whilst in the electrically heated stuffer box and the take-up is arranged to be slower than delivery. The movement of the slider plunger on the top of the stuffer box (Figure 5), due to the packing pressure exerted on it by the yarn, is used as means of controlling the speed of the feed rollers, the yarn being taken off to the winding package through a controlled hole in the plunger.

The drive to the feed roller incorporates a friction clutch operated by a stuffer box plunger. Roller speed is thus reduced by pressure of the yarn on the lid and thus runs at an almost constant speed with the clutch acting as a slipping drive.

The rate of withdrawal of yarn is also adjustable so that the plunger remains at a constant level and in this manner a constant and uniform length of treatment in the stuffer box is achieved[17]. If the yarn withdrawal occurs at a rapid rate, the plunger actuates a solenoid through a leverage system, so causing a slippage of the take-up roller and hence reducing the take-up speed.

It has been shown that in the stuffer box crimping process crimping occurs immediately behind the feed roller nip[19], contrary to previous ideas and claims that the effect takes place inside the stuffer box, each filament buckling simply as a strut (Figure 6).

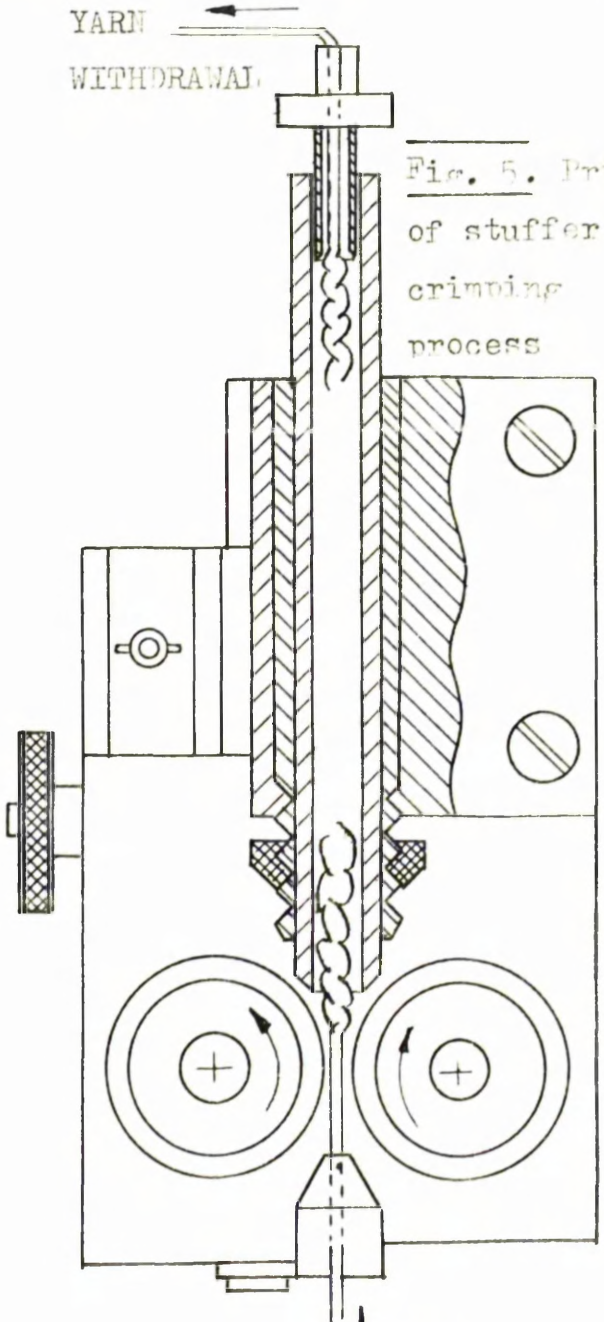


Fig. 5. Principle of stuffer box crimping process

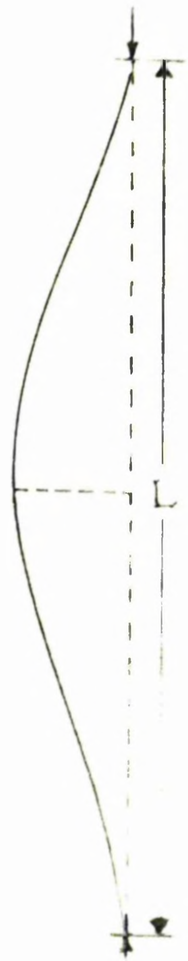
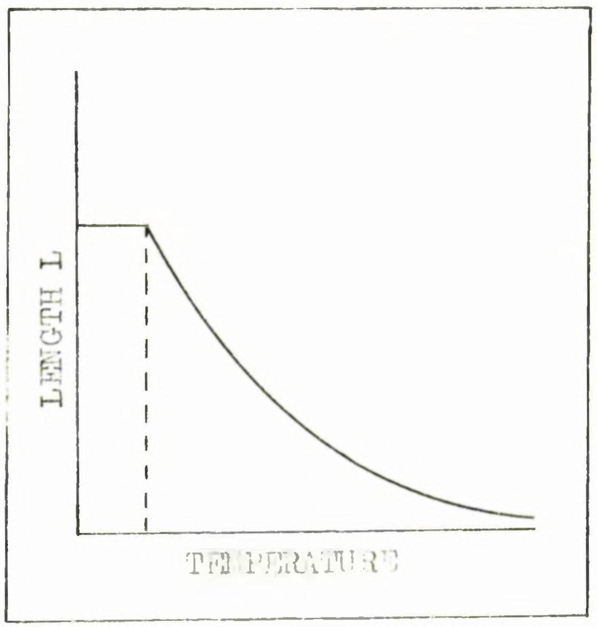


Fig. 6. Showing the buckling of an individual filament under end load compression (left), and (right). the change in the buckling length L, with changes in the temperature of nylon 66 yarn.



The buckling length L of a filament is given by Euler's formula[20]

$$P = K \frac{EI}{L^2} \quad \ldots\ldots \quad [A]$$

where P = end load, E = Young's modulus for the material, I = second moment of area of the filament cross-section.

As 'I' is proportional to the fourth power of the diameter, it is therefore proportional to the square of the denier. From Equation [A], $L \propto \sqrt{EI/P}$ for a given stiffness and given filament cross-section, the crimp length can only be reduced by the increased compressive load. A high compression load presents problems of extreme difficulty in the control of the yarns, both from the point of view of propelling it in the stuffer box and in achieving an adequate grip on the yarn by the rollers without causing excessive crushing. It follows, therefore, that there is a limit to the practicable reduction of crimp length with this process unless the stiffness of the filament is reduced. This can only be done by softening the filaments before crimping. For most materials the stiffness falls as the temperature is increased and this is particularly true in the case of thermoplastic fibres like nylon and Terylene[21]. From the relationship between temperature and Young's modulus it is possible to arrive at a practical and suitable crimping temperature.

The distribution of the heating media is of some importance as a part of the mass of the crimped nylon contacts the walls of the hot stuffer box while passing through the heated zone, whereas the bulk of the yarn receives its heat by contact with the hot air in the box and by radiant heat extending inwards from the walls of that box. This radiant heat will not reach all of the yarn, that nearest the walls receiving most of the heat. The specific heat of air is only a fraction of the specific heat of metal at the same temperature. This heat differential produces a yarn having certain variables within itself and affecting such factors as dye absorption. There are ways of overcoming this problem, these having been developed by Joseph Bancroft and Sons Co., details of which are not published but made available only to licensees of the stuffer box process of bulking.

Before the yarn in its crimped form is withdrawn by application of tension it must be cooled. Heat-setting in the stuffer box is not complete unless the cooling is complete. In the original process there is no special provision made for cooling, though it must take place while the fibres are still in the deformed state as otherwise the crimp would be removed. Taylor and Bhattacharyya[19] designed two devices to exploit the advantage of reduced crimp length and increased crimp frequency which can be achieved by delivering pre-heated filaments into the stuffer box. These devices consist of a pair of heated feed rollers to heat and deliver the yarn into a setting tube provided with a means of applying back pressure and in which the yarn is cooled and set. One of the devices employed uses "Ballotini" as a means of applying back pressure and cooling while the other uses mercury. They found that this method yielded an improvement in the linear frequency and stability of the crimps. It is claimed that the fundamental difference between this method and those in commercial use is that the processing sequence consists of softening, buckling and then cooling instead of buckling followed by the application of heat for the purpose of setting as in the commercial process. Thus with a pre-heat technique, it is possible to achieve a desired effect at a lower temperature and with heat applied to the yarn for a shorter period of time. As a consequence, the amount of degradation in the basic polymer is reduced as is evidenced by the superior strength of a pre-heat crimped yarn.

In Czechoslovakia another stuffer box crimped yarn was recently developed under the name Anilon[22]. The principal difference between this method and the conventional Banlon method is that a wedge with a "run-on-edge" is inserted beneath the feed rollers in close proximity to them. The wedge has an oblique groove at an angle of 45° in the run-on-edge. The yarn to be crimped is stuffed into an obliquely set stuffer box which can freely adjoin the feed rollers. A controller feeler adjusts the yarn content in the stuffer box, the yarn being fed in and forced against the existing mass of yarn. The rest of the process is almost similar to the Banlon process. The claims made for the process are the ease of the manufacture of the machines and a probability of a reduced number of broken filaments. In the Banlon process, the yarn tends to be caught beneath the stuffer box, the rollers having a tendency to attract the cold yarn. This effect may also be expected in the Anilon process.

'Spunized' (registered trade mark of Spunize Company of America, Inc., U.S.A.) and 'Tycora' (registered trade mark of Tycora Texturized Yarn Co. Inc., U.S.A.) are other crimped yarns produced by the stuffer box methods. The processes employed were specifically devised to texturize coarse yarns and carpet fibres. The Spunized process differs in two respects from the Banlon process: the continuous filament fibres are not textured individually but in tow form and the thermo-setting is carried out in an autoclave at a later stage as a separate operation.

Yarns crimped by stuffer box processes are essentially of non-torque types, therefore the operation of doubling one S twisted and one Z twisted end, usually applied to yarns produced by twist-heat-set-untwist methods to balance the twist, is not necessary for yarns crimped by stuffer box techniques.

1.25 Bulked Yarns Produced by Edge Crimping Process

The process of edge crimping heated thermoplastic yarns by drawing those yarns over a crimping edge is claimed in U.S. patent[23] and is assigned to Deering Milliken Research Corporation. 'Agilon' is the registered trade mark and the process of bulking itself is sometimes referred to as the 'Agilon process'. This method is employed almost exclusively to crimp polyamide fibres.

Agilon yarns are made by pulling a heated thermoplastic filament yarn over a specially blunted hardened edge and allowing the yarn to cool during the process as shown in Figure (7). The resultant effect of this process is two-fold, namely,

(a) simple bending over the edge causing an uneven distribution of stress throughout the yarn, and

(b) scraping of the tensioned filaments as they pass over the edge, resulting in re-orientation of some of the fibre molecules.

(a) Simple bending over the edge:

Figure (8) illustrates how the filaments of a thermoplastic yarn, which are relatively uniform before being stretched, heated and drawn under tension over a crimping edge and cooled, become varied across the filament cross-section after processing over the edge. The part of the filament nearest the edge is sharply bent at the edge, being compressed at the point of contact. At the same time the filament is stretched as well at the part farthest from the edge.

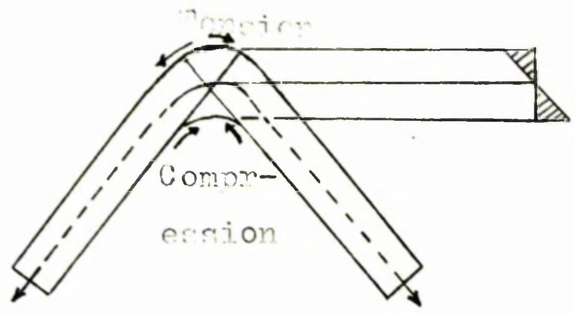


Fig. 8. Illustrating the stresses induced in an individual filament by bending.

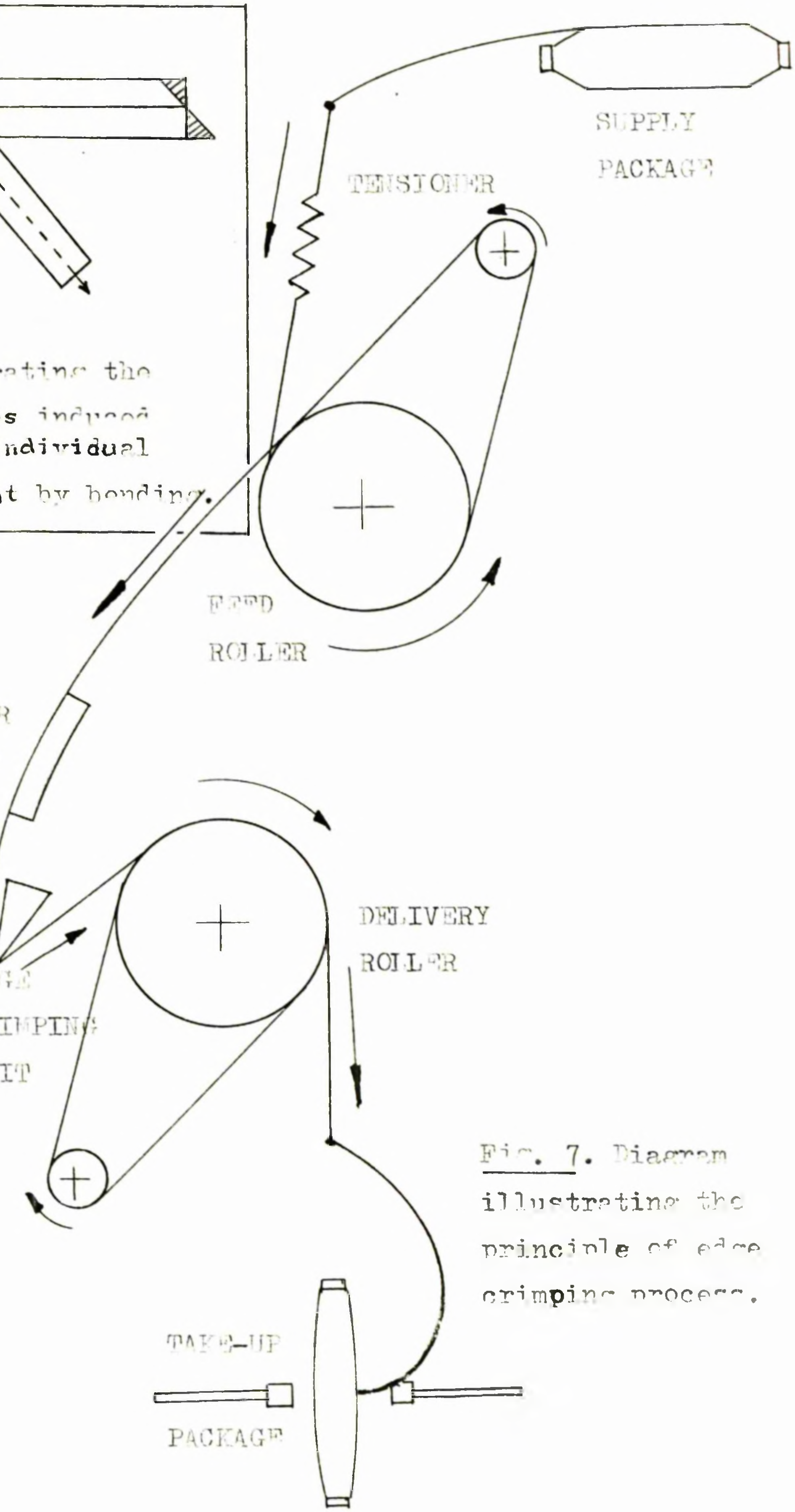


Fig. 7. Diagram illustrating the principle of edge crimping process.

According to the simple theory of bending, the stress at any horizontal layer in the cross-section at the point of bending is proportional to its distance from the neutral axis of the fibre. Since the filament is always moving at the speed of processing, the place in the yarn where this simple state of bending occurs is constantly changing. Also, because there is no restraining couple to prevent the rotation of the filament, the natural effect is for the side of the filament which is in tension to assume a state of compression by rotating towards the drawing edge and vice versa. Thus the filament is constantly being bent one way and then the other as its various layers revert alternatively from the state of compression to tension. This deformed structure of the filament is heat-set as the fibre cools down as it passes over the blade.

The crimp in the Agilon yarn is in the form of a helically-coiled spring, except that the coils reverse their direction at more or less regular intervals and as such the yarns produced by this process are essentially non-torque type.

(b) Molecular re-orientation:

It is known that in a drawn synthetic fibre such as nylon, the molecules are orientated in an approximately parallel order to the fibre axis. When such a fibre is pulled over an edge under tension, the side nearest the edge is flattened. It has been observed[24] that the molecules in the area near the flattened edges get re-orientated parallel to the scraping edge and are therefore perpendicular to the fibre axis, whereas areas away from the scraped side indicate that the molecular structure in those areas remains unchanged and is therefore orientated in a reasonably parallel order with the fibre axis. This change of orientation will effectively shorten the fibre on its deformed side and will therefore be responsible for inducing a crimp.

The relative importance of either (a) or (b) depends on the conditions of processing and the type of yarn used. If a yarn is composed of few filaments only, each filament will be in contact with the edge and will therefore be deformed, and hence the scraping effect will be predominant in the crimping of such yarns. Alternatively, if the yarn is composed of many filaments, only a small proportion of the filaments will be scraped along the edge at any one time and therefore the part played by the 'scraping effect' in yarn crimping will not be as much as that due to bending.

It is to be noted that fabrics knitted from Agilon yarn do not give a very clear structure[24]. However, if Agilon yarn is allowed to relax by over-feeding on to a developing heater this will result in a proportion of the crimp to be set out while setting the remainder of the crimp more strongly than before this relaxation treatment. The resultant yarns, known as 'Agilon D', give a much clearer structure.

The amount of over-feed and the temperature of the developing heater can be varied to obtain a wide variety of yarns possessing properties as required, e.g. a low over-feed and high temperature will give a yarn of low bulkiness but clear stitch formation in the knitted fabric whereas if high over-feed and low temperature are employed, these will have very little effect on the normal Agilon yarn which will, therefore, retain a high proportion of its bulkiness and poorer degree of stitch clarity.

1.26 Bulked Yarns Produced by Air Texturing Process

The patent rights for the production of air bulked yarns are held by E.I.du Pont de Nemours and Company, Inc., U.S.A. and date from as far back as 1952[25]. 'Taslan' is the registered trade mark used to designate textured yarns made in accordance with the quality standards set by du Pont.

In a smooth continuous filament yarn the rows of capillaries lie in order, one next to another, parallel in a yarn without twist, in corkscrew formation in a yarn with twist. As a result the yarn is very compact. The order in which the capillaries lie is destroyed during a rewinding operation by fraying the yarn with the aid of a jet of compressed air. This underlines the basic principle for the manufacture of Taslan textured yarns. In its simplest form, continuous filament yarn is fed through an air jet to take-up rollers which draw off the yarn at a speed lower than the speed with which it is fed to the air jet. A sectional view of the air jet is shown in Figure (9). The excess of feed speed over take-up speed and the action of air passing through the jet results in the formation of numerous randomly-spaced loops in the yarn filaments hardly visible to the naked eye and also in a corresponding decrease in yarn length and increase in the resultant denier.

In contrast to other methods used in the production of bulked filament yarns, thermoplastic deformation of the yarn is not employed in the Taslan process. Consequently, this process is applicable to all continuous multi-filament yarns, whether cellulosic or synthetic and is entirely mechanical in operation. The process has recently gained importance since it can also be used to crimp glass fibre yarns. By providing extra texture, the fabric designers are able to make glass fibre curtainings with not only greater opacity but also with substantially greater surface interest[26].

The Taslan process provides an opportunity of processing a wide variety of yarns. It is evident that the processing conditions such as over-feed speeds, jet size, air pressure, take-up speed and tension can be varied to produce a range of loop sizes and frequencies in a range of textured yarn effects based upon the use of any given yarn construction. Also in addition to texturing single ends of yarn, multiple ends of different types of yarns can also be processed at the same time by this process.

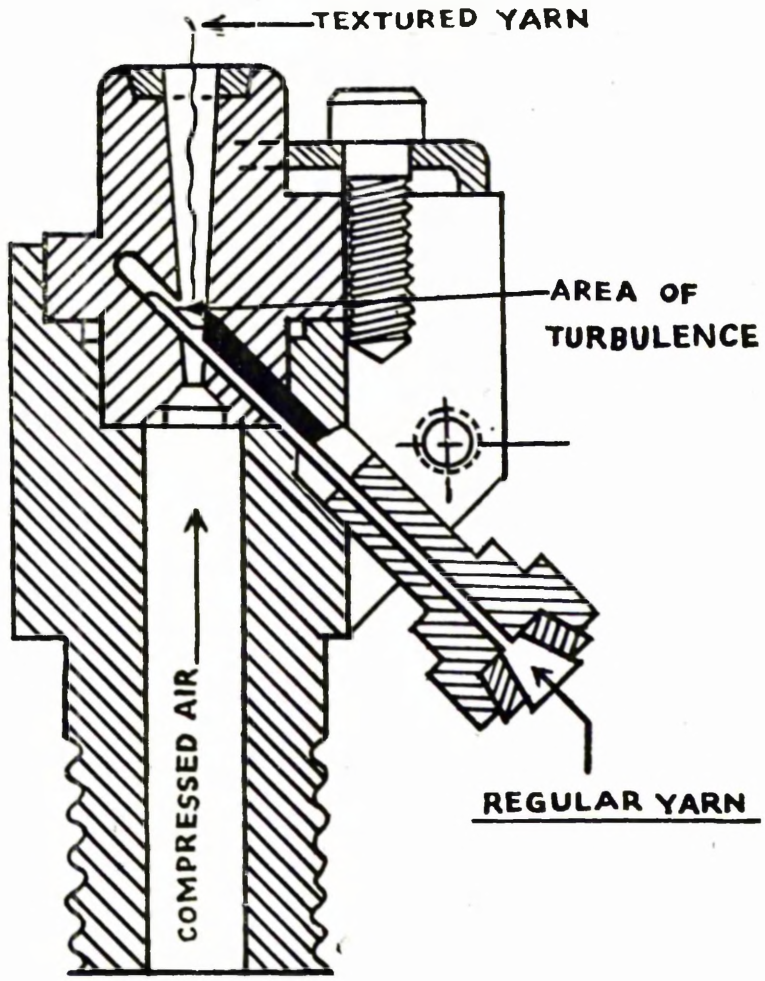


Fig. 9. Sectional view of the air jet system of bulking the yarn.

Recently a new type of bulking device for thermoplastic yarns was devised and in many ways resembles the Taslan texturing process[27]. In this device a stream of hot gas is used to produce the bulk effect on the continuous filament yarns. The yarn is fed into the device at one channel and the stream of hot gas is fed into the same channel at an angle of about 60° on a slightly eccentric axis. This angle and eccentricity produces a whirling action which combined with the temperature of the gas softens and whirls the individual filaments. Both gas and filament leave the bulking device at the same point but the yarn is almost immediately withdrawn from the jet by air to preserve the bulk effect and the yarn is allowed to cool. The technique claims to be able to produce a supplementary elongation of 200% on a 90 denier, 30 filament nylon yarn.

1.27 Bulked Yarns Produced by Other Methods

Numerous other bulking processes have been proposed, but they have not attained much popularity or commercial success. Some of these methods are outlined herewith:

a) Continuous filament nylon yarn is knitted in a tubular fabric and then the fabric is heat set in an autoclave. The fabric is then and the yarn wound on to a suitable package. This type of yarn is known as 'Crinkle' type textured yarn and is torque free. Generally, heavy denier yarns are processed by this method for us in ladies' and men's sweaters. The details of this uneconomical process are disclosed in British patent[28].

b) Attempts were made to make the crinkle yarn process more economical and this resulted in the development of a number of mechanical crimping processes[29], the main element in which is usually a pair of gear wheels. These are heated and the yarn is passed between them two or three times, being longitudinally displaced to a slight degree on each occasion. The result is a fine but very pronounced crimp effect. This process is employed primarily to make carpet yarns by crimping coarse polyamides.

c) Certain methods[30,31] have also been reported which can only be applied at the extrusion or drawing stage and so they are available to only fibre producers. It is known that asymmetry of properties across the filament can be produced in different ways on the already drawn yarns. Similarly, the same effect can be produced at the extrusion of a thermoplastic fibre and the apparatus and product have been described[30].

d) 'Crimp spun' yarns have been produced with the aid of a crimper. This consists basically of two press rollers, a stuffing box or over-feed chamber and a control valve. The stuffing box if not heated and the crimp effects are not set when the yarn is run into the crimper. The crimped yarn from here is conveyed to the converter, cut and lightly drawn. Gill boxes are then used to produce a homogenous, lightly crimped combed sliver and the crimp is set with saturated steam. The sliver is then spun into yarn by the usual methods. The "Perlock"[32] and 'Airvel'[33] processes are other processes based on this principle.

Table (1), which includes basic processes for the production of stretch, modified stretch and bulk type filament yarns, summarises the methods described so far.

Table I

(Guide to stretch and bulked filament yarn processes)[14]

Product	Licensor	Method	Yarn Type
1) Helanca	Heberlein Patent Corporation	Twist-heat set-untwist	Stretch and modified stretch yarn
2) Fluflon	Leesona Corporation	Same as above	Same as above
3) Saaba	Same as above	Same as above	Modified stretch yarn
4) Superloft	Same as above	Same as above	Stretch and modified stretch yarn
5) Textralized	Joseph Bancroft and Sons Co.Inc.	Stuffer box crimping	Bulked yarn
6) Spunize	Spunize Corporation of America	Same as above	Same as above
7) Agilon	Deering-Milliken Research Corporation	Edge crimping	Stretch and modified stretch yarn
8) Taslan	E.I. du Pont de Nemours and Co.Inc.	Looping	Bulked yarn
9) Crinkle	No licensor	Knit-deknit	Bulked yarn
10) Mylast	Clarence and Meyers Co.	Gear crimping	Bulked yarn
11) Stevetex	J.P. Stevens and Co.	Crimping	Bulked yarn

1.3 Appearance, Properties and Uses of Bulked Yarns

1.31 General

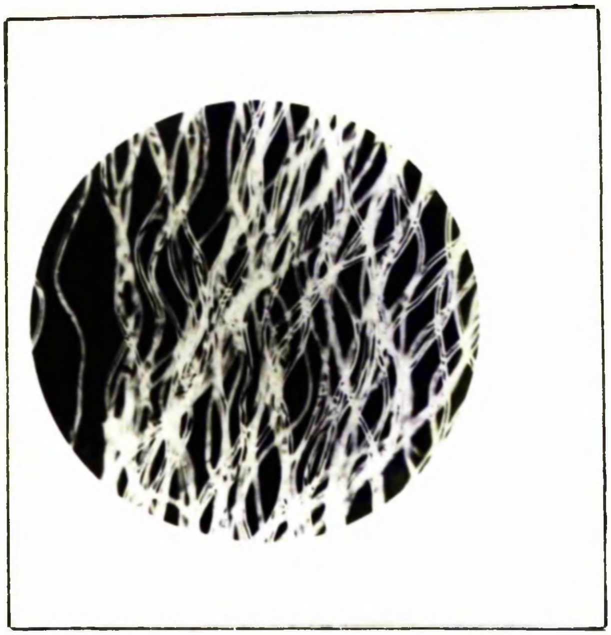
As has been stated previously, bulk or textured yarns are the result of an attempt to bridge the gap between two basic types of yarns (continuous filament yarn and spun yarn). To achieve this objective continuous filament yarns are processed to give them an increased specific volume or bulk, so that they hold more air between the filaments and hence their thermal properties are very much improved. The cold, smooth wiry appearance of the filament yarn is replaced by a warmer, rougher but softer and resilient yarn. This change in yarn form is accomplished by a physical modification of the continuous filament yarn. However, the superiority of the textured yarn lies in the fact that although they simulate spun yarns in many respects, they retain many of the desirable properties normally associated with the filament form of the yarn. Thus the yarns retain the typical hard-wearing properties associated with synthetic fibres and because of the good crease recovery of fabrics produced from filament yarns, the fabrics produced from textured yarns also exhibit good crease recovery properties. As the moisture absorbing capacity of the textured yarns is increased, hydrophobic yarns become more moisture absorptive in fabric form this being a desirable additional property.

1.32 Appearance of Bulked Yarns

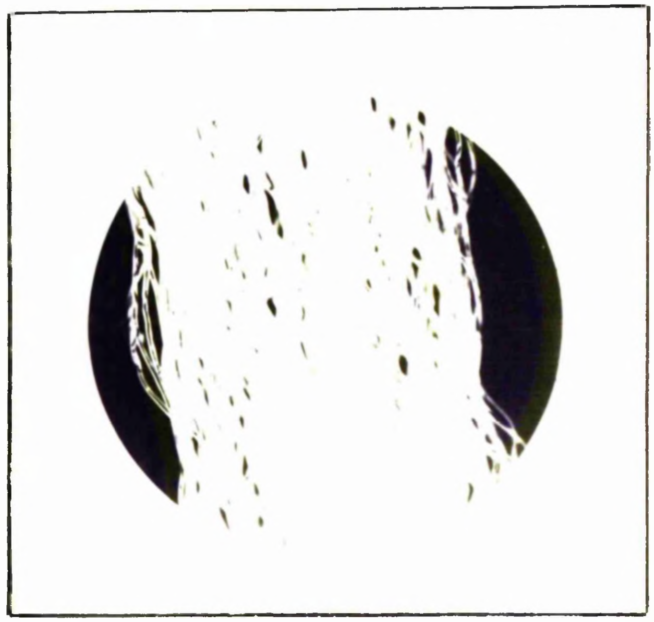
Yarns textured by conventional long processes and continuous false twist processes are similar in appearance and are characterised by their twist lively nature (torque crimp) and by the looping effect which the filaments assume. When these crimped yarns are allowed to relax, an increase in the amount of relaxation increases the size of the crimps and the number of crimps per unit length of yarn. [Plate 1 (1)]

The effect of post-treating false twist yarn is to cause each turn of twist in the original torque crimp yarn to manifest itself as a helical crimp. It will be noted that the post-treated torque crimp filaments, relaxed to the same degree as the torque crimp filaments contain many more uniform crimps than single processed torque crimp filaments. [Plate 1 (3)]

Yarns textured by stuffer box techniques appear to have zig-zag crimp. In this method of crimping each filament is relatively free to bend or crumple as it will when it hits the mass of already crimped yarn that immediately preceded it. The surface that it impinges upon is so variable and so changeable that it is difficult to conceive that the entire length of each filament is composed of a series of uniformly bent, reverse V's (∧∧∧∧∧) with straight unbent lengths of yarns between the zig-zag as is normally indicated in literature[35]. One suggestion[36] is that the individual crimps are mostly rounded like a written letter 'n' and arced at differing



(1)



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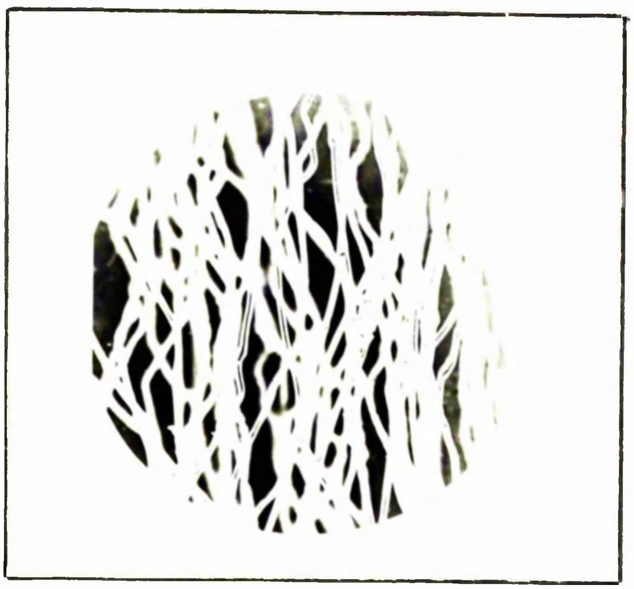
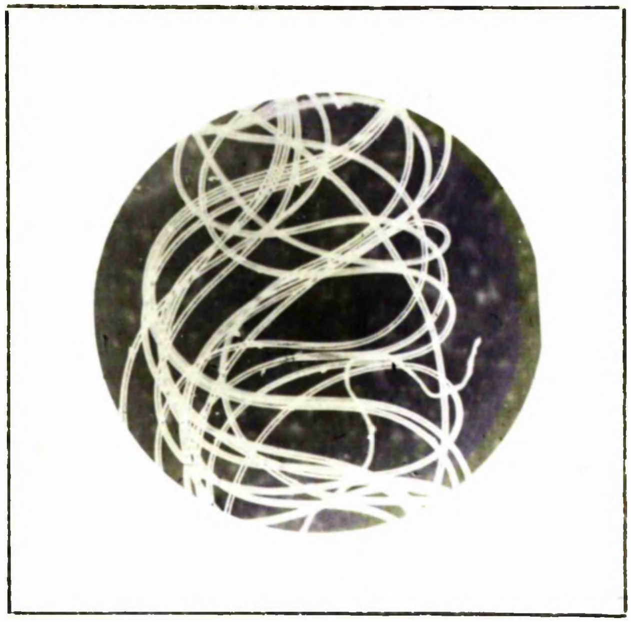


(2)

<u>Plate 1.</u> Photomicrographs of (1) False twist crimped nylon yarn, 70 den., (2) Textralized yarn, 70 den. and (3) Saaba yarn, 70 den.



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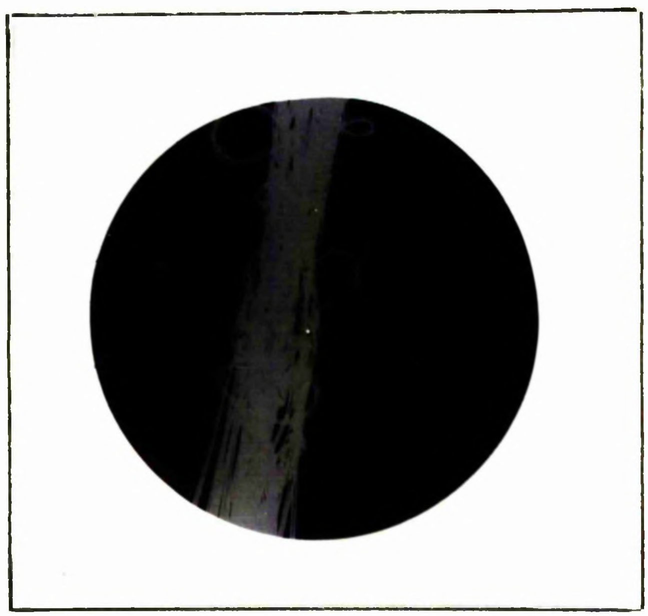


(5)

<u>Plate 1</u>. Photomicrographs of (4) Agilon, 45 den. and (5) Taslan, 70 den. yarns

angles rather than being V-shaped in a single plane. [Plate 1(2)]

Agilon yarns, i.e., those made by the edge crimping [Plate 1(4)] method have a reversing helical structure which in the multi-filament form is reduced to a confused configuration similar in appearance to false twist yarns but not twist lively. The most noteworthy feature of air bulked yarns, the one that differentiates them from yarns textured by other processes, is the number of very tiny loops in the individual filaments of the basic yarns. These loops occur within the yarn in addition to those formed on the surface. Between each loop on any single filament there are relatively long straight sections. Because the loops occur in random order, each loop in the yarn is anchored by adjacent filaments. [Plate 1(5)]

1.33 Physical Properties of Bulked Yarns

1.331 Stress-strain characteristics

In general, the object of modifying a continuous filament yarn is to simulate certain properties of spun staple yarns. Therefore a comparison of the stress-strain properties of continuous filament stretch and staple yarns will provide an estimate of how far this particular objective is achieved.

Figure (10) shows the stress-strain curves for increasing loads on Banlon, Agilon, Samba and false twist crimped yarns[37], all 2-fold 70 denier yarns of 2 denier per filament. As will be noted from the figure, false twist crimped yarn is capable of large extension from its fully relaxed condition and is used where a high percentage of extension is required in a fabric. The other three yarns show almost similar properties except that for extremely low loads Agilon yarn is more extensible. Since Banlon yarn is the least extensible of these four stretch yarns, it becomes more suitable for weaving. However Munden[30], in comparing the stress-strain properties of Banlon, Helanca and Fluflon yarns has indicated that at low loads Banlon is more extensible than false twist yarn of comparable count and has attributed this fact to the saw-tooth nature of the crimp in Banlon yarn and also to its finer filament denier (filament denier 2 as compared to 3 of false twist yarns investigated).

It must be emphasised that the stress-strain curves represented in Figure (10) are for the "crimp removal" condition of the stretch yarns, and if extended further the yarns will follow a normal stress-strain curve of the parent unmodified filament yarn. Thus, when fully extended all the yarns behave alike provided they are made from the same parent filament yarn. It is only when they are allowed to relax that they contract to different extents dependent upon their method of processing. So, paradoxically, the stretch yarns are most different at their zero extension end of the curves, and most similar at the high extension end of the curves where these are fairly widely separated.

In contrast to the behaviour of other textured yarns, the Taslan textured yarns show the nearest approach to the staple yarn. Figure (11) shows typical stress-strain relationship of a staple yarn, a Taslan yarn and a continuous filament yarn made from the same polymer[39]. The breaking extension of Taslan yarns is intermediate between those of filament and staple yarns and this is why Taslan yarns have proved useful for weaving.

The effect of filament denier on the stress-strain curves is shown in Figure (12)[37]. It is seen that three yarns of the same resultant denier but varying in number of filaments give different extension and recovery curves and that the extension to and recovery from full crimp removal increases with an increase in filament denier for a given load. Arthur[37] states that this difference in retractive power is to be expected if the torsional stress in the filament is considered. For a given twist, the torsional stress is proportional to the fourth power of the filament radius or alternatively the square of the denier. On the same basis of argument it is to be expected that this difference will also be observed in other types of stretch yarns.

1.332 Influence of Processing Conditions on the Stress-strain Properties of Bulked Yarns

The principles involved in the production of bulked yarns

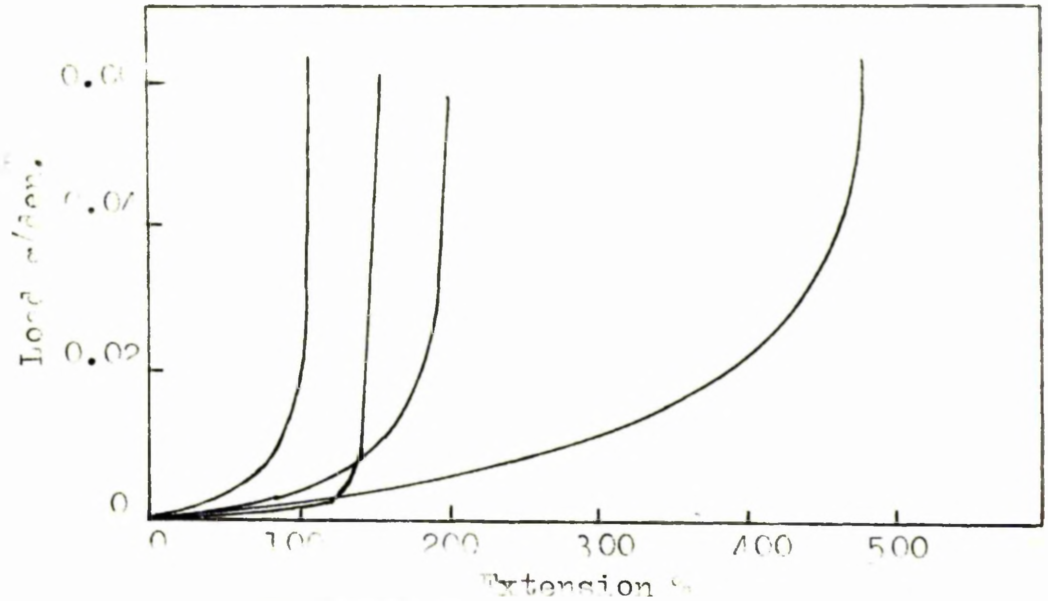


Fig.10. Typical stress-strain curves of some bulked yarns.

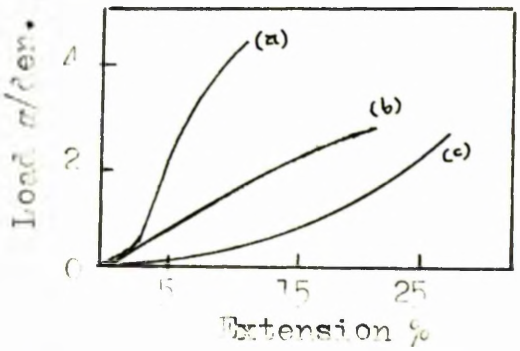


Fig.11. Typical stress-strain curves of (a) continuous filament. (b) Taslan and (c) spun yarns.

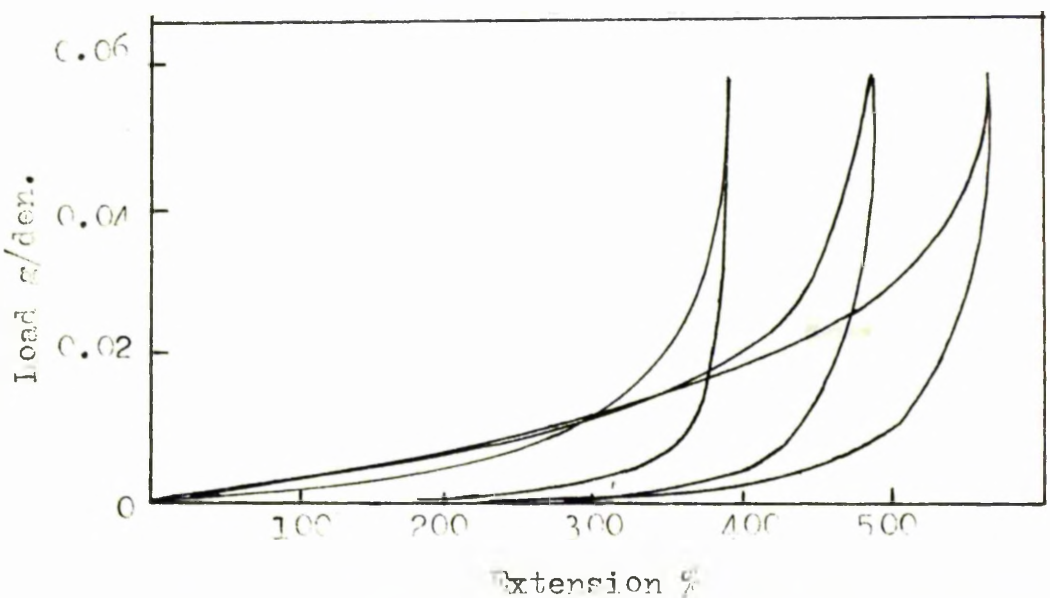


Fig.12. Effect of filament denier on the stress-strain curve of false twist crimped yarns.

by various methods are now well known. However, there appears to be a lack of published information on the influence of processing conditions on the properties of these yarns and also of the inter-actions between various processing parameters.

Among reports of fundamental work on the effect of processing conditions on physical properties of yarns is the one by Burnip et.al.[40]. They studied in detail the influence of changes in twist, temperature and tension on the properties of nylon 6.6. yarns processed by two false twist methods. The tension in the false twist process can be controlled in two ways. In one method described by the Permatwist Company[41], the yarn passes over a constant tension device such as a gate tensioner before entering the heater and this is referred to as "constant tension processing". In the other method, use is made of positive feed rollers and the yarn is fed through nip rollers to the heater and the tension varied by changing the relative speeds of delivery and withdrawal. This principle is generally employed on the Scragg C.S. machines[42] and may be referred to as "constant extension". Burnip et al.[40] employed both of these methods in their investigation.

The stress-strain properties of the resultant yarns textured under different processing conditions on constant tension apparatus were determined and it was found that breaking strength was influenced mostly by the processing temperature and reduced by about 50% under excessive temperature (temperatures employed were 130° C, 195°C and 245°C). The breaking extension increased with the processing temperature until the polymer became excessively degraded. Similar results have also been reported by Syahi[43] who investigated the properties of false twist nylon 6.6 yarns.

Increasing pre-tension values (3 gm., 7 gm. and 16 gm.) in processing resulted in yarns of decreased breaking strength and extension.

The change in twist (50 t.p.i., 80 t.p.i. and 170 t.p.i.) even at high levels did not show any significant influence on the breaking strength of the yarns though it did cause an increase in breaking extension up to an optimum value beyond which excessive levels of twist reduced the breaking extension.

The influence of the processing temperature on breaking load and breaking extension of yarns textured on constant extension apparatus was the same as that reported for the constant tension apparatus.

The effect of the amount of over-feed (-2%, 0% and 4%) on breaking load was less pronounced than that of temperature whereas the breaking extension increased with an increase in the amount of over-feed.

There appears to be no information published on the influence of processing parameters on the properties of yarns textured by various other methods. It is surprising that this sort of work has not been carried out. If it has been done the information has not been published.

The only other reference[19] found was that of the influence of processing temperature on the breaking load and breaking extension of yarns textured by modified stuffer box techniques. The modifications introduced were that of pre-heating the filaments before they entered the stuffer box, a pair of heated rollers being employed for this purpose. For an increase in stuffer box temperatures, the breaking strength of yarns decreased whilst the extension to breaking point increased. A notable feature of this modified process is that due to a pre-heat technique it is possible to achieve a desired effect at a lower temperature and with heat applied to the yarn for a short time. Consequently the amount of degradation caused in the polymer is reduced and this has been shown by the improved tensile strength of pre-heated textured yarns as compared with normal Banlon yarns.

1.333 Water Absorption

The water-holding capacity of yarns textured by different methods demonstrates the differences in the structure of these yarns. In Table (2) are shown the percentage water absorptions of relaxed skeins of yarns[37]. These were estimated after the skeins were immersed in water for several hours and then allowed to drain for a specified time. The general order is as expected but it is interesting to note that among the false twist crimped yarns increasing the filament denier produces a decreased absoption. It is also observed from the Table that staple yarn and continuous filament yarn absorb about the same amount of water under the test conditions used and the author[37] has suggested that the water held in the yarn will be almost entirely that due to capillary forces in the interstices. This appears to be contrary to the findings of Hollies et al.[44,45], who have shown that the capillary effects are greater through small continuous capillaries formed by continuous filament yarns than through large and rough discontinuous capillaries such as are found in spun staple yarns and to a somewhat lesser degree in the bulked yarns.

It is probable that the amount of water held in a suspended state in a bulked yarn is governed by three major factors

(1) Amount of interstices in the yarn

(2) Size of these interstices

(3) Surface tension properties of water.

Table 2

Yarn		Absorption,%
False twist crimped		
1 Denier per filament		1779
2		1651
3		1567
Banlon high bulk	2 denier per filament	1010
Banlon normal bulk		875
Agilon	2 denier per filament	906
Taslan		588
Saaba		1135
Spun staple, 1/12's c.c. nylon 6 denier per filament		350
Continuous filament nylon 2 denier per filament		355

1.334 Effect of Heat on Filament Nylon Yarn.

The advent of thermoplastic materials has introduced new yarns which differ in many respects from those produced from natural fibres. One of the important properties of these yarns is that they can be set,[46,47,48] that is a fabric from these yarns can be heated either alone or in presence of a swelling agent, so that the configuration of its constituent yarns remain stable during normal usage of the fabrics.

Forward and Palmer[49] carried out a detailed investigation of the influence of heat and of swelling agents on nylon 6.6 yarns and have shown that when a drawn nylon yarn is cooled, in a dry atmosphere, from 25°C to temperature t_1, its length increases from L_0 to L_1. On returning to the original temperature, the length decreases to its original value L_0. The same cycle of operations can be repeated any number of times, and within the limits of experimental error, at a given stage the length of the sample is always the same (i.e. L_0 at 25°C and L_1 at t_1). No irreversible changes in the length of yarn are caused by the changes in temperature, only reversible changes occur. Thus, the yarn may be said to be set with respect to the original temperature.

However, when the same drawn yarn is heated to temperature t_2, the length of yarn decreases from L_0 to L_2. On cooling to 25°C again, although the length increases to L_3, it is still less than the initial value L_0. During any further cycles of heating and cooling between t_2 and 25°C, the length is always the same at a given temperature (L_2 at t_2 and L_3 at 25°C). It can, therefore, be said that during the first heating a partially reversible decrease in length occurs, and during subsequent heatings the recovery is similar to that of the first heating. Again, it may be said that the yarn is set with respect to the higher temperature.

Forward and Palmer[49] have further shown that the shrinkage of nylon 6.6 yarns in dry heat and in water increased linearly with temperature and that at 150°C in dry heat, a 7% decrease in length occurs and is irreversible. This shrinkage is responsible for the increase in the resultant denier of crimped nylon yarns.

1.335 Shrinkage Properties of Bulked Yarns

Garments made from bulked yarns are generally subjected to steam, wet or dry heat setting and finishing treatments. The object of these various treatments is to impart handle, shape and some degree of stability to the finished product.

All bulked yarns exhibit varying degrees of shrinkage under the influence of either steam or dry heat, the amount of shrinkage depending on the previous thermal history of the yarns. Hunden and Slater[30] found that under dry heat the shrinkage of nylon 6.6 yarn is less than that under steam heat. Thus, to obtain a similar degree of shrinkage as that due to steam heat, a much higher temperature in dry heat setting is required. In all cases, however, the shrinkage will depend upon the previous thermal history of the stretch yarn and will be less for yarns originally processed at high temperatures. Hence the measurement of free shrinkage will provide an indication of the previous thermal history. This obviously becomes an important factor in the finishing of fabrics and garments made from textured yarns.

Hunden and Slater[30] have shown that the yarns heat set by dry heat have an equivalent temperature which would give the same amount of shrinkage in steam, and this has been termed as the "Equivalent Steam Setting Temperature" (E.S.S.T.). It should be realised however, that the amount of shrinkage will differ as to whether the yarn is allowed to shrink freely or is held to length during its previous treatment, but it is the E.S.S.T. and not the temperature of dry heat which will determine the necessary finishing conditions for the yarn or fabric.

1.336 Influence of Processing Parameters on the Residual Shrinkage of Bulked Yarns

If after bulking, the yarn is allowed to shrink freely during processing, then any further shrinkage after reheating is termed as the "residual shrinkage". It is this property which is used in the determination of equivalent steam setting temperature (E.S.S.T.).

E.S.S.T. is determined by measuring the shrinkage per cent, R, of the yarn at temperature T_2 in steam. If the rate of shrinkage K (the shrinkage coefficient) is known, then the previous temperature T_1 is given by

$$T_1 = T_2 - R/K$$

The shrinkage coefficient K is 0.1 ± 0.02 per cent per degree centigrade for most nylon 6.6 yarns[50] under free shrinkage conditions. However, in the production of stretch and bulked yarns free shrinkage does not always occur and under these conditions a shrinkage coefficient of approximately 0.12 per cent per degree centigrade is observed.

The amount of such residual shrinkage will depend on the processing conditions employed in the production of bulked yarns. Burnip[41] has studied the influence of temperature, tension and twist on the residual shrinkage properties of nylon 6.6 yarns crimped by the false twist method. It was observed that there was no significant difference in the residual shrinkage of the sample with regard to the temperature factor. This does not seem to be in accordance with the general theory which suggests that the higher the processing temperature, the less is the residual shrinkage. The effect of tension and the amount of twist on the residual shrinkage of the yarns was significant. It is reasonable to assume that the higher the tension, the greater is the resistance to shrinkage on the heater of the false twist apparatus and therefore the residual shrinkage when no restraint is present will be greater than for samples processed under conditions of low tension. The high residual shrinkage of yarns processed under conditions of low twist is explained by the fact that at high twist levels the yarn speed would be less, so the yarn will be on the heater plate for a greater period of time and thus will have more time to shrink, its residual shrinkage tending to be low.

Though the above findings relate to the yarns crimped by the false twist method, it is reasonable to presume that similar trends, with respect to the processing conditions, would be expected from other types of textured yarns.

1.34 Uses of Bulked Yarns

The main outlet for bulked yarns is in the knitting industry except for Taslan air textured yarn which has the lowest amount of stretchability. Most other types of textured yarns are difficult to weave due to their very high stretch property.

False twist crimped yarns have been extensively used in the manufacture of half hose and woven fabrics for special purposes such as swim-suits etc. The high extensibility of these yarns precluded their use in certain knitted outerwear and underwear fields but with the development of modified false twist crimped yarns, the outerwear field is being increasingly exploited. Stuffer box crimped yarns are principally used in the knitting industry. A variety of yarn deniers is knitted on machines of different gauges to produce impressive dress and suit fabrics. Some of this yarn is also used in the manufacture of underwear. More recently warp knit fabrics from these yarns have been developed and seem to have made a great impact for such purposes as dress materials, blouses, swimwear, jackets, loungewear and even printed stockings.

The main use of Agilon is in the production of hose where the yarn properties give a fabric which has desirable properties of stretch, fit and appearance. A certain amount of this yarn has also been used in carpets.

Post relaxed Agilon yarn (i.e. Agilon D) has been found suitable for use in knitted outerwear and underwear. Although a large proportion of Agilon D yarn has been used in weft knitting, several speciality warp knit fabrics have also been produced.

Yarns produced by the Taslan method have been used for variety of products such as men's shirtings (polyester blend), shoe laces (nylon), drapery (glass), sheeting (nylon), tenting (nylon), neck-ties (acetate) and women's sweaters (acrylic fibre).

Having surveyed the various methods employed in the production of bulked yarns, their properties and uses, it is pertinent to consider the work that has been done in relation to weft knitted fabrics - the major outlet for bulked yarns. However, before bulked yarns came to be extensively used in the weft knitting industry, a considerable amount of work was published on fabrics knitted from conventional types of yarns and since this work has formed the basis for the development of fabrics produced from bulked yarns it is necessary to review that work.

1.4. Dimensional Properties of Knitted Fabrics

Knitted fabric consists of a yarn or yarns formed into a matrix of interlocking loops extensible in all directions, the greatest extension being along the length or width of the fabric. The loops are maintained in this configuration as each has at least four cross-linking points of contact with its neighbours. Although these loops are held in this configuration, they are easily distorted by even small strains set up in the fabric, this accounting for the highly extensible nature of the knitted fabric as compared with its woven counterpart.

Until recently in the weft knitting industry the emphasis was on knitting being more of an art than an easily adjustable mechanical process, in the sense that a knitter produced a finished fabric of the required characteristics and dimensions by use of his experience rather than by any standard controls. However, with the advent of development of new types of yarns, increased fabric production and the use of much larger and complicated machines, a realization came to the industry that the traditional approach had to be changed and that the development of knitting into an efficient industrial technique must take place.

It is therefore not surprising to find that in the recent years many attempts have been made to establish basic relationships which determine knitted fabric characteristics in terms of yarn properties and knitting variables.

One of the earlier attempts to investigate the fabric geometry of plain knit structures is by Chamberlain[52]. By assuming certain geometrical configurations taken up by the yarn in the structure at one particular tightness of knitting, he suggested the following relationships between fabric construction measured in terms of length of yarn (ℓ) in the stitch and the following fabric dimensions:

Stitch density S $= 20/\ell^2$

Wales per inch $= 4.15/\ell$

Courses per inch $= 4.8/\ell$

and c.p.i./w.p.i. $= 1.15$

Stitch density is the product of the c.p.i. and w.p.i. Chamberlain, however, was unable to prove these relationships experimentally and therefore, he came to the conclusion that the process of knitting must remain an art and could not be reduced to a more scientific level.

Later, Shinn[53] using the same analysis as that given by Chamberlain, obtained the same relationships between fabric construction and fabric dimensions. Peirce[54] realising the limitation of the formulae obtained by Chamberlain as applicable to only one tightness of knitting where the ratio of stitch length to yarn diameter was equal to 16.6, attempted to extend the geometry of this model to less tightly knitted fabrics and suggested the following formula:

$$\text{Stitch length } \ell = 2p + w + 5.94\, d,$$

where p = course spacing, w = wale spacing and d = yarn diameter.

Fletcher and Roberts [55] investigated the above relationship experimentally for fabrics of many knitted constructions, knitted to a wide range of stitch lengths and from a variety of yarns. They have in general, been able to interpret their results in terms of a relationship between stitch length and course and wale spacings. But the numerical constants obtained from best fit curves have differed widely from those given in the equation due to Peirce. They further observed that after the fabrics were laundered, a parabolic relationship existed between course and wale spacing of the form:

$$p^2 = a\,(w + b)$$

where the numerical values for 'a' and 'b' varied with the type of knitted construction and type of yarn used.

1.41 Configuration of the Knitted Loop

From the above it is clear that the earlier attempts of Chamberlain[52] and Peirce[54] to generalise the geometrical relationships of plain knitted structures were never entirely successful. The reason for this failure probably lies in the fact that the models they assumed for the knitted loop were far from reality. The model proposed by Peirce[54] was criticised by Leaf and Glaskin[56] for the reason that the model necessitated discontinuities in torsional strain along the loop. An alternative model proposed by them assumed that the projection of the central axis of the yarn on the plane of the fabric is composed of circular arcs was consistent with the physical requirements and was a definite improvement upon the previous model. However, they also were unable to obtain experimental results that correlated accurately and consistently with the relationships suggested by their model.

Munden[57] by using an assumption initially suggested by Leaf[58] proposed another model. By assuming that any homogeneous strip of material bent into a loop will always take up the same configuration, independent of its physical properties and presupposing that no material plastic flow takes place, Munden was able to show that the dimensions of plain knitted fabrics were uniquely determined by the length of yarn knitted into each stitch. For this to apply, the fabric must be in its completely relaxed state, or alternatively its configuration must correspond to a state of minimum energy. This concept of a fully relaxed state has played an important part in understanding the dimensional properties of knitted fabrics.

1.42 Fabric Dimensions and Stitch Length

In 1953, Doyle[59] was the first to show that the stitch length, or the length of yarn making up one loop, was closely related to the stitch density for a wide range of plain fabrics knitted under various conditions. He suggested that as a parameter of fabric quality the stitch length 'ℓ' was preferable to all others, such as courses per inch or wales per inch which were traditionally used and are still used, as the stitch length is unaffected by strains set up in the fabric. He also indicated that for commercial plain knit constructions the stitch density of the fabric in the relaxed state is given by the following formula:

$$S = k_I/\ell^2$$

where S = stitch density, ℓ = length of yarn in the stitch and k_I = constant (approx. = 19.3)

This constant k_I was found to be independent of yarn count or denier, the type of the machine on which the fabric was knitted, the knitting tensions or any other yarn or machines variables. Thus, it follows that the fabric dimensions are uniquely determined by the length of yarn in the stitch. This would appear to be contradictory because an experienced knitter will describe many yarn and knitting variables, all of which from his experience, affect the characteristics of the knitted fabrics. These yarn and machine variables will be considered in the next section.

The findings of Doyle were confirmed by Munden[57] as indicated in the previous section and his results may now be summarised as follows:

(a) The stitch density S, is a more reliable measure of fabric quality than either courses (c) or wales (w) per unit length alone, as it is less affected by small strains. Stitch density is given by:

$$S = c.w. \qquad \text{---------------} \qquad (i)$$

(b) $$S = k_1/\ell^2 \qquad \text{---------------} \qquad (ii)$$

where ℓ = the knitted stitch length. The constant k_1 is determined experimentally from the slope of the graph of S against $1/\ell^2$

(c) $$c \text{ (c.p.i.)} = k_2/\ell \qquad \text{---------------} \qquad (iii)$$

(d) $$w \text{ (w.p.i.)} = k_3/\ell \qquad \text{---------------} \qquad (iv)$$

In (iii) and (iv) ℓ is the knitted stitch length and k_2 and k_3 are constants determined from the slope of the graph of c and w against $1/\ell$.

(e) $$c/w = k_2/k_3 = k_4 \qquad \text{---------------} \qquad (v)$$

where k_4 is a constant.

It must be emphasised again that all the above relationships hold good only in the case of fully relaxed fabrics.

On combining (i) and (v),

$$e = \sqrt{(S.K_4)} \quad \text{------------------------} \quad (vi)$$

$$\text{and} \quad w = \sqrt{(S/K_4)} \quad \text{------------------------} \quad (vii)$$

In relation (vi) and (vii), S can be expressed by (ii). Thus the length and width of a fully relaxed plain knitted fabric can be calculated from e and w and the total number of courses and wales and depend on ℓ and the constants K_1 and K_4 only.

For a range of fabrics knitted from worsted and woollen blended yarns, the following K values after dry and wet relaxation have been reported[57]:

	Dry relaxation	Wet relaxation
K_1	19.0	21.6
K_2	5.0	5.3
K_3	3.8	4.1

The relationship of the type shown in equation (iii) connecting the course spacing with loop length has been well established for plain fabrics. For more complicated structures like interlock and double pique, the corresponding relations are not so simple and generally contain a term involving a yarn diameter[60]. Nutting and Leaf[61] attempted to generalise the geometry of weft knitted fabrics, realising that it is desirable to retain the simplicity of equation (iii), which can be written in the form

$$1/c = A\ell \quad \text{--------------------} \quad (viii)$$

where A is a constant related to the fabric construction:

In order to generalise this equation, they introduced a term involving the yarn diameter and assumed that any diameter effect would be linear and additive and also the diameter is proportional to the square root of the yarn count, (tex). The proposed general equation could, therefore, be written in the form

$$1/c = A\ell + D\sqrt{T}$$

$$\text{or} \quad 1/c\ell = A + D\sqrt{T}/\ell \text{ ------------- (ix)}$$

where D is a constant related to the fabric construction and T is the count in the tex system.

To find experimentally whether (ix) represents a reasonable generalization, Nutting and Leaf knitted a range of fabric constructions, using yarns of various types and counts. The fabrics were wet relaxed and measurements made on them indicated that over the range of commercial fabrics (i.e. fabrics for which cover factors lie between 12 and 16) the effect of diameter correction was not very marked and could therefore be neglected for practical purposes. Thus the authors suggest that the simple equation (viii) could be used to describe the geometry of fairly wide range of fabrics.

It has been suggested by Munden[57] and Nutting[62] that the values of fabric geometry constants k_1, k_2 etc. depend upon the loop shape. Nutting[62] has described the change from dry to wet relaxed state as follows: "On wetting, the state (dry relaxed) of balance or equilibrium is disturbed since the physical characteristics of the fibres are altered; they are, therefore, unable to bear the same stress and the curvature in all planes becomes greater --- This proceeds until a second formal state of equilibrium is reached in a fully wetted out fabric".

Nutting and Leaf[61] have demonstrated theoretically the conditions under which two straight elastic rods will take up similar configurations when deformed by forces and couples applied at their ends. From the geometrical analysis it was shown that the necessary condition is that the ratio of the flexural and torsional rigidities of the rods should be the same. This implies that the shape of the knitted loop and hence the values of fabric geometry constants depend on the ratio of flexural to torsional rigidities and provides an explanation for their changes with changes in loop configuration.

1.43 Effect of Knitting Variables on Fabric Quality

The term "knitting quality"[63] is used to imply the following three different features of the knitted fabric:

(i) The characteristic handle of the fabric which is directly associated with yarn quality

(ii) The regularity of the knitting construction

(iii) The tightness or openness of the knitting construction.

As in many other industries, quality control standards are becoming increasingly important in the Textile Industry[64] - due to the high standards of quality expected by retailers and consumers. For this purpose, the use of stitch length as the quality parameter is now established and preferred to any other parameter for the reasons already indicated earlier. Nevertheless, any experienced knitter will immediately describe many knitting variables that affect the dimensional and physical properties of the knitted fabrics. These variables may be divided into two categories:

(i) Machine variables: Cam setting, machine gauge, needle and sinker timing, take down tension, yarn input tension etc. and

(ii) Yarn variables: Count, twist, friction, condition, quality, colour, package hardness etc.

These variables must be controlled to maintain a constant stitch length because it is this parameter which is responsible for the change in fabric quality as a result of change in the observed variables. These variables are, therefore, considered in more detail:

(i) Machine variables:

In practice, knitted fabric quality is not determined by the alteration of the yarn input tension but by the adjustment of the cam control to position the needles to draw a specific length of yarn in each loop. Any variation in yarn input tension, friction and other variables may cause considerable differences in stitch length at any one cam setting, but basically this control is the main governor of quality on machines not equipped with any form of yarn feeding device. The most important effect these machine variables have on the fabric is that changes are caused in fabric dimensions.

(ii) Yarn Variables:

The two most important yarn variables have been found to be (a) yarn input tension (i.e. the tension of the yarn as it enters the feeding point) and (b) yarn frictional properties. The other yarn variables only cause changes in quality if they affect either (a) or (b)[65].

To illustrate the significance of these two variables Nutting[66] demonstrated that at a constant cam setting and for low friction worsted yarn, a variation of only 7 gm. in the yarn input tension resulted in a 15% change in stitch length. The rate of change in stitch length appeared to decrease as the yarn input tension increased, thus a lower range of input tensions produced a larger change in stitch length than a higher tension range. He also showed that frictional variations between two otherwise identical yarns resulted in marked changes in stitch length and hence in fabric quality, even when knitted at the same cam setting and at a constant yarn input tension.

1.5 Dimensional Properties of Fabrics Knitted from Bulked Yarns

1.51 General:

A certain amount of work has been published on the evaluation of dimensional properties of fabrics knitted from bulked yarns. Because the introduction of these newtypes of yarns created new problems for the knitting industry, it was natural first to investigate and understand the fabric geometry of plain knit construction and also to study the influence of various factors that affect the properties of these fabrics.

The Annual Conference of The Textile Institute in 1961 was devoted to the subject of "Bulked Yarns and Other Modified Textiles". Several papers were presented on the application of bulked fibres to the production of knitted fabrics but each worker differed in the presentation and interpretation of his results. In this context, it is pertinent to quote the summing-up remarks of the Chairman[67] for that Conference. He said. "I refer to thse papers coming from educational establishments and H.A.T.R.A., together with one paper from industry, which are mainly concerned with the provision of data illustrating the effect of altering processing variables on the properties of the resultant yarns and fabrics. I have to confess that after hearing several of these papers I was pretty much in a fog. My difficulty was that most of the papers gave masses of data, which, in the absence of any theoretical frame-work on which they may be hung, could neither be remembered nor understood." He further remarked and said, "Of course, this is inevitable in the earlier stages of development of any science or technology, the first questions to be asked invariably begin with the word

'What?', and it is only when many 'What?' questions have been answered that it is fruitful to ask more fundamental questions initiated by the words 'How?' and 'Why?'. One hopes that in the near future one may be able to rely less on memory and more on understanding".

In order to provide the background for the discussion and understanding of the subject, a brief survey of the previous work on plain knitted fabrics produced from bulked yarns is given. As this survey will frequently involve the use of the terms 'Crimp rigidity' and 'Yarn collapse', their definitions and implications will be considered first.

1.52 <u>Yarn Crimp Rigidity</u>

One of the most important properties of bulked and stretch yarns is the strength of the crimp giving rise to longitudinal 'yarn collapse'. This property has been called 'yarn crimp rigidity'[60] and is said to affect such fabric properties as handle, dimensions, elasticity and appearance.

The test for the determination of crimp rigidity of a yarn has been devised by H.A.T.R.A. The conditions have been so chosen as to provide a simple test and yet one which would give an indication of the behaviour of the yarn in fabric form. If 'L_1' is the length of the yarn after loading for two minutes at 0.1 gm./denier and 'L_2' is the length after loading for two minutes at 0.002 gm./denier, the crimp rigidity of the yarn is given by

$100 \times \frac{L_1 - L_2}{L_1}$ %. All measurements are carried out in water at 20°C.

1.53 Yarn Collapsing Properties

Since the yarn bulk is the result of the collapse of the yarn from its straightened condition, many methods including the measurement of crimp rigidity of a yarn are based on this principle. The use of the term crimp rigidity is often not considered proper and according to Munden et al.[69] the term rigidity has a quantitative significance as the ratio of the force producing deformation to the deformation itself. The crimp rigidity test does not measure this quantity; the measurement obtained is simply a quantitative measurement of the degree of the collapse of the yarn from its straightened condition under a given deforming load. Munden et al., therefore, suggested the term 'Percentage yarn collapse' as a measure of this property.

Fourne[70] also measured the bulking quantity of textured yarns and defined it as the 'Potential stretch percentage'. In this test a 100 meter length of yarn was wound on to a hank and after a relaxation treatment, single strands of yarn, each of 30 cm. length were loaded with a load of 0.002 gm./denier and after two minutes, the length of the yarn was noted (ℓ_2). Then the samples were again loaded with 0.8gm./denier and after two minutes from loading, the length of the yarn was again noted (ℓ_1). The potential stretch percentage ($P_c\%$) was calculated from the formula

$$P_c\% = \frac{l_1 - l_2}{l_1}$$

The method used by Munden et al. for the measurement of percentage yarn collapse is similar to that described above except that for heavier loading they used 0.1gm./denier instead of 0.2gm./denier. These methods of measuring yarn collapsing properties differ from the standard crimp rigidity test in many respects. In particular, the yarn is thoroughly relaxed before the measurement of its collapsing properties, and also measurement is made on individual lengths of yarn instead of on a hank form. It has been found that this latter feature led to more consistent and reliable results. Also the order of loading is different, i.e., the lighter load is applied first followed by heavy load.

It has been indicated by Brown[71] that the yarn collapse measured by the method suggested by Munden et al.[69] gave a good correlation with the amount of yarn collapse that actually occurred in the fabric and that the crimp rigidity test was value-less in this respect.

McCann and Sturley[72] measured crimp rigidity and percentage yarn collapse for a range of false twist nylon 6.6 yarns processed under various different combinations of twist and temperature and have shown a good correlation between crimp rigidity and yarn collapse values irrespective of differences in processing conditions.

On the basis of this observation, it is evident that if Brown did find a good correlation between percentage yarn collapse in the yarn form and the yarn collapse in the fabric form, there is no apparent reason why such a correlation should not be obtained between yarn crimp rigidity and the amount of yarn collapse in the fabric.

1.54 Effect of Stitch Length and Yarn Crimp Rigidity on Fabric Stitch Density

Both the stitch length and the yarn crimp rigidity will affect the stitch density of fabrics knitted from bulked yarns. Munden and Fletcher[38] studied the effect of these two variables on the properties of plain structures produced from different types and deniers of bulked yarns. When stitch densities of these fabrics after relaxation and finishing were plotted against their stitch lengths, series of curves were obtained. On the same graph the stitch density of the fabrics produced from unbulked yarn was also plotted against their stitch lengths. Some of the salient features of this work are described below:

(a) In all cases, the stitch density of the relaxed fabric decreased as the stitch length increased or alternatively as the knitting stiffness decreased.

(b) The curves for the fabrics knitted from bulked yarns were above that of the fabric from unbulked yarn, indicating that for a given stitch length the stitch density for bulked yarn fabric is higher.

(c) Helanca, crimped nylon and Fluflon (all torque crimp false twist yarns) fabrics resulted in a higher stitch density for a given stitch length than Banlon (stuffer box crimped) fabric. This was attributed to higher crimp rigidity (approx. 35%) of the torque crimped yarns as compared with than of Banlon (approx. 12%).

(d) The heavier yarns, knitted to the same stitch length as yarns of finer deniers, produced fabrics of a lower stitch density, since the thicker yarns prevented the collapse of the fabric to the same extent. This is further substantiated by the work of Fitton and Hopkinson[73] who indicated that the extent of fabric collapse which is a direct result of the constituent yarn collapse depends on the following two factors:

(i) Crimp rigidity of the yarn, and

(ii) The amount of space available in the fabric for yarn collapse to occur and is dependent on the yarn diameter and the stitch length, the ratio of these two being the cover factor.

It has been shown by Fitton[74] that as the crimp rigidity of the yarn is increased, the stitch density of plain fabrics knitted from these yarns is also increased for the same range of stitch lengths. Similar observations have been reported by Cotton and Bladen[75] for 1x1 rib fabrics knitted from false twist nylon yarns. Yarns of differing crimp rigidities used by Fitton[74] in knitting plain fabrics were produced by heater plate temperature variations and according to him, differences in crimp rigidity caused by the variation in amount of twist inserted during yarn processing produced a similar increase in stitch density with increasing crimp rigidity. This appears to be contrary to the published results of Vidhani and Nutting[76] who investigated the properties of parent and post-treated false twist nylon 6.6 yarns. Whereas they obtained a good correlation between stitch density of plain knitted fabrics and crimp rigidity of post-treated yarns and parent yarns produced by heater temperature variation, they did not get the same relation for fabrics produced from parent yarns processed under twist variation.

It has been established[57] that for plain fabrics knitted from normal staple and filament yarns, stitch density (S) is inversely proportional to the square of the stitch length (ℓ). Therefore a similar approach has been used by various workers[69,73,75,77] to interpret the results obtained with fabrics knitted from bulked and stretch yarns. All these workers have shown that in plotting S against $1/\ell^2$, a linear relationship between stitch density and stitch length exists. However, the straight lines so obtained do not pass through the origin but give an intercept (S_c) on the S axis. The results have been mathematically expressed in the form

$$S = S_c + k/\ell^2 \quad \text{------------------} \quad (1)$$

where k is the slope of the line (S v/s $1/\ell^2$) and all other terms have their significance as already expressed.

It is natural to compare this equation (i) with that given for fabrics knitted from normal staple and filament yarns, which is of the form[57]

$$S = k/\ell^2 \quad \text{or} \quad 19/\ell^2 \qquad \text{------------------} \quad (ii)$$

The difference between equations (i) and (ii) can be resolved if it is considered that the stitch length measured in equation (i) is on the yarn sufficiently stretched to remove the crimp whilst the stitch density is calculated on the relaxed fabric dimensions for which the relaxed stitch length (ℓ_r) is less. On the basis of this explanation, it follows that if the relaxed stitch length (ℓ_r) as the yarn lies in the fabric is known, then equation (i) would confirm to such a relationship as

$$S = k/\ell_r^2 \qquad \text{------------------} \quad (iii)$$

The stitch length cannot be measured directly in fabric form because the knitted loop is of a complex shape and can be easily distorted. Methods have been suggested to calculate this relaxed stitch length by making certain assumptions. These are now considered in the following section.

1.55 <u>Yarn Collapse in the Fabric</u>:

Brown[71], Cotton and Bladon[75], have suggested similar methods for the calculation of yarn collapse in fabric form for plain knit and 1x1 rib fabrics produced from bulked yarns.

It is reasonable to suppose that the fabric collapse is directly caused by the collapse of the yarn in the stitch or loop. If it is assumed that the relationship

$$S = k/\ell_r^2$$

continues to hold good for fabrics produced from bulked yarns (where ℓ_r is the relaxed or collapsed length of yarn in each stitch), then it is possible to estimate (ℓ_r) by assuming $k = 19$. The validity of this latter assumption may not be justified but roughly similar conclusions would arise from any other reasonable value. Then knowing the unroved straightened stitch length (ℓ), the percentage yarn collapse in the stitch can be calculated from the following formula

$$\text{Percentage collapse of yarn} = 100 \times \left(\frac{\ell - \ell_r}{\ell}\right) \%$$

When the percentage yarn collapse calculated in this manner is plotted against measured stitch length (ℓ), it is observed[71,75] that a linear increase in yarn collapse occurs with increase in (ℓ). The results of Cotton and Bladon[75] further indicate that this increase becomes more pronounced as the crimp rigidity of the yarn increase.

Munden et al.[69] have shown that in measuring the yarn collapse by the method developed by them, a relationship between the relaxed dimensions of the fabric, yarn collapse properties and knitted stitch length could be obtained. Their results are further supported by the work of Okamoto and Husomi[78].

It has previously been pointed out[73], that the yarn collapse in the fabric is related to the openness of the knitted structure (i.e. the inverse of the fabric cover factor). In the case of knitted fabrics this cover factor is given by $\sqrt{\text{denier}}/\ell$. Therefore when the ratio of calculated yarn collapse to measured yarn collapse was plotted against $\ell/\sqrt{D}$ the points fall approximately on a straight line passing through the origin. This indicated that the stitch length ℓ, yarn denier D, stitch density S and measured yarn collapse C_R were related by an equation of the form

$$\left(1 - \frac{19}{\ell\sqrt{S}}\right) \times 100 = C_R \times \frac{\ell}{\sqrt{D}} \times m$$

where m is the slope of the graph of $\frac{\text{calculated yarn collapse}}{\text{measured yarn collapse}}$ against $\frac{\ell}{\sqrt{D}}$

From the above, it follows that

$$S = \frac{19 \times 10^4 D}{\ell^2 (100\sqrt{D} - mC_R\ )^2}$$

If mC_R is small compared with 100 D, this reduces to the form

$$S = \frac{19}{\ell^2} + \frac{19mC_R \times 2}{100\ \ell\sqrt{D}}$$

From these relations it is seen that if $C_R = 0$, i.e. yarn does not collapse, this will reduce to the form

$$S = 19/\ell^2$$

Fitton and Hopkinson[73] have shown independently that the stitch density of plain knit fabrics from bulked yarns can be calculated from the relation

$$S\ell^2 = P_1 + P_2 C.R. + P_3 \frac{(C.R. \times \ell)}{D}$$

where p_1, p_2, and p_3 are constants and other terms have their usual significance. They have also given the values of p_1, p_2 and p_3 obtained from multiple regression calculation and indicated that by using this form of equation, stitch density can be predicted within limits of $\pm$ 60 loops per square inch. Also if C.R. = 0, this reduces to the form

$$S = 23.5/\ell^2$$

which is close to the equation obtained in practice, $S = 19/\ell^2$.

While it is interesting to note the similarity between the equations suggested by Fitton and Hopkinson[73] and those suggested by Munden et al.[69], it is to be noted that whereas Munden et al. have shown the method of deriving their equations, Fitton and Hopkinson have not published their method of arriving at the equations suggested by them. Nevertheless, these equations do indicate that dimensional properties can be predicted from the knowledge of three variables, i.e., yarn collapsing properties, knitted stitch length and yarn denier, with reasonable accuracy. It must be emphasised that these equations need to be tested further by using yarns of differing deniers and collapse properties.

1.56 Effect of Yarn Tension on Dimensional Properties

When producing fabrics from bulked yarns the use of both high and low input tensions on the yarn as it is fed to the knitting elements have been suggested in order to obtain a regular and satisfactory knitted structure. Whereas a high input tension is suggested to avoid any irregularities that might arise if a yarn with high collapsing properties is supplied to the needles in a partly collapsed state, the use of a low input tension is advocated to prevent any loss of crimp which may be caused if the strain on the yarn at the knitting point rises to an extreme value.

It has been established that the dimensions and quality of a knitted fabric depend to a large extent on the length of yarn forming each loop. Because of this the true effect of tension on the knitted fabric has often been obscured since it invariably leads to a considerable change in knitted stitch length. Therefore, in order to evaluate the effect of tension on the yarn properties, it is essential to consider the effect of tension independently of any change in stitch length.

In this context, mention must be made of the automatic knitting control device known as the 'Positive Feed'. With the use of this system, the yarn is fed to the needles at a controlled rate by passing it over a high friction surface cylinder rotated at a speed necessary to feed the correct amount of yarn to the needles in order to produce a fabric of any required stitch length. The quality of the fabric is therefore predetermined by the rate at which the cylinder feeds the yarn to the knitting elements. By this means the stitch length becomes independent of yarn input tension, yarn friction and cam setting. The advantages to be derived with the use of positive feed system have been published[79, 80]. When this method is however considered for knitting of bulked yarns, there are some limitations. For example, the value of input tension (i.e. tension between supply package and feed unit) will affect the degree of collapse of the yarn as it is laid on the feed cylinder and will therefore cause variation in the amount of yarn fed to the needles.

Munden et al.[69] carried out an investigation into the effect of changes in yarn knitting tensions on the dimensional properties of fabrics knitted from bulked yarns both by normal knitting and by feed unit methods. For this purpose they used false twist nylon (percentage yarn collapse - 65.2) and Crimplene (percentage yarn collapse - 16.2) yarns. These yarns were knitted at a range of tensions and were compared with results obtained with filament Terylene yarn knitted under identical conditions.

It was concluded that under normal knitting conditions (i.e. without using a positive feed), a change in yarn tension from 2 to 15gm. may affect the knitted stitch length by up to 15%. On the same machine, when knitting is done under yarn feed conditions, the stitch length is unaffected by a change in tension between feed unit and knitting elements, but a change in tension between package and feed unit from 2 to 25gm. may cause the stitch length to change by 6%. It is suggested that this variation may be reduced if the input tension is not allowed to be less than 10gm.

At the start of this survey on fabrics knitted from bulked yarns, it was noted that the information published on this subject contains a very large amount of data which may perhaps hold good only for the range of fabrics studied. As each worker appears to have presented and interpreted his data in his own way it is extremely difficult to draw any particular generalisations. Further relevant features of information published will therefore be considered later in the discussion of the results obtained for the purpose of this thesis.

1. 6 Purpose and Scope of the Present Investigation

It has become evident from the survey of literature that in the last few years many research workers have attempted to study the influence of the factors that control the dimensions of relaxed plain fabrics knitted from bulked yarns. For this purpose, the concepts of fabric geometry developed by Munden[57] in relation to fabrics knitted from unbulked yarns have been employed and some new types of relationships between bulked yarn properties and fabric properties have been suggested.

The object of the work described in this thesis is two fold:

1) To investigate the effect that bulked yarns and machine variables have on the dimensional properties of 1x1 rib fabrics when knitted on standard machinery. This 1x1 rib structure is of particular interest, since, as well as being of considerable commercial importance, it is also a basic knitted structure.

Nylon yarns bulked by two different methods, namely, false twisting and stuffer box crimping have been used in the present study, therefore in addition to other yarn variables the influence of the bulking process on the properties of 1x1 rib fabrics has also been studied. In order to be able to interpret the data obtained, the concepts of fabric geometry developed by previous workers has been used wherever necessary. The concept of fabric geometry is based on the essential condition that the fabric should be in a completely relaxed state and generally two relaxed states have been recognised: a dry relaxed state, taken up after some days' exposure to standard atmosphere; and a wet relaxed state, taken up after soaking in water. It is generally known that fabrics produced from bulked yarns are finished by multi-stage finishing treatments which involve the use of such processes as wet relaxation, dry tumbling, steam-setting, etc. The number of fabrics knitted especially for the present work in the laboratory have been relaxed separately by steam relaxation, wet relaxation and dry tumbling and comparison has, therefore, been made between these three single relaxed states and the control or griege sample. It is considered that at the present moment the use of a single (process) relaxed state is not only a convenient but almost a necessary simplification. Once the behaviour of the fabrics relaxed by a single process has been fully understood, then the work may be extended to study the influence of the sequence of finishing treatments on fabric properties.

Of the machine variables, the most important is the stitch cam setting to obtain variation in the knitted loop length. The influence of this variable on the dimensional properties of 1x1 rib fabrics has also been studied.

2) To study the stretch and recovery properties of 1x1 rib fabrics knitted from the yarns that have been used in the investigation of dimensional properties of these fabrics.

One of the most characteristic properties of fabrics knitted from bulked yarns is their extensibility. However, it is not only sufficient that the fabric should extend easily, it is equally essential that on releasing the stretching force, the fabric must revert back to its original size and shape. Despite the fact that this property of stretch and recovery is so important, it is surprising that little attention has been paid to it. There is hardly any published information based on experimental observations as to the various factors that influence the stretch and recovery behaviour of these fabrics.

Once again the fabrics in their steam relaxed, wet relaxed and dry tumbled states have been used for this study and the results compared with those of the greige fabrics.

EXPERIMENTAL METHODS

C O N T E N T S

2.1 Materials

In this study of the dimensional properties of 1x1 rib fabrics, nylon 6.6 yarns bulked by false twist and stuffer box methods were used to produce fabrics. Commercially available stuffer box bulked yarns marketed under the name "Textralised" were obtained from British Depa Crepes Ltd. False twist crimped yarns were supplied by I.C.I. (Fibres) Ltd. and were prepared for the purpose of the present investigation from the standard type 100 nylon 6.6 yarns. In addition, some unbulked yarns, type 100, obtained from I.C.I. were also used to distinguish between yarn and fabric properties by comparing fabrics of the same construction from bulked and unbulked yarns. The yarns used varied in denier, filament denier, bulking properties etc.; the details being shown in the following tables. The coefficients of friction of the yarns were determined in accordance with the recommendation quoted in B.S. Hand Book[81]. Bulking properties of these yarns after various relaxation treatments were determined by two methods and are described in the next section.

Table 1 (a)

(Textralised nylon yarns)

Code No.	Denier	Type	Grade	Coefficient of friction
T1	1/70/20	HB	D	0.405
T2	1/70/34	O	D	0.40
T3	1/100/34	HB	D	0.520
T4	1/140/68	H	D	0.210
T5	1/150/50	O	D	0.470
T6	1/205/34	O	D	–

Table 3 (b)

(False twist crimped nylon yarns)

Batch	Code No.	Denier	Crimps/inch	Coefficient of friction
M53/1503	F1	2/70/34	80	0.543
M53/1503	F2	2/70/34	80	0.445
M50/0456	F3	2/70/20	80	0.390
M50/0456	F4	2/70/20	80	0.385
M50/0456	F5	2/70/20	80	0.332
M470/08046	F6	2/100/34	65	0.422
M470/08046	F7	2/100/34	70	0.402
M470/08046	F8	2/100/34	70	0.407

Table 3 (c)

(False twist-FT, Textralized-TZ and Unbulked-U nylon yarns)

Batch	Code No.	Denier	Type	Crimps/inch	Coeff. of friction
M401/086/26	FT 1	2/70/34	S Z STAB	80	0.40
M570/08194	FT 2	2/205/34	S Z OFT	50	0.44
-	TZ 1	1/70/34	0	-	0.40
-	TZ 2	1/205/34	0	-	-
-	U 1	70/34 Z	100	-	-
-	U 2	205/34 Z	100	-	-

2.2 Bulking Properties of the Yarns

2.21 Crimp Rigidity Test

The only conventional test available in this country by which the bulking potential of a bulked yarn is assessed has been proposed by H.A.T.R.A. and is known as a Yarn Crimp Rigidity Test[68]. Since crimp rigidity of bulked yarns is known to affect the dimensional stability and other properties of fabrics produced from these yarns, it is essential to determine the values of this yarn parameter so that these may be related to fabric properties. The H.A.T.R.A. crimp rigidity apparatus was used to determine the crimp rigidity of the yarns used in this work.

The test involved winding a specimen of hank of a pre-determined number of strands depending on the yarn denier used. A small weight in the form of a S-shaped hook was applied to the hank and on this was placed a heavy weight. The weight of the small hook corresponds to 0.002 g/denier and the heavy weight to o.1 g/denier, based on the total denier of the hank.

The loaded hank was then immersed in a cylinder containing water and a few drops of the wetting agent (Teepol) at room temperature (20°C). Two minutes from the time of immersion the hank length (L_1) was measured against an elastic scale provided inside the glass cylinder. The heavy weight was then removed by means of a grid (provided inside the cylinder) and the hank allowed to contract as the crimp developed. After two minutes from the time of removing the heavy weight, the hank length (L_2) was again measured.

The crimp rigidity of the yarn is the percentage contraction occurring under the stated conditions and is given by

$$\frac{L_1 - L_2}{L_1} \times 100\%$$

This test has its limitations in that the yarns requiring high temperature treatment to develop the crimp are not given sufficient contraction in cold water to give a reasonable value of crimp rigidity e.g. Agilon and Banlon Terylene yarns. For such purposes a relaxation treatment in water at high temperature prior to testing is necessary.

2.22 Yarn Collapsing Test

Collapsing properties of the yarns were measured by the method employed by Munden et al.[69] This method owes much to Brown[71] who developed the method of collapse measurement to give reliable results. He found that improved reliability was achieved when measurements were made on a single length of yarn rather than on a yarn in hank form as is done in the H.A.T.R.A. crimpt rigidity test. Since fabrics undergo some relaxation process during their usage, Brown suggested that relaxation prior to measurement of yarn collapse would give more realistic values and therefore give a better correlation with actual collapse of the yarn in fabric form. Further, in connection with the order of loading Brown showed that yarn collapse value obtained was smaller where the heavy loading was applied first as is done in the H.A.T.R.A. crimp rigidity test. A similar test procedure[69, 71] was used for evaluating percentage yarn collapse values for the yarns used in the present work. Details of the experimental procedure are as follows:

A convenient length of yarn was taken and one end fixed into spring clip with a load of 0.1 g/denier applied to the other end. Two marking threads were then tied to the yarn at a distance of 30 inches (ℓ_1) apart. Ten such samples of each yarn of different types were then pre-relaxed by the techniques described below:

(a) wet relaxed in a trough of water maintained at 45°C for 20 minutes, removed and allowed to dry on a flat surface at room temperature (20°C).

(b) dry relaxed in an oven at 90°C for 15 minutes in such a manner as to allow free relaxation.

(c) steam relaxed for about five minutes on a bed of a Hoffman press.

After these pre-relaxing treatments the yarns were conditioned in a standard atmosphere (65% r.h. and 20°C) for at least 24 hours before measurements were made on them in the same atmosphere. One end of each sample of yarn was fixed into the spring clip and a load of 0.002 g/denier in the form of a metal clip applied to the other end. After one minute from the time of loading the length (ℓ_2) of the sample between the two marking threads on the yarn was measured. An extra metal clip weight, to give a total load of 0.1 g/denier, was then added and this load was applied for one minute before the length (ℓ_3) was measured. The extra weight was then removed and after the yarn had been allowed to contract for a further period of one minute, the length (ℓ_4) was measured.

The following calculations were then made:

$$\text{Yarn percentage collapse} = \frac{\ell_3 - \ell_2}{\ell_3} \times 100\%$$

$$\text{Yarn crimp rigidity} = \frac{\ell_3 - \ell_4}{\ell_3} \times 100\%$$

$$\text{and Yarn percentage shrinkage} = \frac{\ell_1 - \ell_3}{\ell_1} \times 100\%$$

2.3 Preparation of Fabric Samples

1x1 rib fabrics were produced on a Universal Power Flat Knitting machine. The yarns were threaded up in the normal manner and the same feeder used in each case, the spring compensator and the take-down tensions adjusted to give a good quality selvedge production. The yarns listed in tables 3(a) and 3(b) were knitted with varying number of ends and the stitch cam and other settings kept constant in order to reduce the influence of knitting variables to a minimum. The yarns shown in table 3(c) were knitted at five different stitch lengths by altering the stitch cam setting (vernier adjustment) from 9.5 to 11.5 in the stages of 0.5 units. The details of the machine are as follows:

Number of needles on each bed	520
Length of needle bed (inches)	65
Machine gauge (needles per inch)	8
Number of yarn carriers	4
Type of needles	wire latch
Type of tension device	disc and spring compensated

As the fabrics came off the machine, they were cut into four pieces and a square (6" x 6") was marked on each piece with indelible ink using a template of that size, each piece being given an identifying number.

2.31 Relaxation Treatments

It is known that fabrics knitted from bulked nylon yarns are dimensionally unstable in their griege state. Manden[82] has shown that crimped nylon fabrics continued to stiffen for periods up to three months after knitting. Thus in their griege state fabrics do not arrive at their fully relaxed dimensions. Four pieces of the resultant fabrics were therefore treated separately in the following manner:

(a) One piece was allowed to relax in a standard atmosphere for at least 24 hours before any measurements were made. This is referred to as the dry relaxed state.

(b) A second piece was relaxed in steam using the lower bed of a

Hoffman press. This steaming was done for about two minutes.

(c) A third piece was relaxed in water at 45°C for 20 minutes with slow agitation. This relaxation treatment was carried out in a miniature paddle dyeing machine so that the necessary agitation could be obtained. The fabric was then lightly pressed to remove excess water and allowed to dry in air.

(d) A fourth piece was relaxed by dry tumbling for 15 minutes using a modified Burco Tumblair. For achieving a fairly accurate temperature, a rheostat was introduced in the heating circuit of the tumblair.

After these relaxation treatments, the fabrics were conditions at 65 ± 2 % r.h. and 20 ± 2°C before any measurements were carried out.

2.32 <u>Measurement of Fabric Dimensions</u>

All the following measurements were made on griege (dry relaxed) and on the other three relaxed states for each fabric specimen.

(a) <u>Area shrinkage:</u> The original 6" x 6" marked area was measured and at least three readings were taken at different points along the length and width of each fabric and the average value then worked out.

(b) <u>Courses and wales per inch and stitch density per square inch:</u> The number of courses (c) and wales (w) per inch were obtained by using a counting glass. From these two measurements, the number of stitches per square inch (S) was calculated.

(c) <u>Stitch Length</u>: A stitch is defined as the smallest structural unit in a knitted fabric. In a 1x1 rib fabric, this stitch comprises of two adjacent knitted loops on the same course, one meshed to the front and the other to the back of the fabric. The length of yarn in a knitted loop was calculated from the total number of loops across the width of the fabric and the course length was measured on the H.A.T.R.A. course length tester in which a small dead load (10 g) was used to remove the crimp. Ten readings for each fabric specimen were recorded to obtain an average value of stitch length.

(d) <u>Fabric Thickness</u>: The thickness of each fabric sample was determined as a mean of at least ten readings obtained with a Baty thickness gauge. A disadvantage of using this thickness gauge was that the exact pressure under which the measurement was obtained was not known. Therefore when a Shirley Fabric Thickness Tester became available, the fabrics produced from yarns shown in table (e) were tested for thickness on that instrument. The thickness measurements were made at a number of pressures ranging from 0.02 p.s.i. to approximately 2 p.s.i.

(e) <u>Fabric Weight</u>: Fabric of a known area was carefully cut from the specimen and weighed. This measured weight has been expressed in gm. per sq. meter and used to calculate fabric bulk as will be indicated later.

2.4 Air Permeability of Fabrics

Definition: The permeability of a material can be defined simply as the rate of flow of a gas under a differential pressure through an area of that material.

In its textile applications, the air permeability (P_a) of a fabric is defined more simply as the volume of air in cubic centimeters passed per second through one square centimeter of a fabric at a pressure difference of one centimeter head of water.

Various types of apparatus for the evaluation of air permeability of a fabric have been broadly classified into three types by Seiminski and Hotte[83] as shown hereunder:

(a) In one apparatus the time is noted for a given volume of air to pass through a given area of the fabric under an unspecified pressure difference across the fabric. An example of this type of instrument is the Gurley Densometer[84].

(b) In the second type of apparatus the back pressure developed upon passing air at a constant rate through the sample is noted, the fabric being less permeable to air when the observed back pressure is greater. An example of this type of instrument is Haven's Porosity Machine[85]. This type of apparatus is obviously suitable for a limited range of fabrics only, since it would be inconvenient to have fixed rate of flow for all types of fabrics.

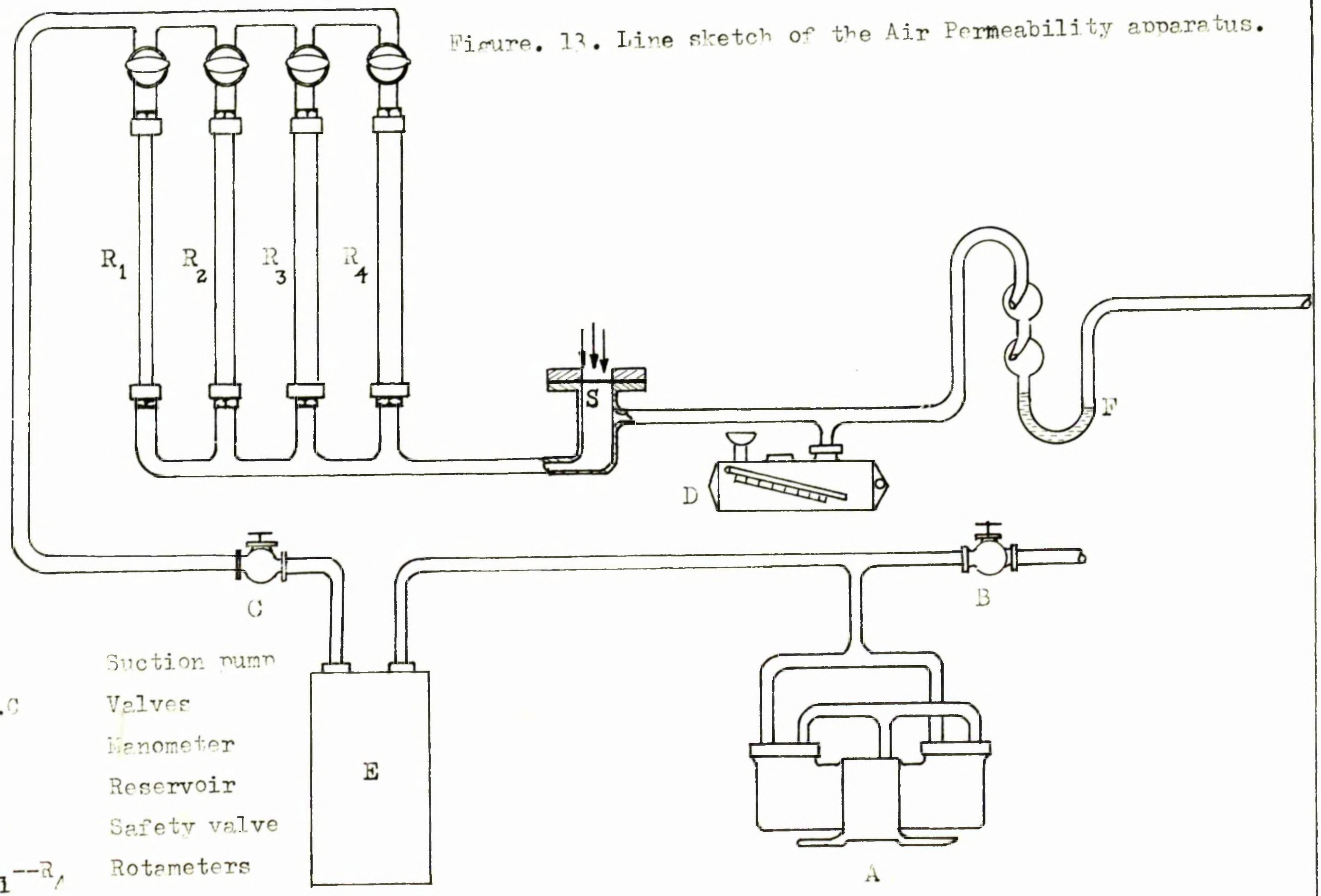
(c) The third method is the most generally used method in which a given pressure drop is maintained across the fabric specimen and the rate of flow of air through a given area of the sample is measured. There are a number of examples of instruments used for this method[86,87].

Lord[88] has described one instrument which is similar to the one developed by Clayton[86] but is more simple and sensitive. This instrument known as the Shirley Air Permeability Apparatus has been used in the present work. The description of the apparatus and experimental details are also described in the British Standard Hand Book[89].

Evaluation of air permeability of fabrics was carried out primarily with the object of investigating if this test could be successfully used as an indication of fabric bulk. Therefore air permeability of 1x1 rib fabrics produced from the yarns shown in table 3(c) knitted at five different stitch lengths and relaxed by the treatments indicated in section (2.31) were determined. Ten specimens were selected from different places in the fabric in such a manner that they represented the material as fully as possible.

Each specimen was then clamped into position as shown in Figure (13) and the test was commenced with R_4 open and the other flow meters closed. The rate of flow of air was adjusted until the required pressure drop was attained. If the flow was less than 30 c.c. per second, R_3 was opened and R_4 closed. This procedure was repeated until the most suitable range for the fabric under test had been selected. The rate of flow of air was noted

Figure. 13. Line sketch of the Air Permeability apparatus.



A	Suction pump
B,C	Valves
D	Manometer
E	Reservoir
F	Safety valve
R_1--R_4	Rotameters

for each pressure drop across the fabric. The test was thus continued to cover the range of pressure drops across the fabric. The other nine specimens were tested in a similar fashion.

The average rate of flow for each pressure drop was divided by 5.07 to give the air permeability in c.c/sec./cm^2. The test was performed under standard conditions of testing, i.e. 65 $\pm$ 2% r.h. and 20$\pm$2°C.

RESULTS AND DISCUSSION

C O N T E N T S

CHAPTER 3 | Page

The following symbols are used in the text:

The definitions of some symbols are followed by the units used in this work.

A	Fabric area density (gm/sq. meter).
c	Courses per unit length (courses/in.).
D	General term used to indicate mass per unit length of a yarn (denier).
D_b, D_u	Measured mass per unit length, under tension T, of bulked and unbulked yarns, respectively, extracted from fabrics (denier).
D_r	Relaxed mass per unit length of a bulked yarn in a fabric (denier).
DT	Fabrics finished by dry tumbling
F	Air flow through a fabric (c.c/cm^2/sec)
G	Greige state fabrics
k_s	General term used to indicate stitch density constant.
k_{sb}, k_{su}	Stitch density constants for fabrics from bulked and unbulked yarns, respectively.
ℓ	General term used to indicate measured stitch length of yarns extracted from fabrics (in.).
ℓ_b, ℓ_u	Measured stitch length of bulked and unbulked yarns, respectively, extracted from fabrics (in.).
ℓ_r	Relaxed stitch length of a bulked yarn in a fabric (in.).

P_a	Fabric air permeability (c.c/cm^2/sec/1cm head of water).
$\triangle p$	Pressue drop (cm head of water).
S	General term used to indicate stitch density of a fabric (stitches/in^2).
S_b, S_u	Stitch densities of bulked and unbulked-yarn fabrics, respectively, (stitches/in^2).
SR	Fabrics relaxed in steam.
S_1, S_2	Stitch density intercepts for unbulked and bulked-yarn fabrics, respectively.
t	Fabric thickness (in.).
T	Measuring tension on yarns extracted from fabrics (gm/denier).
w	Wales per unit length (wales/in.).
WR	Fabrics relaxed in water.

Results and Discussion

The standard H.A.T.R.A. crimp rigidity test has often been criticised on the grounds that the resultant measurement does not correlate accurately with the degree of collapse of the yarns when they are knitted into a fabric. In this chapter the results obtained from various methods of measuring yarn collapse properties and also the results of detailed investigation of dimensional properties of 1x1 rib fabrics and their dependence on various parameters are given and discussed.

3.1 Crimp Rigidity and Percentage Collapse of the Yarns

The results of the standard crimp rigidity test are given in tables 4(a) and 4(b). Each value recorded is an average of nine readings, taken three per package. The variation of results within a package was small but the variation of the mean results between packages were rather large. Whereas the set of Textralized yarns as obtained were supposedly the same crimp rigidity value, each denier of false twist crimped yarn was obtained in as near as possible, 10%, 20% and 30% crimp rigidity values. The values as given in the tables reflect the amount of deviation from the supplier's crimp rigidity value.

The results of crimp rigidity and yarn collapse measurements[69,71] in air on single strands of yarns pre-relaxed by three methods are included in tables 5(a),(b) and (c) and plotted in Figures 14(a) and (b) and 15(a) and (b) in which the average

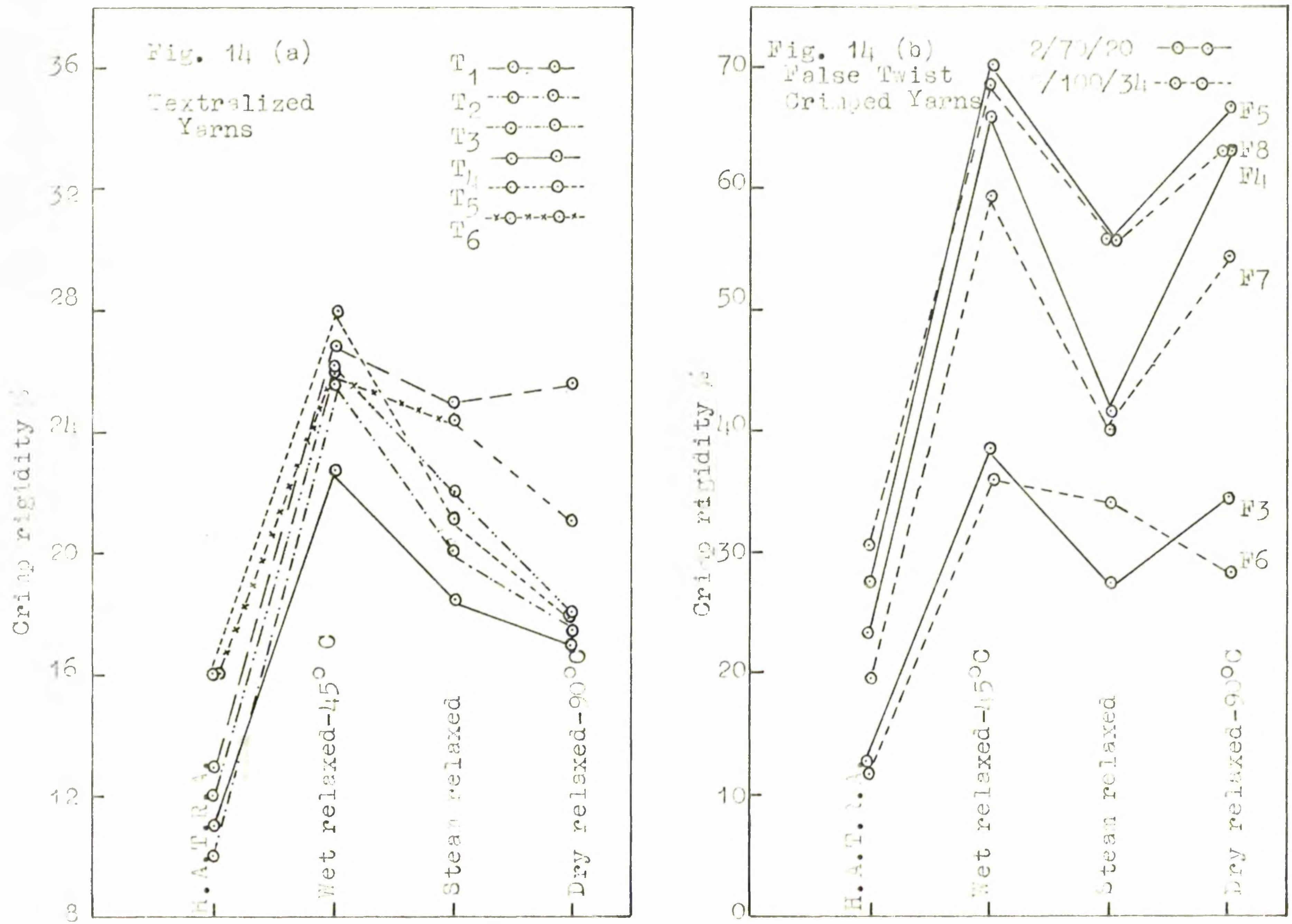


Fig. 14. Crimp rigidity of yarns given different relaxation treatments.

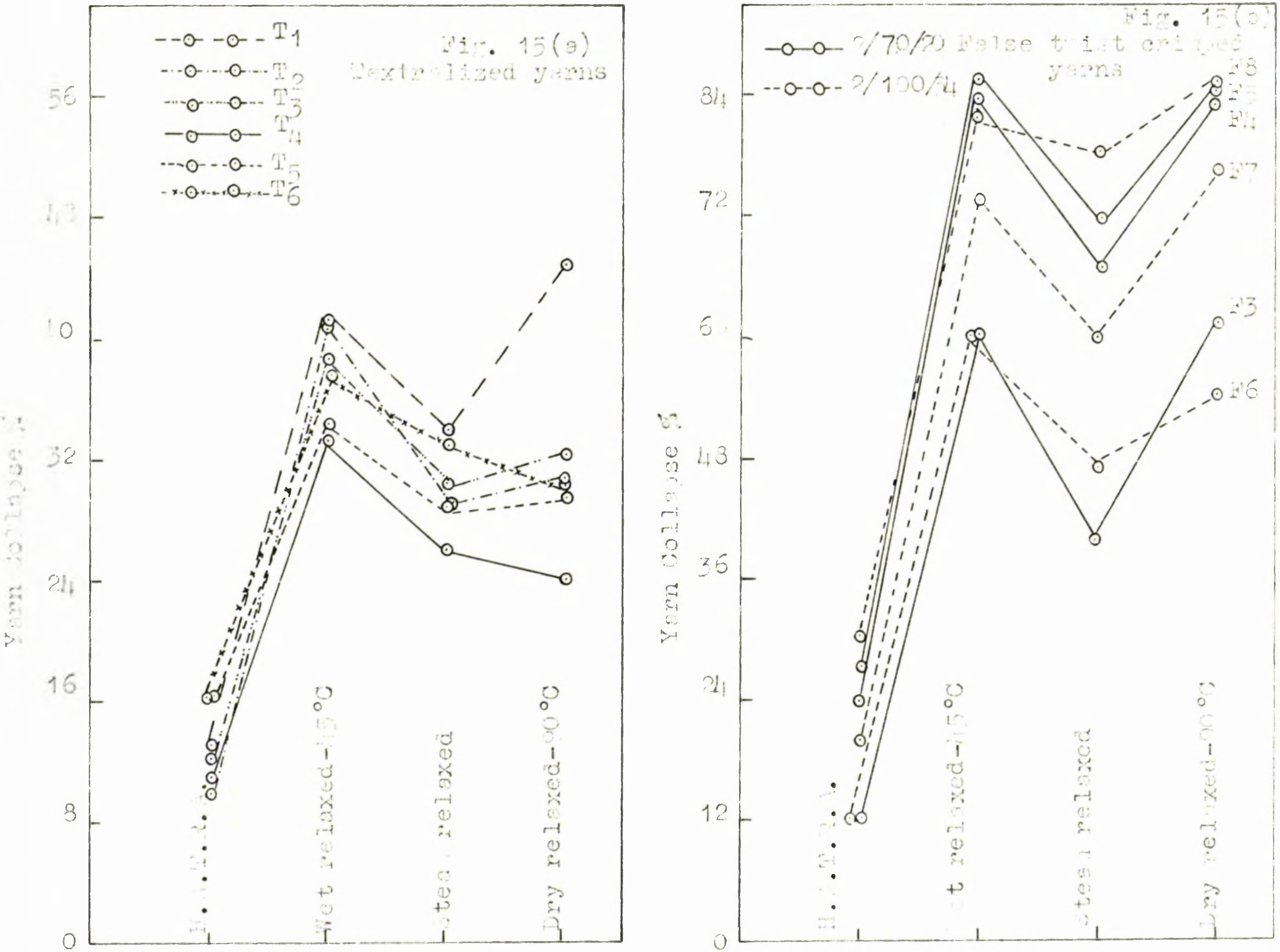


Fig. 15. Percentage collapse of yarns given different relaxation treatments.

H.A.T.R.A. crimp rigidity value is also shown for each yarn. In all cases, the H.A.T.R.A. crimp rigidity value is lower than the results obtained under other test conditions and the differences are very marked. Dry relaxation of yarn at 90°C appears to be as effective as the wet relaxation treatment for the false twist crimped yarns but is less effective for the Textralised yarns. Also, whereas the crimp rigidity values for Textralised dry relaxed yarns are generally lower than those for steam relaxed yarns, the percentage yarn collapse values exhibit the opposite trend for those yarns. The measurement of percentage yarn collapse yields higher values than the crimp rigidity results. It appears, therefore, that if the heavy load is applied first to the yarn as is done in the crimp rigidity test, it never reverts to its initial fully collapsed state achieved by relaxation treatments. Other points of interest to be noted from these figures are that the relative order of the yarns with respect to increasing collapse is the same for both crimp rigidity and yarn percentage collapse for false twist crimped yarns but this does not apply to the Textralised yarns. Textralised yarn of a H.A.T.R.A. crimp rigidity value comparable with that of a false twist crimped yarn exhibit a smaller increase in crimp rigidity and yarn percentage collapse values as determined on pre-relaxed yarns.

The results appear to indicate that full relaxation of false twist crimped and Textralized yarns occur in water at 45°C. This temperature was selected for wet relaxation because fabrics knitted from these yarns have been relaxed at this temperature. It is not possible to say that temperatures lower or higher than 45°C would result in any change in crimp rigidity and yarn percentage collapse values. However, it is interesting to note that Brook et al[90] did not find any appreciable change in crimp rigidity and yarn percentage collapse values for conventional crimp and Fluflon yarns wet relaxed in water at 20°C, 40°C and 70°C.

The high values obtained for wet relaxed yarns can be explained on the basis of the effect of wet and dry treatments on nylon 6.6 yarns. Munden and Slater[90] have shown that for a nylon 6.6 yarn the temperature effect in water is equivalent to a dry-heat temperature approximately 80°C higher. Thus if the dry relaxation treatment were carried out at 125°C, one would then expect the same effect as that obtained with wet relaxation treatment at 45°C. The reason for the low values for yarns relaxed in steam (temperature approximately 110°C) can possibly be ascribed to the frictional force offered to the yarn by the bed of a Hoffman press which leads to only restricted yarn relaxation.

The lower values obtained in the H.A.T.R.A. crimp rigidity test as compared with the results obtained on pre-relaxed yarns require an explanation. The H.A.T.R.A. crimp rigidity test is carried out in water at 20°C with the heavy load applied to the unrelaxed yarn, this load being replaced after some time by a lighter load. If this test were carried out in air, the crimp in the unrelaxed yarn would not manifest itself fully, because the yarn generally acquires a partially cohesive set by virtue of its being kept on a package under tension. In the H.A.T.R.A. crimp rigidity test, water helps to break the temporary bonds responsible for the partially cohesive set and assists in the realisation of latent yarn crimp. However, at the same time the water will also cause the breakage of the low energy bonds which have been induced by the crimping process. It is therefore reasonable to suggest that after a wet treatment is applied to the yarn in its straightened condition in the H.A.T.R.A. crimp rigidity test, only bonds of a sufficiently high energy level with remain. Therefore, when the load is finally removed the collapse properties of the yarn will be lower because only a proportion of the bonds set by the crimping process will remain to facilitate the yarn collapse. This effect explains why the H.A.T.R.A. crimp rigidity values are lower than those noted for the pre-relaxed yarns.

For comparable H.A.T.R.A. crimp rigidity values Textralised yarns show a lower yarn percentage collapse as determined by other methods than do false twist crimped yarns. This indicates that during the crimping process, the crimp in the Textralised yarns must have been set at a high energy level so that the proportion of bonds broken by wet treatment of length-strained yarn are less. Thus the technique of measuring yarn collapse properties under other test conditions has its usefulness in that it might be possible to obtain a relative indication of the crimp setting temperature for yarns crimped by different processes.

Figures 16(a) and (b) show the relationship between yarn percentage collapse and H.A.T.R.A. crimp rigidity for Textralised and false twist crimped yarns. It will be seen that a good correlation exists between these two yarn parameters[72] for the false twist crimped yarns (Fig.16 b) and that the slight difference in yarn denier appears to have little influence. For any given crimp rigidity value, the yarn percentage collapse of dry and wet pre-relaxed yarn is higher than that of steam relaxed yarn. The reasons for this have already been indicated. In the case of Textralised yarns it is not surprising that no such relationship has been found. The values have been plotted (Fig.16 a) for the six yarns which vary in their total denier, filament denier and to a limited extent, H.A.T.R.A. crimp rigidity values. With a wide range of H.A.T.R.A. crimp rigidity values for Textralised yarns of the same count, a correlation with yarn percentage collapse must exist.

In tables 5(a), (b) and (c), figures for yarn percentage

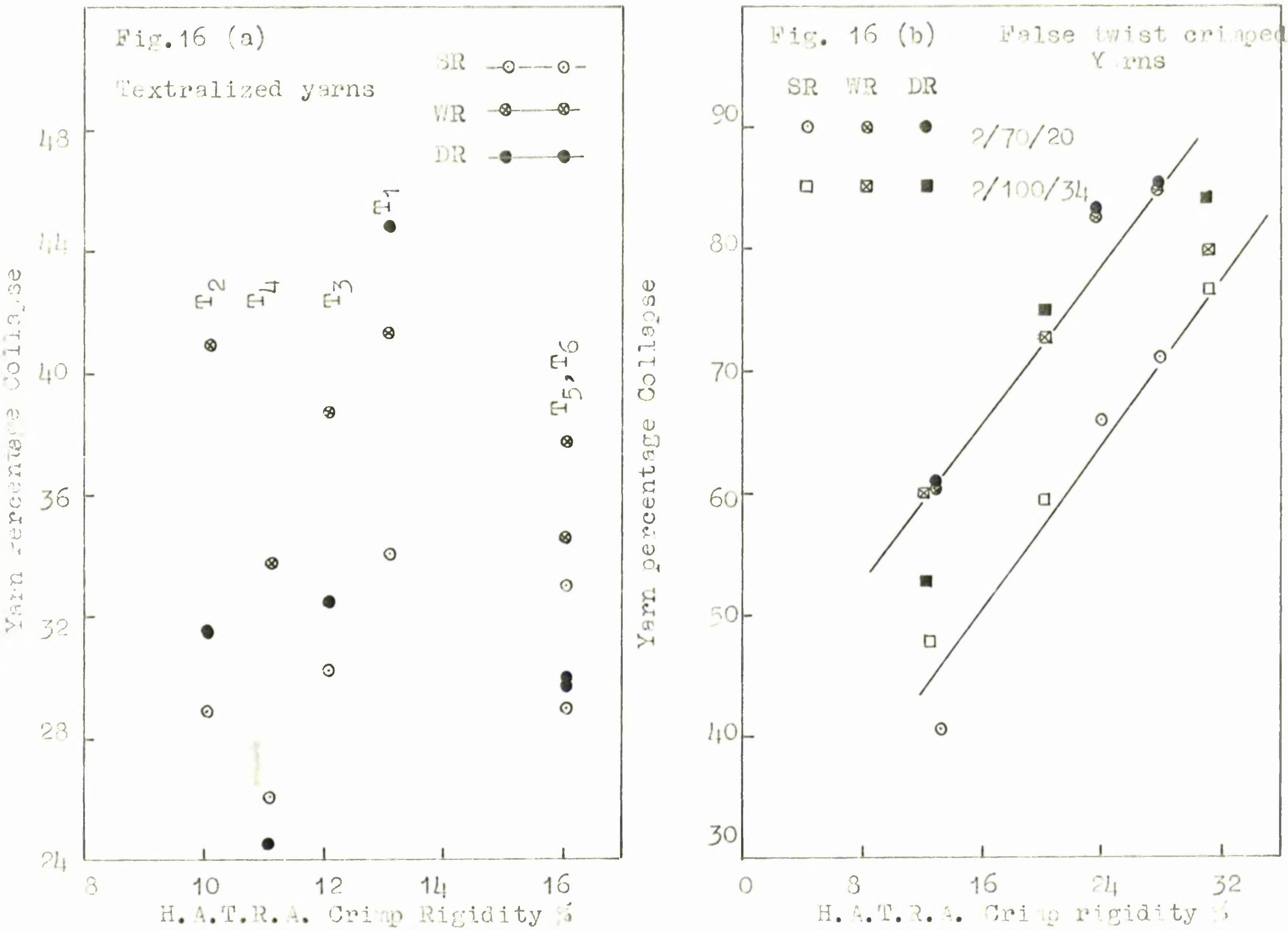


Fig. Relation between H.A.T.R.A. Crimp rigidity and Yarn percentage Collapse.

shrinkage are also given and it will be noted that for false twist crimped yarns, relaxation in steam on a Hoffman press results in a maximum shrinkage which is of the order of about 3%. The shrinkage values for the two yarns F3 and F6 are low as would be expected because these two yarns have been stabilised during processing by the passage through a second heater. The Textralised yarns after relaxation treatments have shown a lower shrinkage value which has not exceeded even 1%.

For bulked yarns and particularly stuffer box bulked yarns, the term crimp intensity has been used and is defined as the number of crimps per unit length. It is conceded that the wave-length of the crimp is not constant and hence an accurate determination of crimp intensity will depend on an extensive statistical treatment of a large number of observations. Determination of a yarn percentage collapse value can be of further use in this instance as a direct measure of crimp intensity, because resistance to the extension under a small load is dependent upon the wave-length of the crimps. A bulked yarn with a greater number of crimps per unit length will offer more resistance to extension under a small load than a yarn having a lower number of crimps.

The usefulness of any particular method of measuring yarn collapse properties lies in the fact that there should be a reasonable correlation with the retraction behaviour of the yarn when that yarn is knitted. Therefore, a critical assessment of the methods of measuring yarn collapse properties will be made later when the collapse of the fabrics knitted from these yarns is considered.

3.2 Dimensional Properties of Fabrics

3.3 Effect of Linear Density (Denier) of Yarn on Fabric Stitch Density.

When it is required to knit bulky 1x1 rib fabrics with rather large loops, then a thick yarn is used in order to maintain a full handle. It is common practice, however, to knit such fabrics by using several ends of a fine denier yarn rather than use one end of a multi-folded yarn. Experiments were performed to study how the dimensional properties of fabrics were affected by increasing the yarn denier as a result of an increase in the number of ends knitting at one time and using one feeder.

The results of measurements on fabrics knitted from Textralised yarns using a varying number of ends are presented in tables 6 - 11. Initially various measurements were taken immediately after knitting and finishing treatments, and also after one day and seven days conditioning in the relaxed state in a standard atmosphere. It was found that except for the fabric in its greige state, there was little fabric movement after any further conditioning. Subsequently therefore, measurements were taken only after one day of knitting and finishing the fabrics and such data obtained is presented in the tables.

Figure (17) shows the influence of an increase in yarn denier on the stitch density of the fabrics made from Textralised yarns. For the sake of clarity, data for the fabrics from three yarns only are plotted which are so selected as to cover the maximum range of filament deniers. Also only two relaxed states namely, wet relaxed and dry tumbled are considered though the general trend, as can be seen from tables 6 - 11, remains the same for greige and steam relaxed fabrics, the only difference being in the relative values of stitch density. It will be noted from Figure (17) that the stitch density of fabrics made from yarns T1 and T2 increases as the total yarn denier increases but the increase in total denier of yarn T6 leads to fabrics of lower stitch density.

All the fabrics under consideration were knitted on an 8 gauge power flat machine with the same stitch cam settings and the recommended[91] yarn deniers for such a machine lie in the range 400/600. The increase in stitch density of fabrics from yarns T1 and T2 is therefore not surprising[77] because such fabrics, particularly those from lower yarn deniers, are of fairly loose construction. The maximum count that could be used for such yarns by employing eight ends amounted to 560 denier. If it were possible to use more than eight ends on the knitting machine, this would have resulted in a decrease in fabric stitch density. The results for fabrics produced from the varying ends of yarn T6 bear

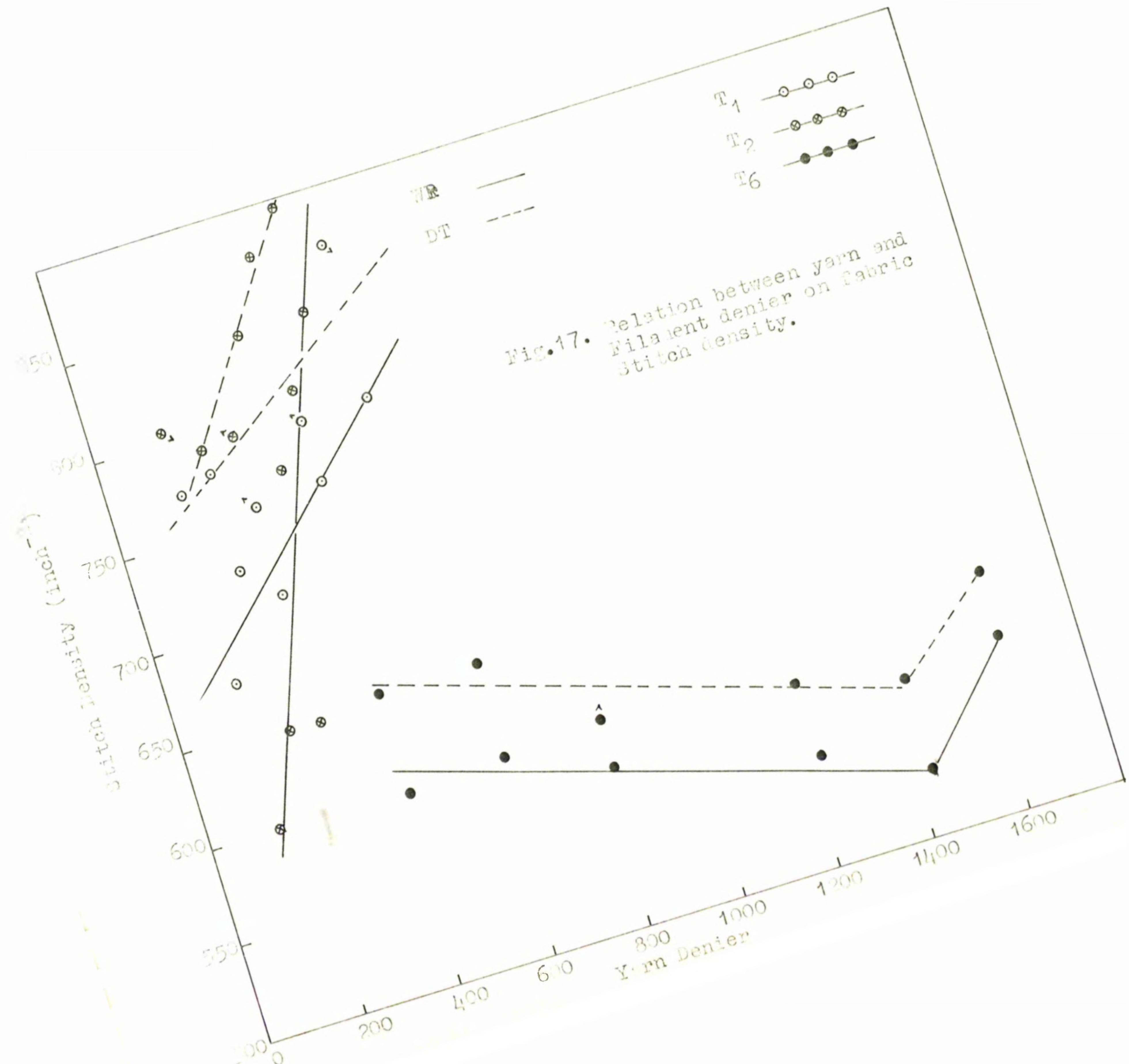


Fig.17. Relation between yarn and Filament denier on fabric Stitch density.

out the significance of this explanation. After the yarn reaches the value of approximately 600 denier, all the available space within the loop is filled and any further increase in yarn denier must lead to a swelling of the loop with a resultant decrease in stitch density. However, there would probably be an optimum value of yarn denier up to which this decrease in stitch density could be observed. Beyond this optimum value, any further increase in yarn denier will exert an increasingly severe compressional force on the adjacent knitted loops leading to some increase in stitch density as shown in Figure (17) for the fabrics produced from yarn T6. These fabrics were knitted by using multi-ends of yarn T6 reaching a denier value as high as 1640 and, as such, the fabrics in the upper count range are of no commercial importance. The results from such fabrics have, however, corroborated the apprehension that is put forward. It must be stated that any change in stitch density due to change in yarn denier mainly arises because of the accompanied change in the stitch length of the knitted loop as no special device was employed to control this fabric variable. The amount of change in stitch length with change in yarn denier for the same machine setting will be considered in the next section.

It is interesting to note from Figure (17) that fabrics knitted from yarns of high filament denier have resulted in lower stitch density values for the same total yarn denier. The denier per filament of yarns TI, T2 and T6 are 3.5, 2 and 6. The results show more remarkable changes beyond 400 (total) yarn denier perhaps because below this value of yarn denier the fabrics are very slack and therefore easily distorted. Also the difference in stitch density for fabrics from yarn TI (3.5 d.p.f.) or yarn T2 (2 d.p.f.) and yarn T6 (6 d.p.f.) at, for example, 400 yarn denier, is more pronounced than for the difference in fabrics knitted from yarns TI and T2. Smith[92] has shown that the stiffness of an ideal cylindrical rod is proportional to the fourth power of its diameter and since diameter is proportional to square root of the denier, it follows that stiffness of a filament increases as the square of the denier. The differences as stated above can therefore be directly ascribed to this effect. As the filament denier increases, its stiffness increases and therefore in fabrics made from such yarns, more resistance will be offered to bending and consequently to a change in loop shape which is necessary to give rise to increase in stitch density values.

It will be observed that yarns T2 and T4 are essentially similar in all respects other than a difference in the number of filaments constituting the yarns and the total denier value. It would therefore be expected that knitting fabrics from double the number of ends of yarn T2 would give roughly the same dimensions as fabrics produced from yarn T4. The results obtained for stitch density values are presented in Figure (18) and it will be noted that despite some scatter the fabrics knitted from yarn T2 have considerably higher stitch density values for any given total yarn denier. No reasonable explanation for this behaviour could be thought of and it was decided to check the coefficient of friction of these two yarns. Whilst measuring[81] the coefficient of friction, two ends of yarn T2 were tested together so as to create the same total number of filaments and yarn count as in yarn T4. The values obtained were 0.4 and 0.21 for yarns T2 and T4 respectively. Nutting[66] has demonstrated that high yarn kinetic friction produces high knitting tension and therefore a short stitch length. The fabrics produced from yarn T2 are of shorter stitch lengths as will be seen in the next section. This provides an explanation for an apparently anomalous behaviour, the significance of which lies in the fact that in practice if for some reason the heavier denier yarn is replaced by a lighter denier one, keeping total denier etc. the same, it will not be possible to obtain the same finished dimensions unless the coefficient of friction of the yarns is the same or a yarn feeding device is used.

Of the two relaxation processes for which results have been plotted in Figures(17) and (18), it is apparent that the dry tumbling process gives somewhat higher values for stitch density than those obtained with the wet relaxation treatment, which is rather surprising because wet relaxation is carried out at 45°C and

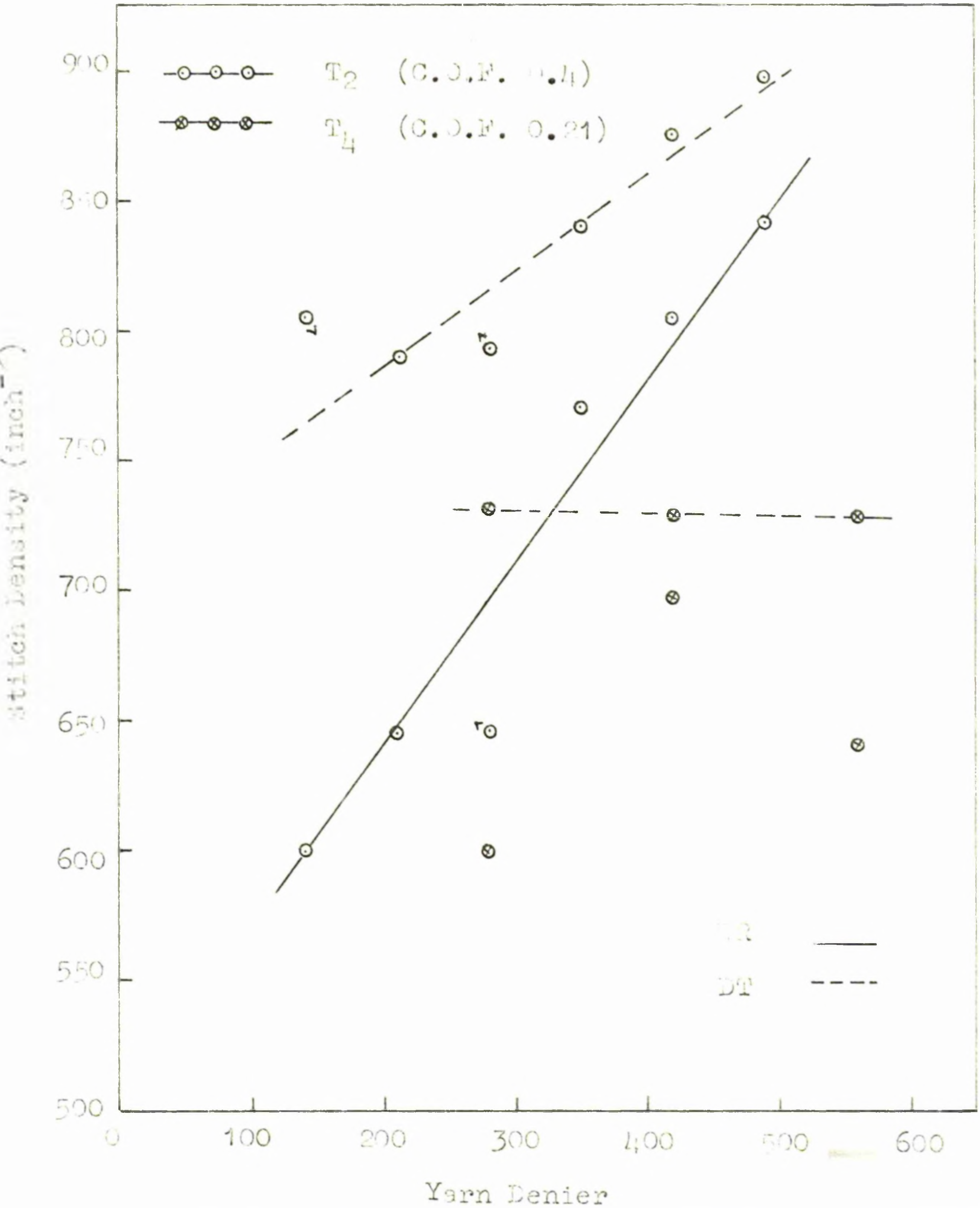


Fig.18. Changes in stitch density caused by variation in the coefficient of friction of yarns.

to obtain a similar effect, at least in yarn form, dry relaxation should be carried out at 125°C[50]. It is thought that water creates a dragging effect on the fabric during treatment which hinders its full relaxation and hence lower stitch density values of the wet relaxed fabrics. Finishing of fabrics in steam on a Hoffman press bed results in only partial relaxation as will be noted from the stitch density values for such fabrics (tables 6 - 11), these varying only slightly above the values for fabrics dry relaxed in their greige state and being much less than those for fabrics either wet treated or dry tumbled. This suggests that heat energy (from steam) is not by itself sufficient to cause complete relaxation without physical agitation and the implication is that such a fabric is dimensionally unstable as when subjected to wet treatment or dry tumbling in subsequent usage it will relax further.

The data obtained from measurements on fabrics knitted from false twist crimped yarns (F1 to F8) are presented in tables (12 - 19). The relationship between fabric stitch density and the yarn denier used is shown in Figures (19 - 21) for fabrics knitted from yarns F2, F5 and F8 all of which are of approximately 30% crimp rigidity. Although, as will be seen from the tables, similar trends exist for fabrics produced from other false twist crimped yarns used, the results are graphically shown for the above mentioned three yarns only to avoid inclusion of too many figures. It will be noted that as the denier of the yarn is progressively increased, the stitch

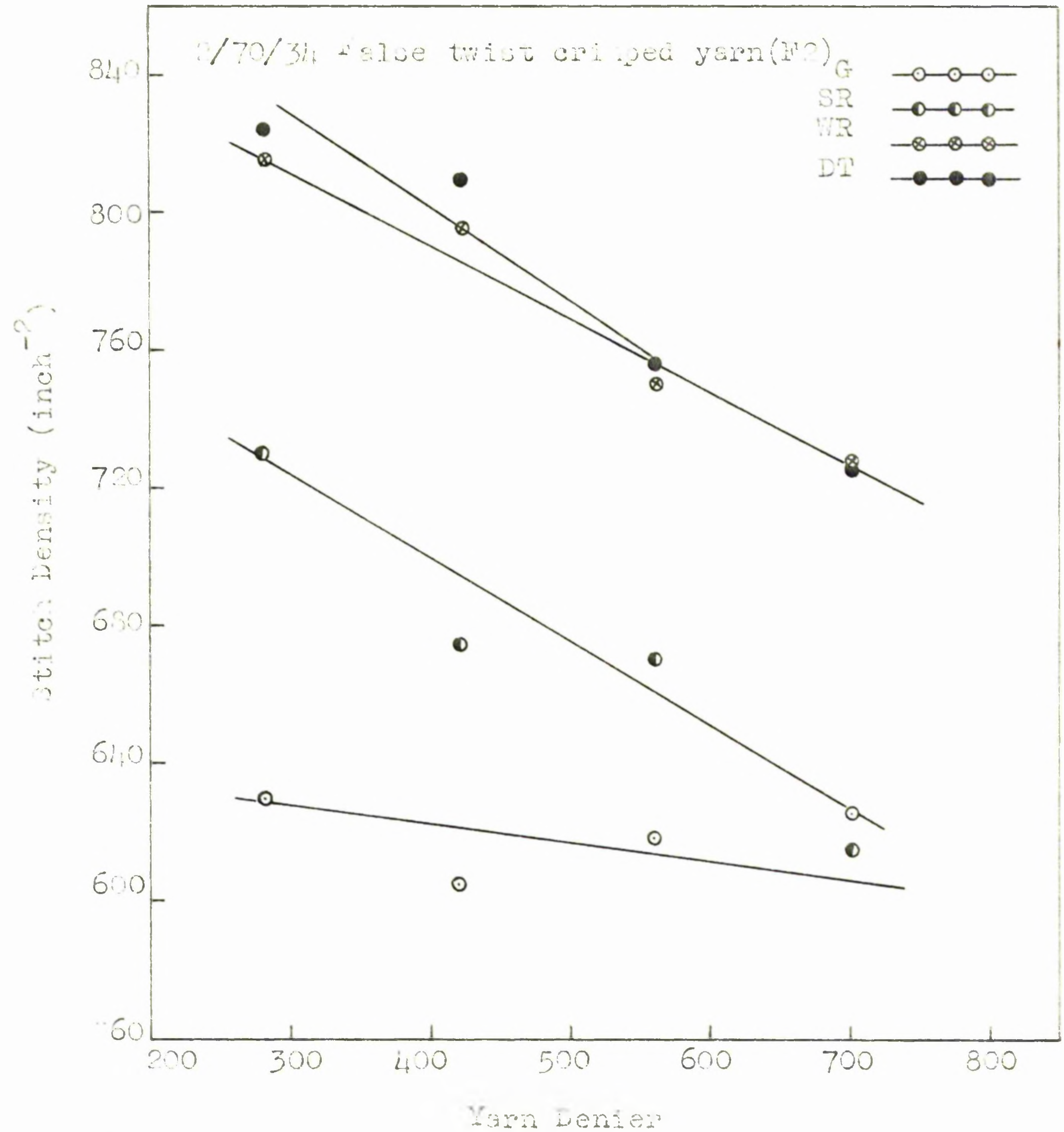


Fig. 19. Relation between yarn denier and fabric stitch density.

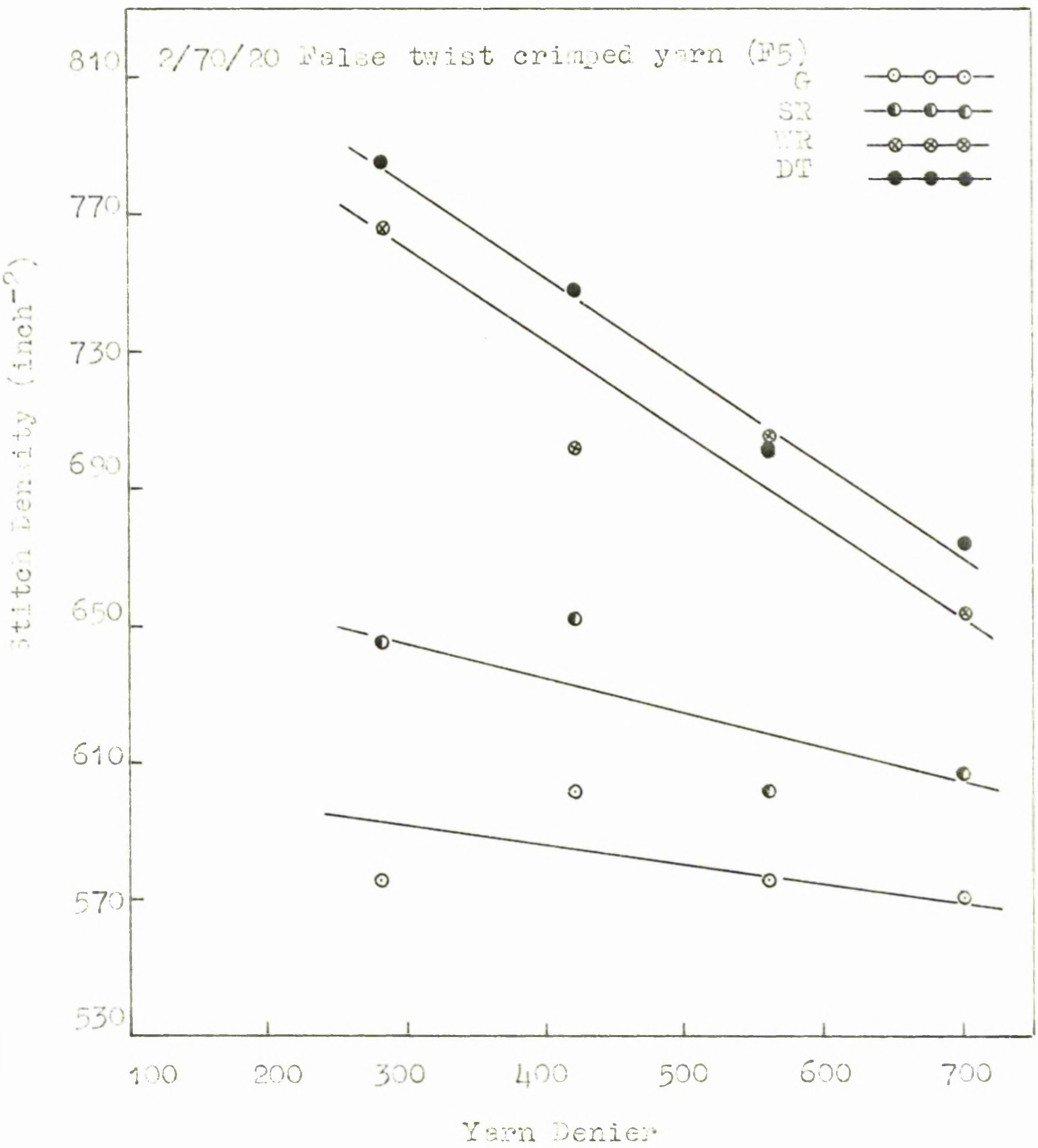


Fig. [illegible]. Relation between yarn denier and fabric stitch density.

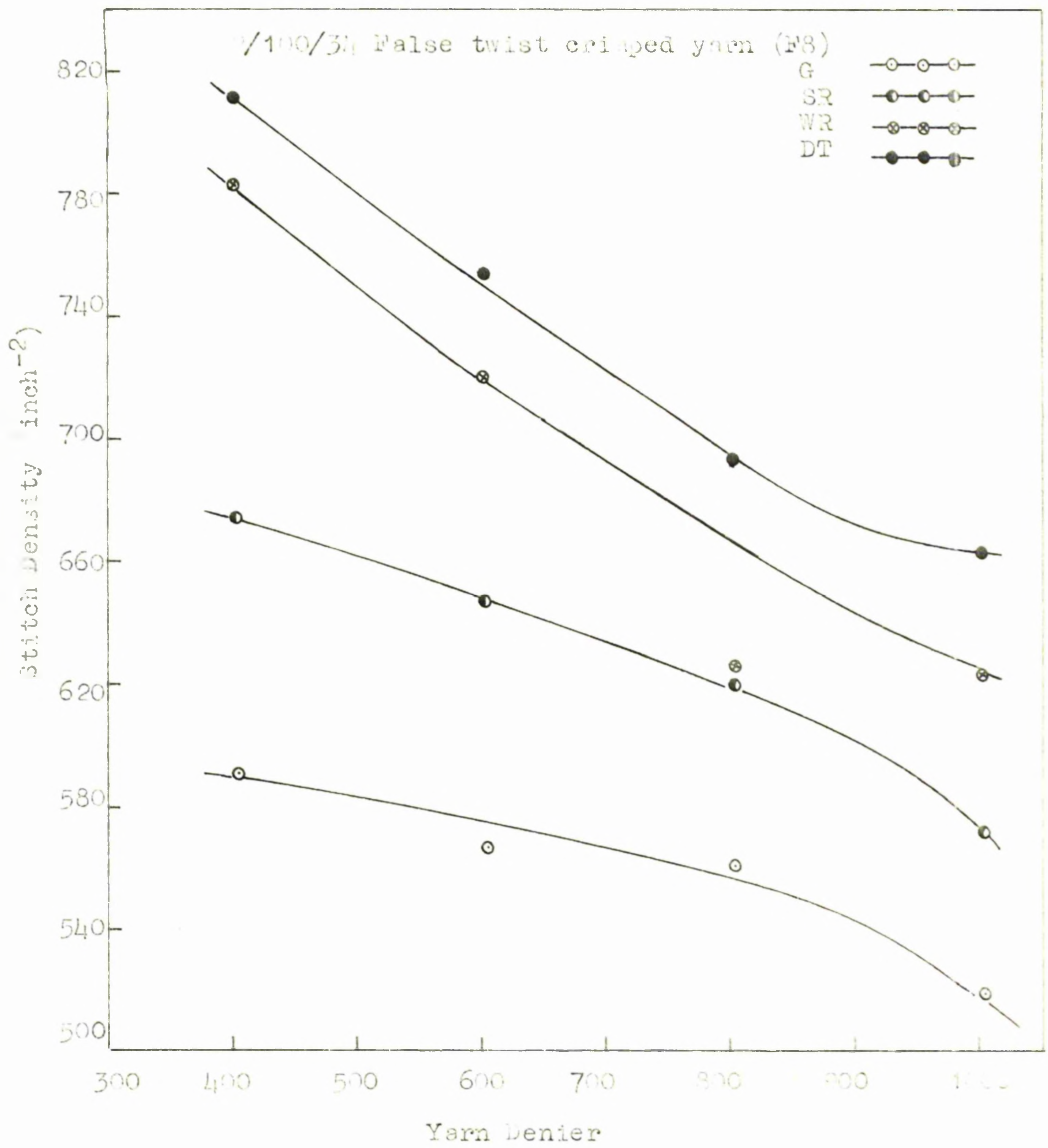


Fig.21. Relation between yarn denier and fabric stitch density.

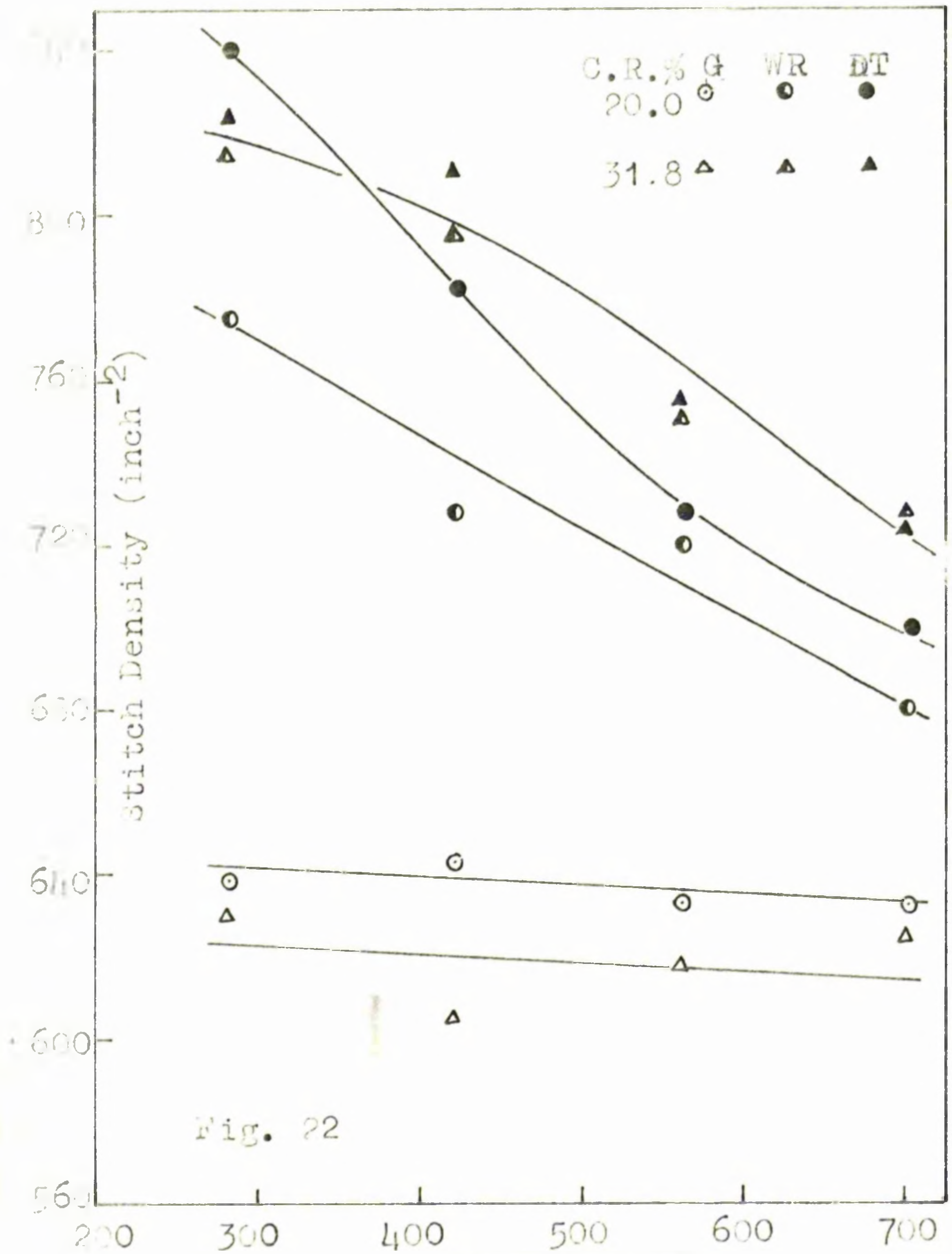
density value of the resultant fabric goes down. Thus in this respect the behaviour of false twist crimped yarns is different from that of the Textralized (stuffer box crimped) yarns for which the fabric stitch density increased with an increase in yarn denier up to about 600 - 700 total yarn denier. This difference can be associated with the nature of false twist yarn in which the inherent crimp develops rapidly on release of strains and the individual filaments constituting the yarn tend to spring apart. This would naturally create some resistance to further yarn collapse and reduced stitch density values result. This resistance to yarn collapse is also assisted by the fact that there will be a greater interfilament entanglement as the yarn denier increases because of an accompanying increase in the number of filaments. It is interesting to note that Vidhani and Nutting[76] also found that increasing yarn denier for a false twist yarn of a given crimp rigidity knitted to a fixed loop length reduced the effective crimp contraction and hence produced fabrics of a lower stitch density. It must be pointed out that the fabrics produced from differing yarn deniers in the present study were not of the same stitch length as no yarn feeding device was employed. Nevertheless, the effect of an increase in yarn denier on fabric stitch density is similar to that found by Vidhani and Nutting.

For any given fabric, the increase in stitch density due to finishing treatments is a direct result of the fabric collapse. It will be seen in Figures (19 - 21) that the amount of this collapse is greater in magnitude for the slacker fabrics, as would be expected. In general, the effect of relaxation treatments is the same as already described for fabrics from Textralised yarns.

3.31 Effect of Yarn Crimp Rigidity on Fabric Stitch Density

Yarn crimp rigidity is a measure of yarn contraction and it is reasonable to suppose that it will exercise some control on the relaxed fabric dimensions. It has been established by various workers[73,74,75,76] that if a range of false twist nylon crimped yarns, differing in crimp rigidity values are knitted to the same stitch length, the stitch density will increase with an increase in crimp rigidity.

From Figures (22 - 24) the influence of yarn crimp rigidity on fabric stitch density is noted. In Figures (23 - 24) the results are plotted for fabrics made from a varying number of ends of a particular yarn denier and each denier was available in three crimp rigidity values. In Figure (22) data is plotted for only two crimp rigidities as the fabrics from the yarn of approximately 10% crimp rigidity could not be knitted due to some yarn manufacturing fault. For the sake of simplicity an attempt has been made to draw smooth curves though this is not fully justified because there appears to be a great deal of scatter. However, even if lines are drawn passing through all the points, this will not drastically alter the conclusions. The scatter in the results



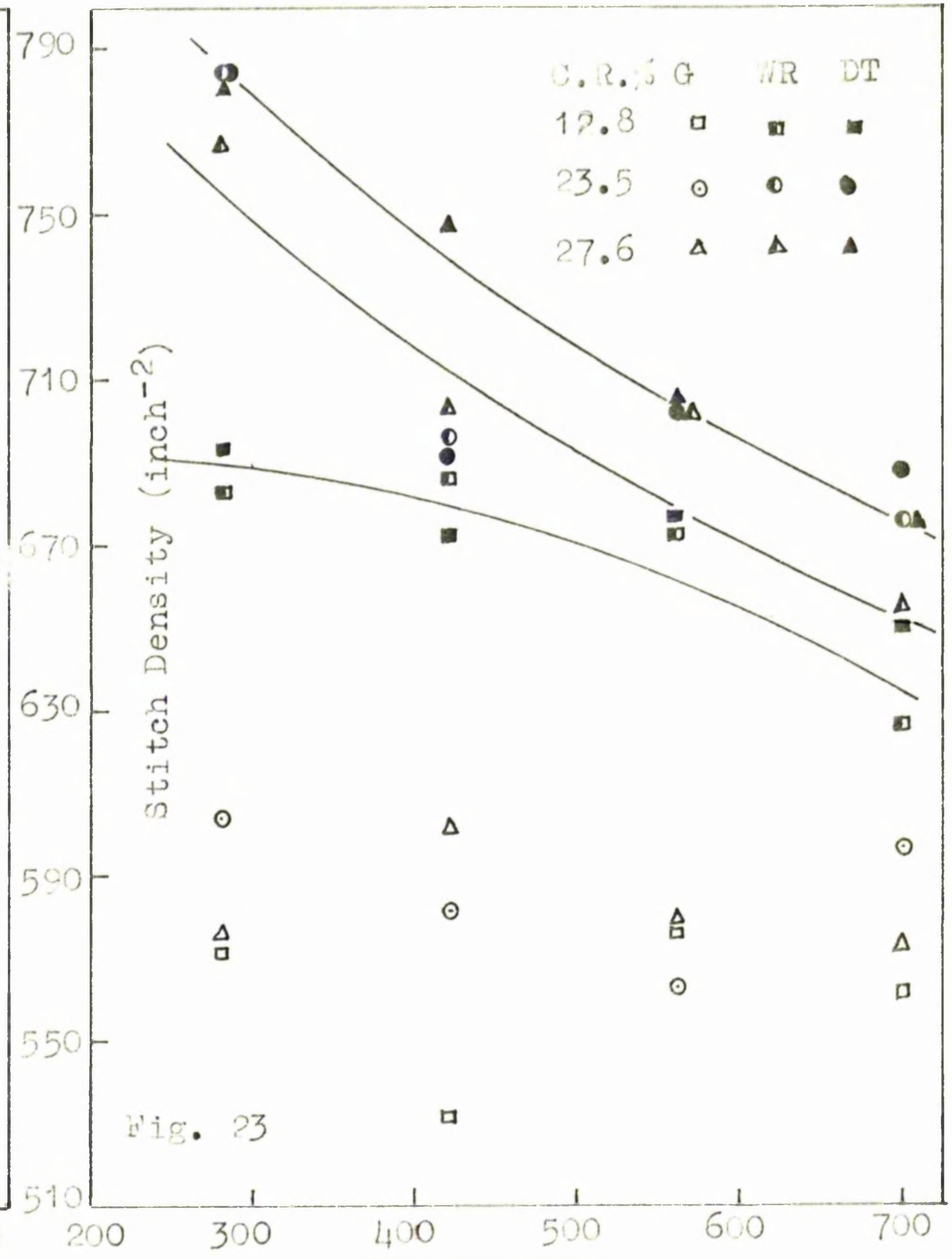


Fig. Effect of yarn crimp rigidity on fabric stitch density

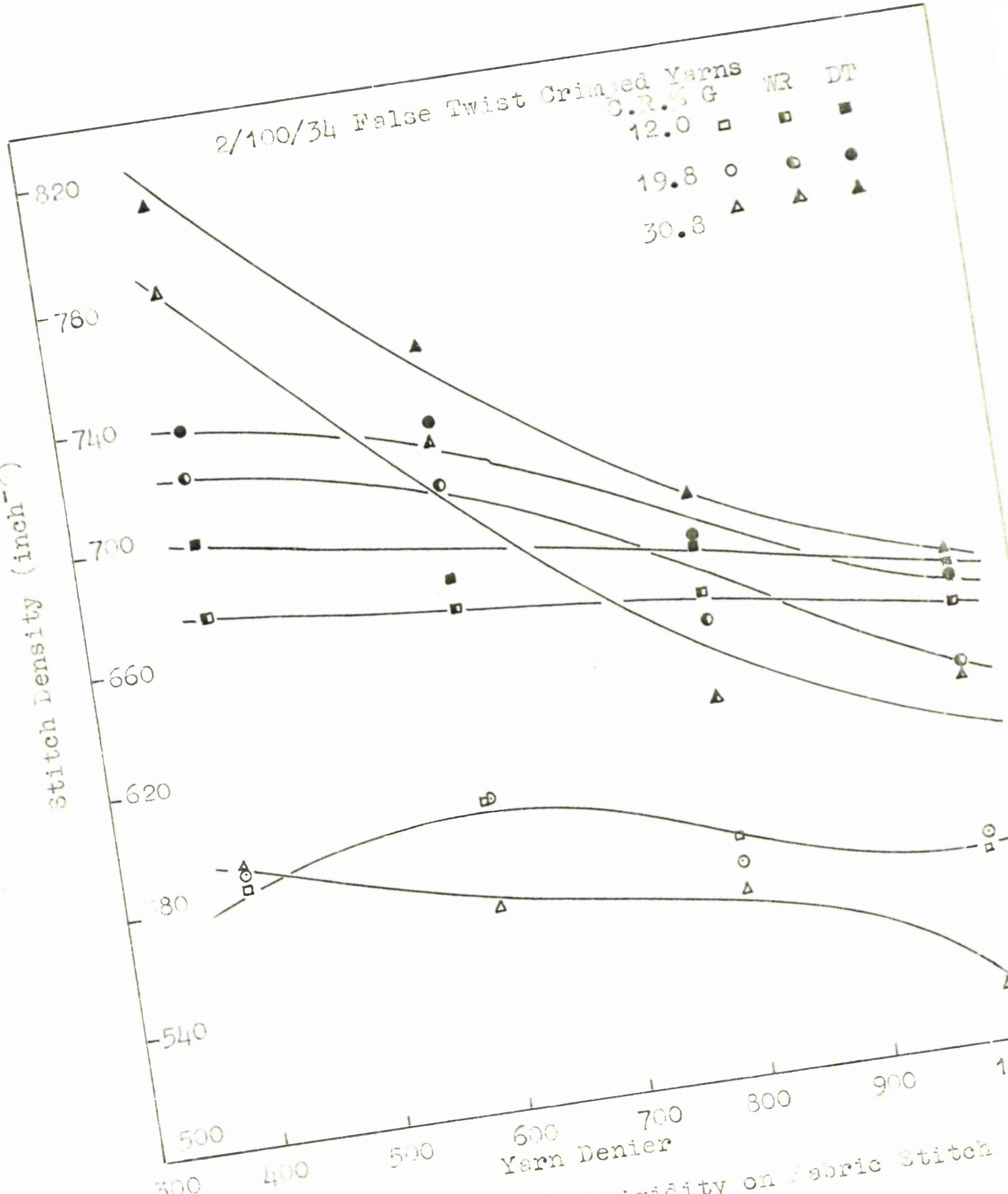


Fig. 24. Effect of crimp rigidity on fabric Stitch

reflect the difficulty in obtaining completely relaxed fabrics, this being particularly noticeable for the 1x1 rib structures used in the present work, these being easily distorted.

In general it is seen that fabric stitch density increases for the finished fabrics with an increase in yarn crimp rigidity. For dry relaxed fabrics in their greige state, higher yarn crimp rigidity results in a somewhat lower fabric stitch density. It is evident that full yarn crimp is not realised until the fabric is given a more thorough relaxation treatment.

In Figure (24) fabrics made from yarns (F6, F7 and F8) covering a wide range of deniers were considered and it is interesting to note a few points. Firstly, yarn crimp rigidity appears to play a greater role in controlling dimensions of fabrics made from lighter denier yarns. In fact for fabrics produced from 1000 denier yarn, the fabric stitch density for three different crimp rigidities is almost the same for a particular relaxed state other than for greige fabrics. Secondly, the stitch density of wet relaxed fabrics above approximately 750 yarn denier, is more for lower crimp rigidity yarns. This arises because yarns of high crimp strength contract until restricted by the lack of available space within the loop. It is believed that the amount of filament separation increases with an increase in yarn crimp rigidity this being responsible for filling up the available space and thus the yarn is not able to collapse any further.

3.4 Effect of Yarn Denier on Fabric Stitch Length

As a result of basic research into the factors that determine the dimensions of a knitted fabric, Doyle[39] and Munden[37] have established that the length of yarn in a loop and the number of loops in the fabric are the only factors affecting the dimensions of a fully relaxed fabric. In the previous section, variation in the number of loops in a fabric as a result of a change in yarn denier has been discussed. The loop lengths or the lengths of yarn in the stitches of fabrics under consideration from Textralised yarns (T1 - T6) were measured and are recorded in tables (6 - 11). These loop lengths are plotted in Figure (25) for fabrics made from yarns T1, T2 and T6 against yarn deniers as was done for fabric stitch density values. It will be seen that as the yarn denier increases the loop length decreases for all these fabrics. Whereas for fabrics made from yarns T1 and T2 one would expect this result as a consequence of increase in stitch density with an increase in yarn denier, the stitch lengths for fabrics from yarn T6 should have increased with an increase in yarn denier because these fabrics exhibited a decrease in stitch density with an increase in yarn denier. It must however, be realised that though this situation must exist for fabrics from conventional or unbulked yarns, it does not necessarily apply to fabrics from bulked yarns because an increase in stitch density of these fabrics is mainly associated with yarn collapse. Consequently a decrease in stitch length with an

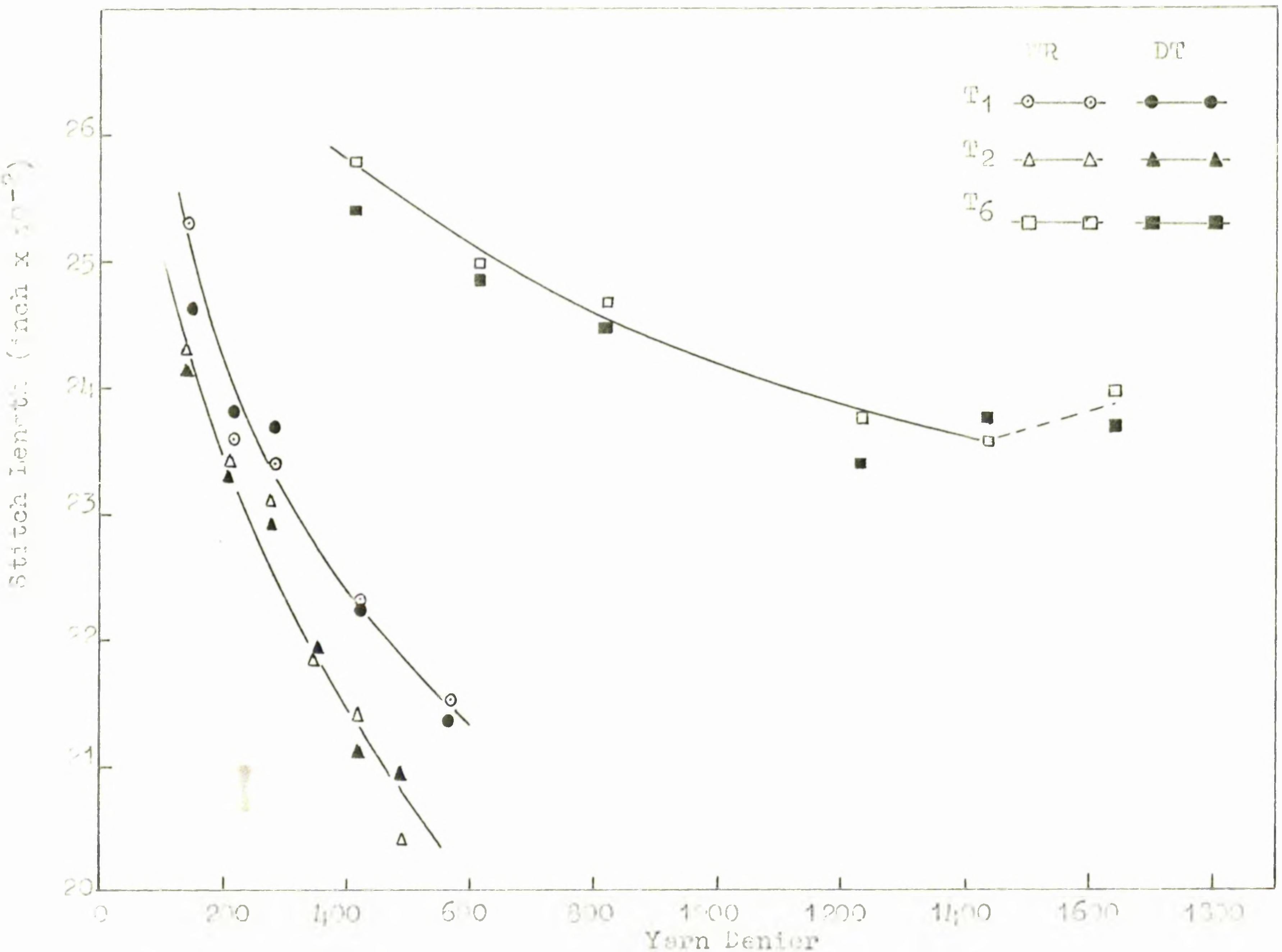


Fig. 35. Relation between yarn and filament denier on stitch length.

increase in yarn denier implies that there is only a small space available within the loop for yarn collapse to occur and hence the stitch density is decreased. For the fabric from yarn T6, a small increase in stitch length is observed when the total denier value is reached around 1600. It might be possible that for the particular machine setting employed, the tension developed is not sufficient to remove all the crimp from this yarn which is, therefore fed to the needles in a partially crimped state leading to a slightly longer measured stitch length.

The fall in loop length of a fabric with an increase in yarn denier needs an explanation as also does difference in loop lengths for any particular denier value for fabrics knitted from yarns differing in their constituent filament deniers. It is known that the length of a yarn drawn to form a loop can be altered by adjusting the maximum depth by which the needles fall. This is in fact an accepted mechanical method of adjusting the stitch length and means are provided on knitting machines for this purpose. This, however, does not always lead to a constant stitch length because changes in other factors such as tension in the yarn during knitting, frictional properties of the yarn etc. can and do alter the stitch length, for example, it is shown by Nutting[66] that a 1% change in stitch length occurs when the yarn tension is increased from 3 to 10 gm., these values being within the range of normal knitting tensions for the particular type of yarn and machine.

Recent published results of Marvin and Hulchandani[93] on the observations of yarn tensions during knitting also point to the fact that variations in yarn tension lead to considerable changes in stitch lengths.

In the present study, since the fabrics were knitted from various yarn deniers without any machine adjustments made, it is reasonable to suppose that the tension of the yarn when knitting lighter denier yarns must have been considerably lower than when knitting heavier denier yarns. This will account for longer stitch lengths for fabrics made from lighter denier yarns, as compared with heavier denier yarns. The variations in stitch length as a result of changes in yarn tension has been attributed to the following factors[94]:

(a) 'yarn extension' at high knitting tensions and

(b) 'robbing back', the robbing of yarn by the needle at the knitting point from the previously formed loops.

Figure (25) also shows that for any given total yarn denier value for the three types of yarns under consideration, the loop length of the fabrics is different for the machine setting which is kept constant. The percentage difference between loop lengths for the yarns T2 and T1 and T2 and T6 when knitted with a given count (e.g. 410 - 420 denier) are 4.3 and 15.8 respectively, this occurring as the filament denier increases from 2 to 6. This might be explained on the same basis as that by which the variation in stitch density with changes in filament denier has been explained in the previous section. In addition to that, it is reasonable to assume that as the yarn is threaded on the machine in the normal manner, the area of contact of each individual filament with various guides, yarn feeders etc. increases with a decrease in filament denier giving rise to greater frictional forces which result in shorter loop lengths.

The data in Figure (25) is plotted for fabrics that have been relaxed by dry tumbling and wet treatment. These relaxation processes have not resulted in any significant changes in measured loop lengths. Even when compared with the loop lengths of the fabrics in their greige state (tables 6 - 11), these two treatments in addition to relaxation of fabrics in steam have not caused any changes in the measured loop lengths. This is as expected because tables 5(a), (b) and (c) indicate that the actual shrinkage of these yarns by the treatments under consideration is of a very low order.

In Figure (26) influence of the coefficient of friction of the yarn on knitted loop length is shown. The fabrics made from different deniers of yarns T2 and T4, which vary in their coefficient of friction but are similar in many other respects, are of different stitch lengths. Thus if the frictional properties of yarns are not checked and the necessary machine adjustments made, this variation in the coefficient of friction would lead to a considerable change in the finished dimensions of the resultant

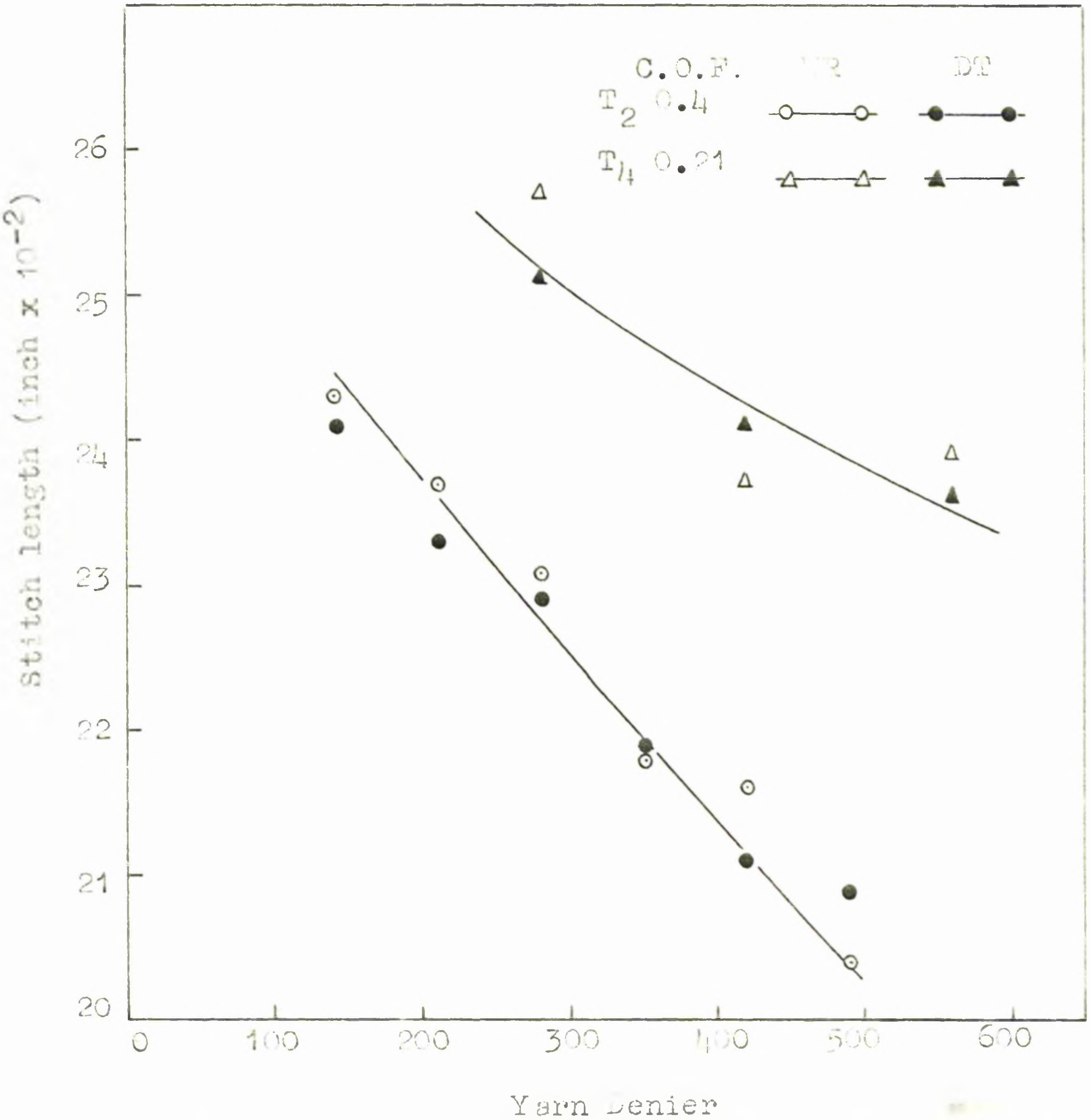
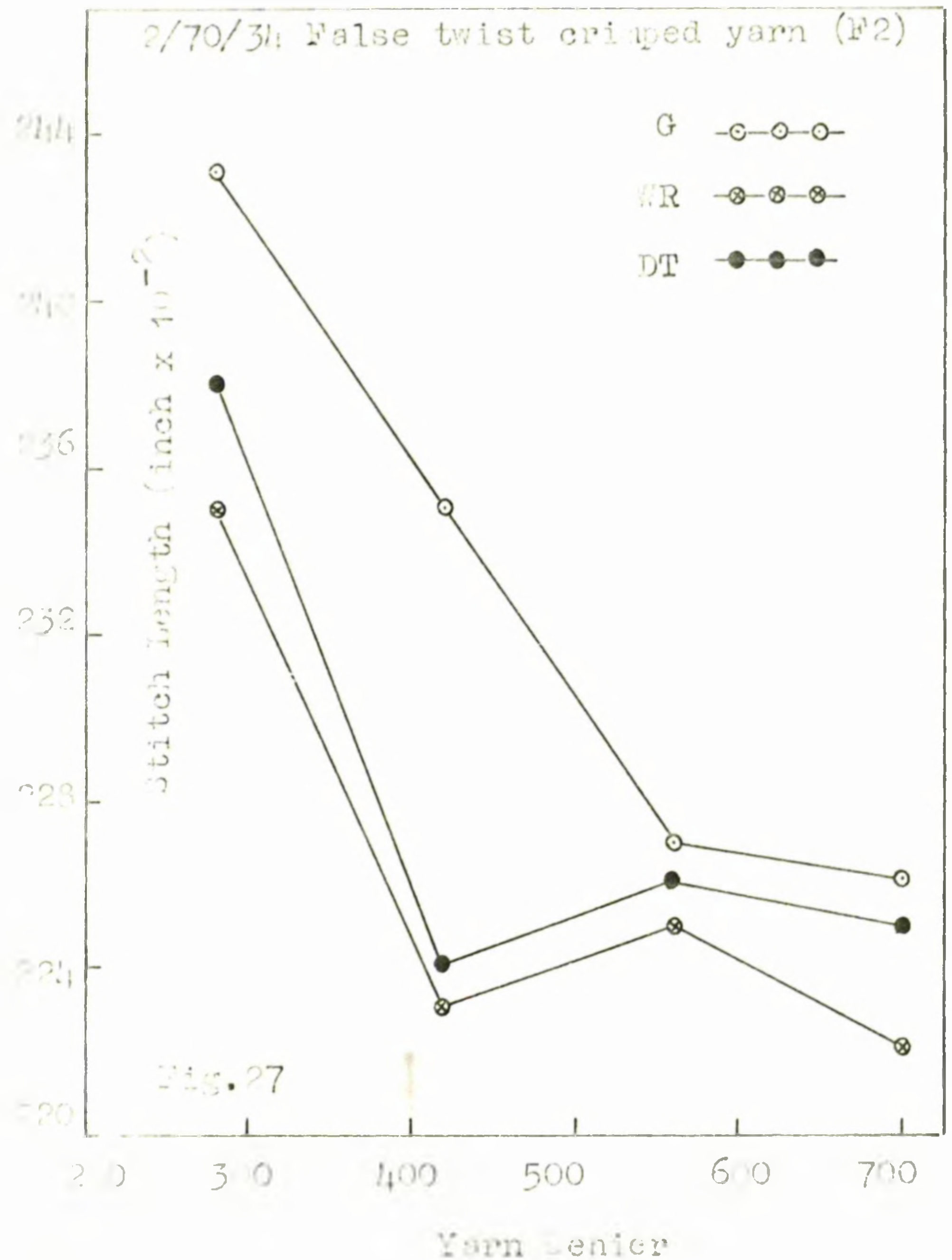


Fig. 26. Changes in stitch length caused by variation in the coefficient of friction of yarns.

fabrics. Also the rate of change in stitch length with an increase in the total yarn denier appears to be high for a yarn with a high coefficient of friction and small changes in the level of total yarn denier will produce relatively large changes in the knitted stitch length and hence in the fabric dimensions.

The loop lengths of fabrics knitted from varying ends of false twist crimped yarns (F1 to F8) are included in tables (12 - 19). In order to demonstrate the influence of change in yarn denier on measured stitch length, results are presented graphically in Figures (27 - 29) for fabrics made from yarns F2, F5 and F8. These fabrics were selected because they were considered in the previous section when changes in fabric stitch density and changes in yarn denier were considered. Examination of Figures (27 - 29) reveal that loop lengths decrease with an increase in yarn denier as was noted for fabrics knitted from Textralised yarns and the explanation offered then should also hold for these fabrics. There are however, certain facts which should be considered. Firstly, the loop lengths for fabrics made from yarns F2 and F5 of 560 denier yarn show some increase and, when the yarn denier is increased further, the measured loop lengths show the usual drop. The amount of this increase when calculated on the basis of loop length for the fabric from 420 denier yarn is within two per cent. It is rather doubtful if this increase has any practical significance, consistent as it appears, and the results for fabrics made from yarn F8 seem



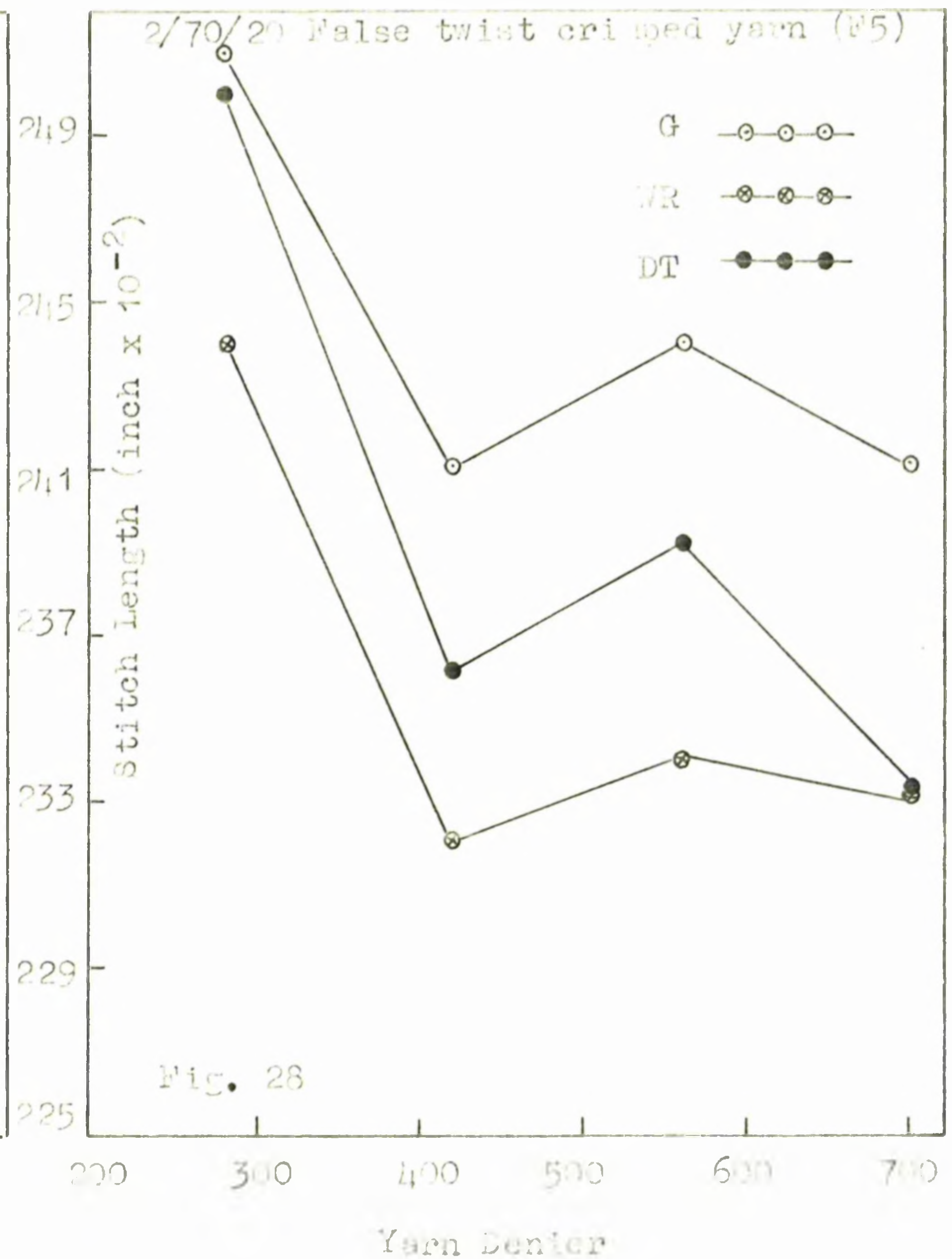


Fig. Relation between yarn denier and stitch length.

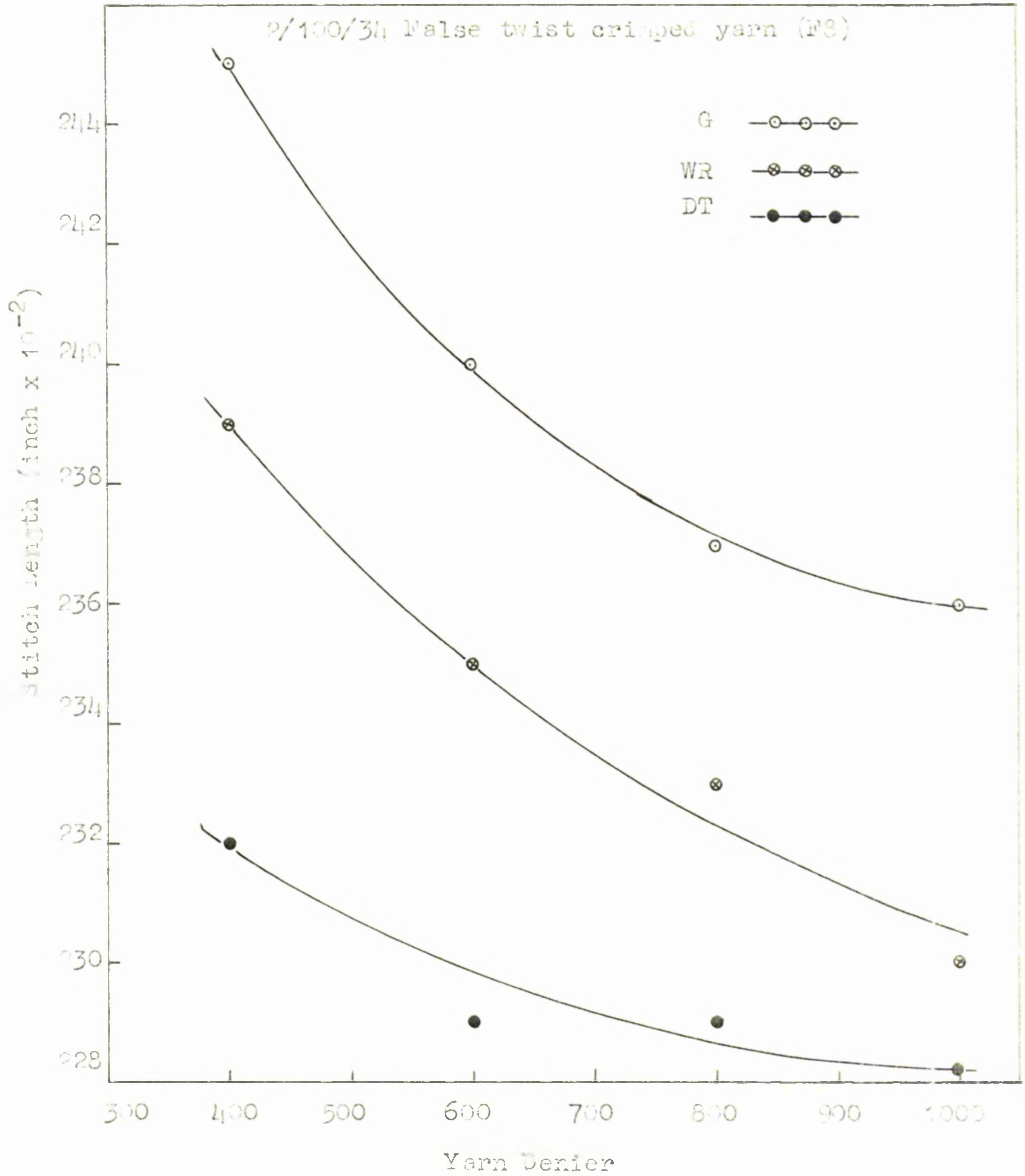
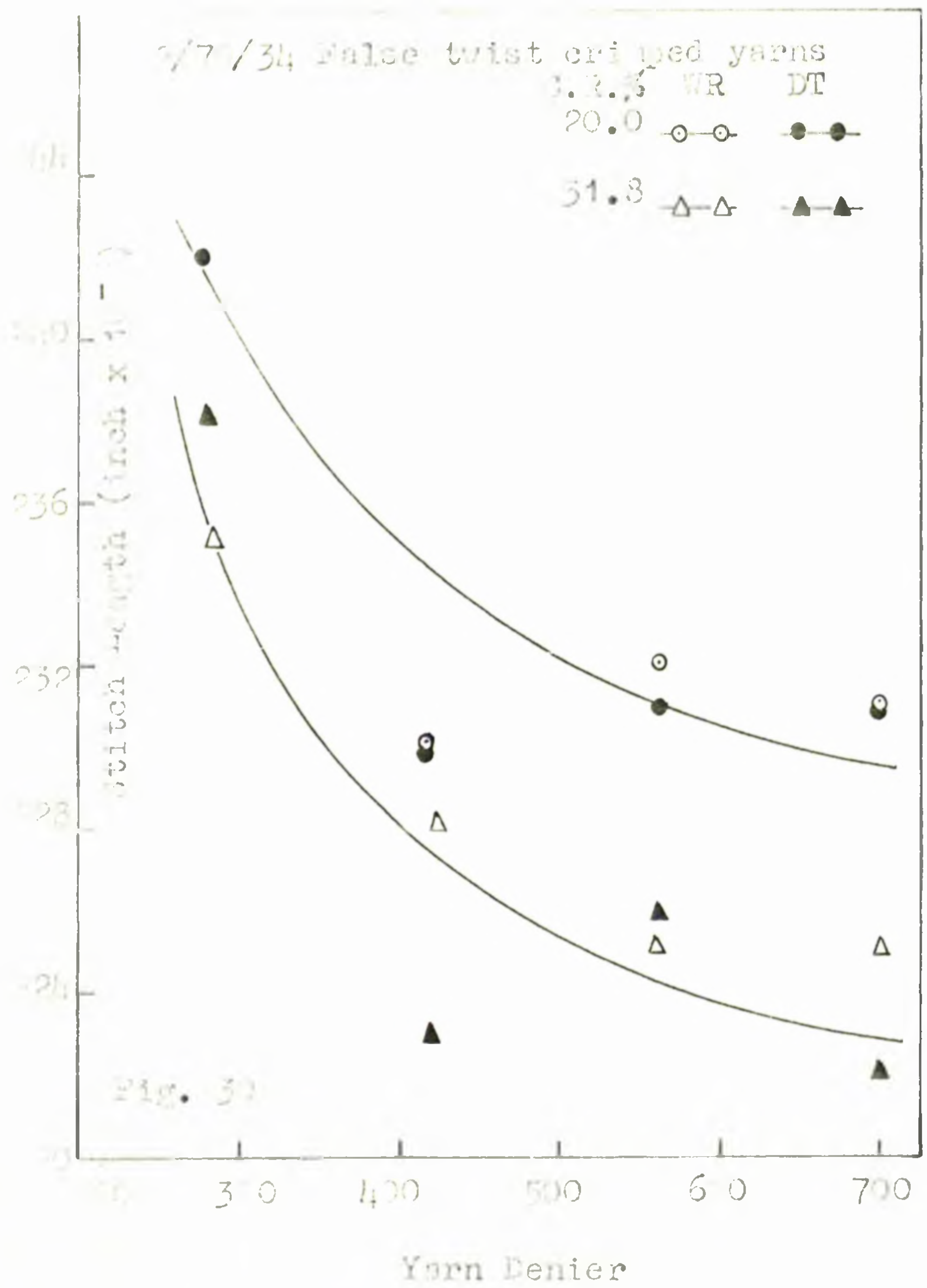


Fig.29. Relation between yarn denier and stitch length.

to support this. When this variation is ignored the curves begin to flatten, Figure (29), and any changes in yarn denier above a certain level do not appear to affect the knitted stitch length to a great extent. Secondly, at any value of yarn denier, the stitch length of the finished or treated fabric is less than in the fabric in its greige state indicating that an amount of yarn shrinkage has taken place. As the details of processing conditions employed during yarn bulking are not known, it is difficult to explain this observed shrinkage.

3.41 Effect of Yarn Crimp Rigidity on Fabric Stitch Length

It is generally accepted that the factor, yarn crimp rigidity and fabric stitch length are of primary importance in controlling the dimensional properties of fabrics. However it has not been shown how yarn crimp rigidity itself influences the knitted stitch length. This is presumably because most of the work reported is for fabrics knitted from bulked yarns and produced on machines equipped with a device for controlling the length of yarn per course. Since no such device was used in the present investigations, any changes that occur in the loop lengths of the fabrics knitted from a given count of yarn of different crimp rigidities can be naturally assigned to this latter factor. Figures (30 - 32) demonstrate this effect for fabrics knitted from false twist crimped yarns (F1 to F8) of approximately 10%, 20% and 30% crimp rigidity values. Despite the range of these results,



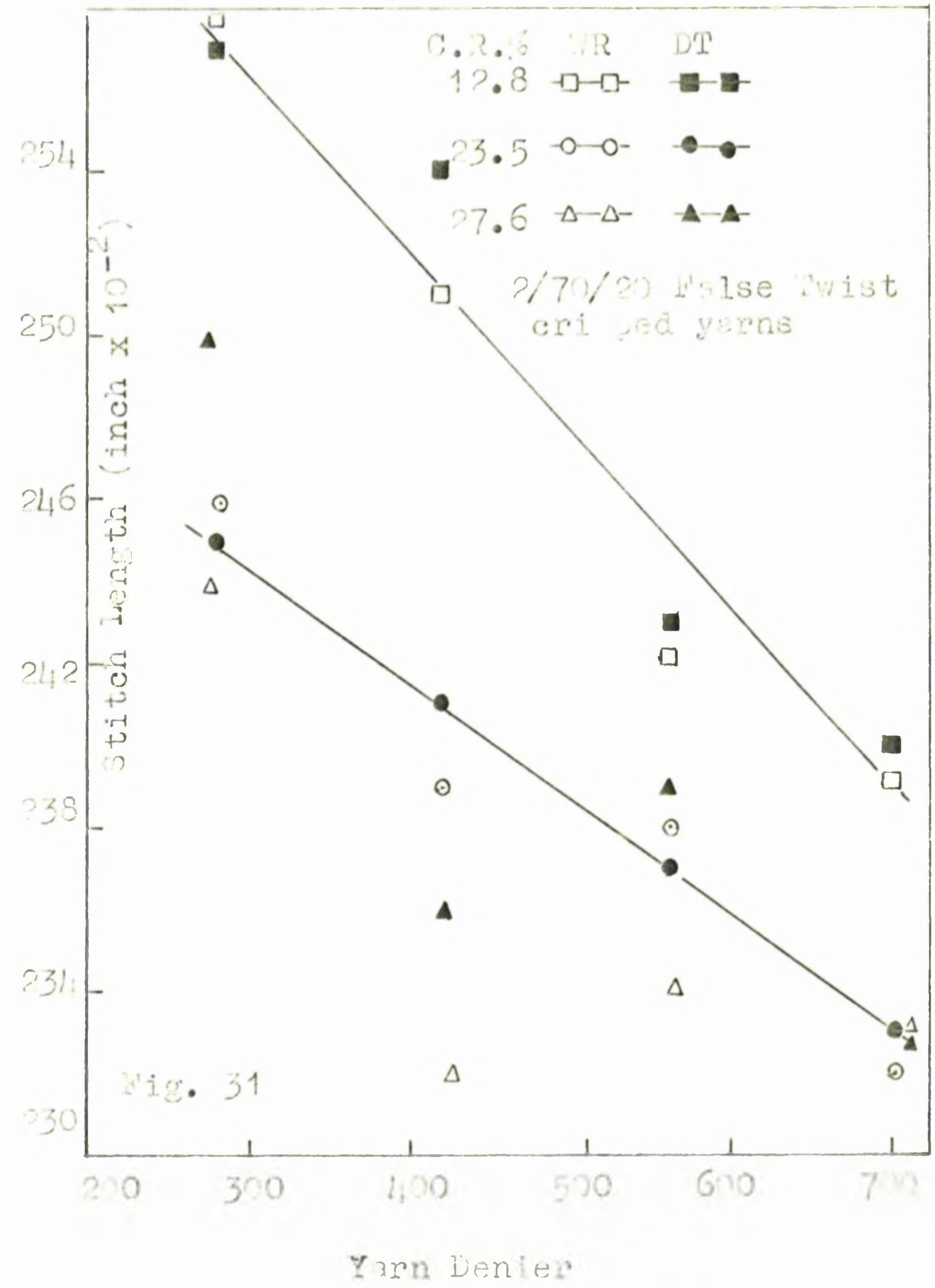


Fig. Effect of crimp rigidity of yarns on stitch length of the fabrics.

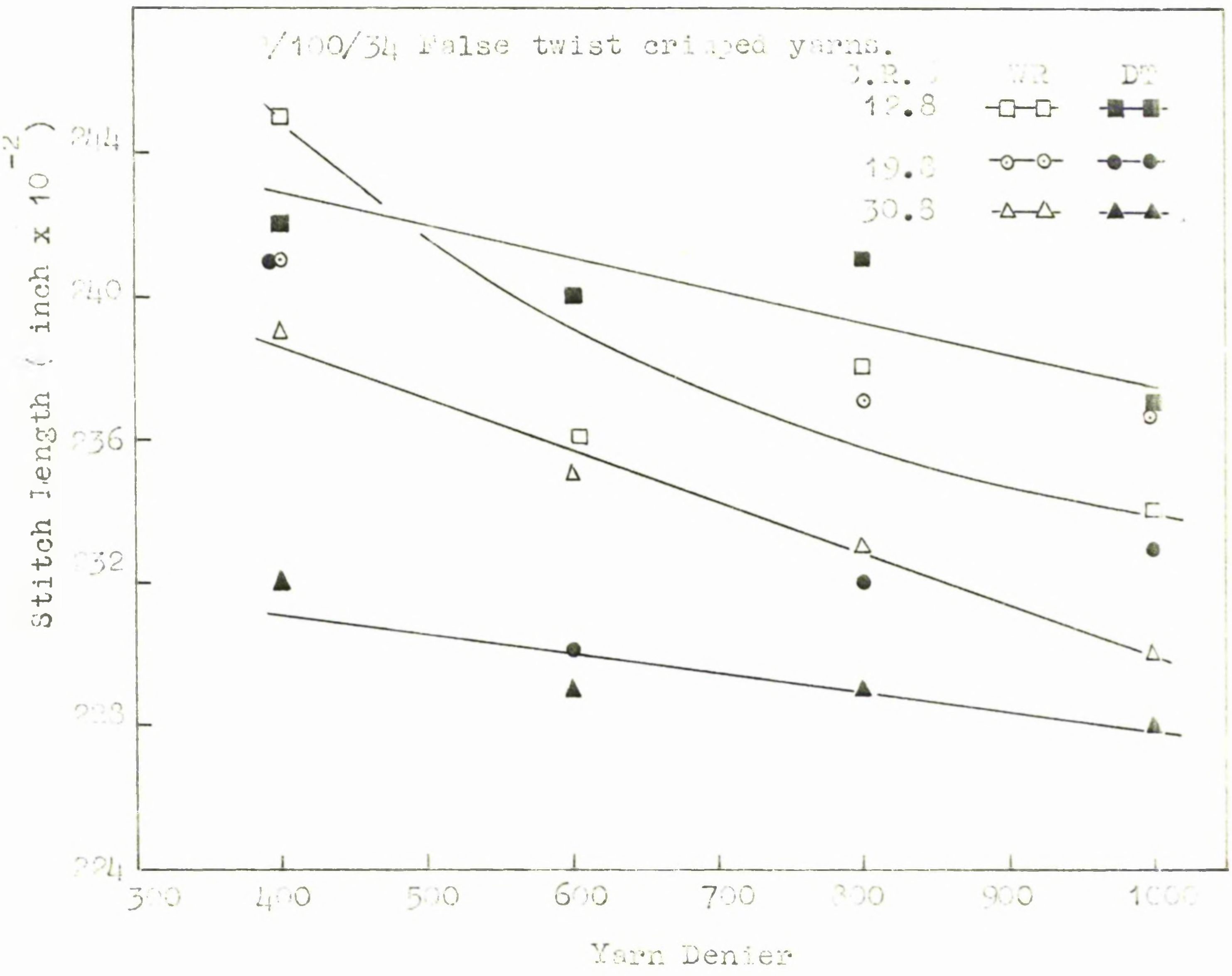


Fig.32. Effect of crimp rigidity of yarns on stitch length of the fabrics.

it will be seen that the loop length decreases as the yarn crimp rigidity increases and that the change is of the order of five per cent. It has been observed by Marvin[95] that the percentage crimp rigidity was responsible for a difference in yarn behaviour between various yarns during yarn withdrawal from the package whilst knitting was taking place. At that time the difference in the coefficient of friction of the 10% crimp rigidity yarn and the 30% crimp rigidity yarn increased by almost 100%, this being due to the yarn possessing a high crimp rigidity relaxing more than that possessing a lower crimp rigidity. The amount of the increase was ascertained by inserting two devices, a Shirley Friction Meter and an electronic transducer which measured yarn tension between the supply package and the knitting guide. It was noted that when the yarn withdrawal action ceased as the knitting head travelled beyond the needle width, the yarn possessing the higher crimp rigidity collapsed more quickly and did not fully regain its uncollapsed state when being drawn in for the next course, this state of partial collapse being responsible for a higher coefficient of friction and subsequently a lower stitch length due to increased resistance from the machine guides. Further confirmation of this was obtained by placing a yarn speed meter as near to the knitting point as possible when it was noted that the yarn possessing the highest crimp rigidity value had a lower yarn speed per course, this indicating an increase in yarn tension between package and guide and also a smaller stitch length.

3.5 Effect of Yarn Denier on c/w Ratio

The length to width ratio of a fabric is determined by the ratio of courses per inch to wales per inch or what is known as the stitch shape. Since this factor controls the dimensions of a fabric, it is essential to know which changes in fabric length and width are caused by changes in yarn denier.

If the ratio c/w as calculated from the values of c and w (tables 6 - 11) for relaxed fabrics knitted from Textralised yarns (T1 - T6) is plotted against yarn denier, it will be noted that this ratio decreases with an increase in yarn count up to about 450 denier beyond which it begins to rise. This is illustrated to some extent in Figure (33) for wet treated and dry tumbled fabrics made from yarns T3 and T6, these only being shown to avoid over-crowding. It is clear that for the fabric made from yarn T3 there is a minimum value of c/w around 400 denier. This means that up to that yarn denier the fabric width increases on relaxation. This does happen as may be seen from tables (6 - 11) where a 40% increase in width occurs for fabrics made from lighter denier yarns. The reason for this increase in fabric width may be understood if it is realized that a decrease in yarn denier gives a fabric of lower stitch density (section 3.3) and as such, a smaller number of loops available to share the stress exerted by the take-down tension mechanism with the result that the loops are highly distorted in length. During fabric finishing, these loops will tend to assume

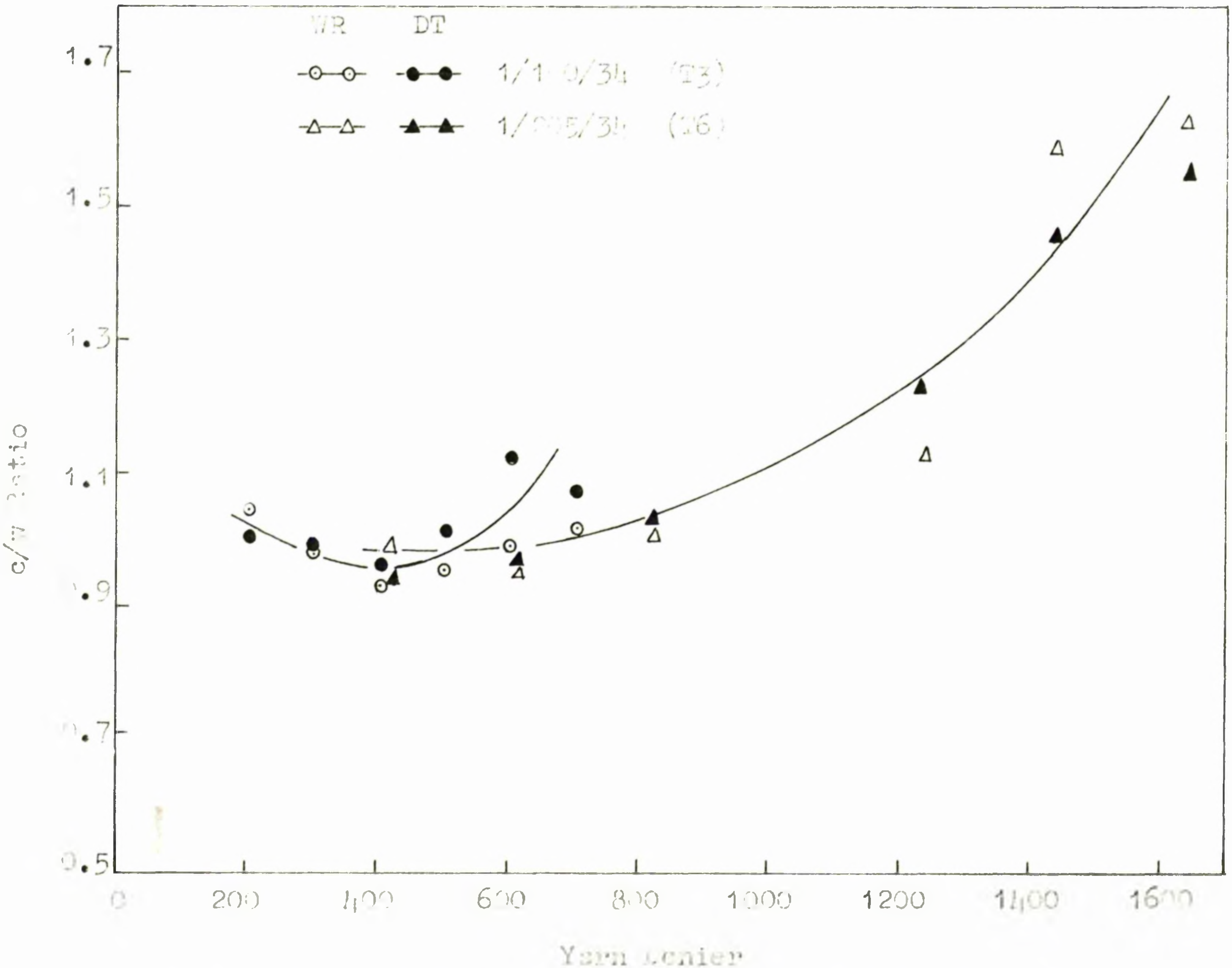
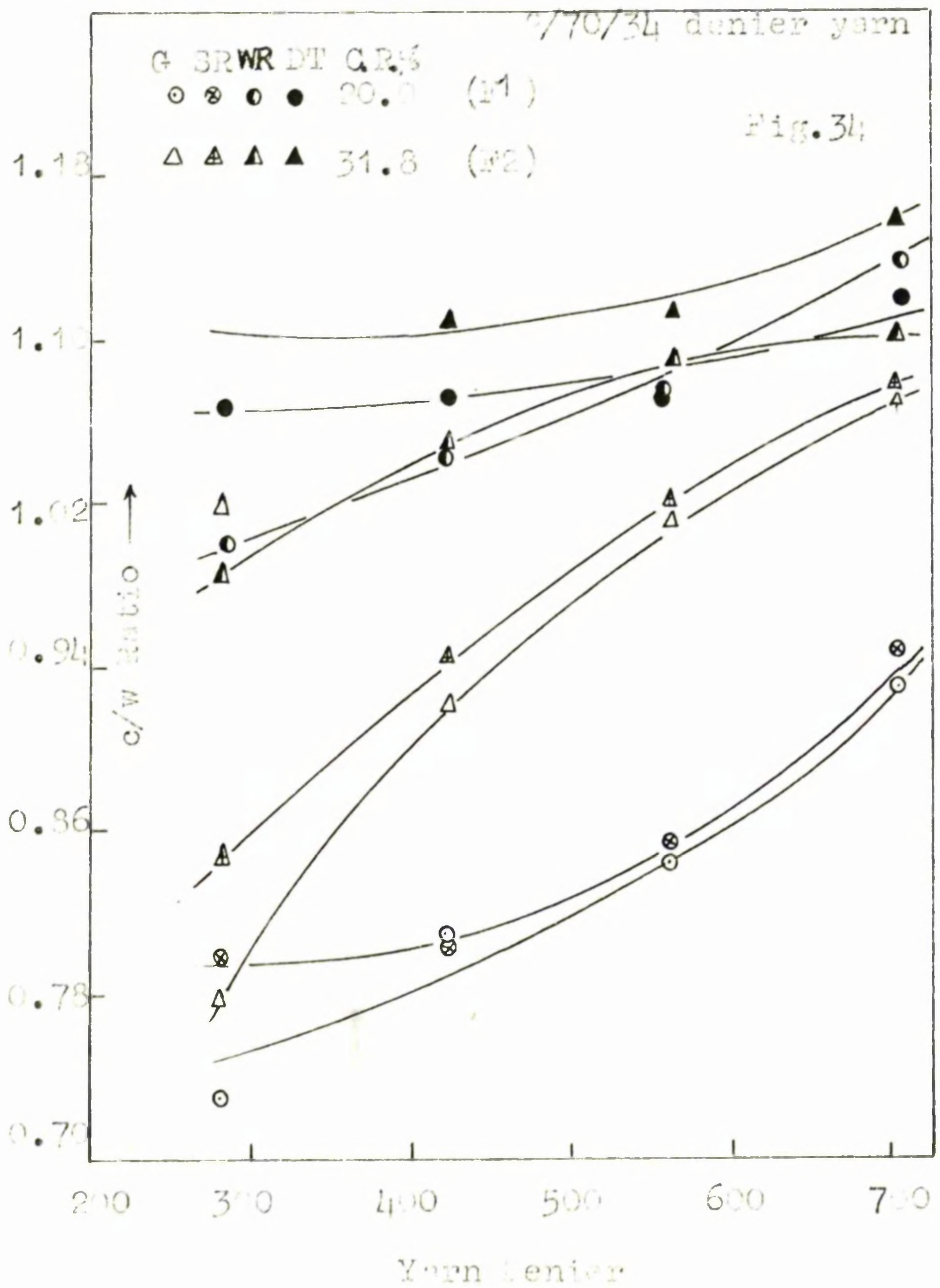


Fig.33. Relation between yarn denier and c/w ratio of fabrics knitted from textralised yarns.

their normal configuration, this resulting in an increase in width. When fabrics are knitted from yarns of a heavier denier, the loops will not be distorted to the same extent and after finishing exhibit a smaller increase in width and, if the yarn denier be further increased, exhibit a decrease in width and hence an increase in c/w ratio. That this does happen in actual practice has been confirmed by Fox[96]. It will be noted that increasing the yarn denier affects courses per inch more than wales per inch. It cannot, however, be claimed that this explanation clarifies the situation fully, because it is thought that yarn flexural rigidity will also affect c/w ratio.

Why does a minimum value of c/w ratio occur in the region of 400-500 denier? From the available information, it is rather difficult to offer a satisfactory explanation, but neverthless it may be speculated that since the fabrics were knitted on an 8 gauge power flat machine for which the suitable range of yarn denier is 400-600, the needle spacing and yarn space in the needle and hook might have some influence on that happening.

The changes in c/w ratio with changes in yarn denier for fabrics from false twist crimped yarns (F1 - F8) are shown in Figures (34 - 36). Unlike fabrics from Textralized yarns, these fabrics do not show a decrease in this ratio up to about 400-500 yarn denier. In these figures, curves for greige and steam relaxed fabrics are also included for comparison and it will be seen that



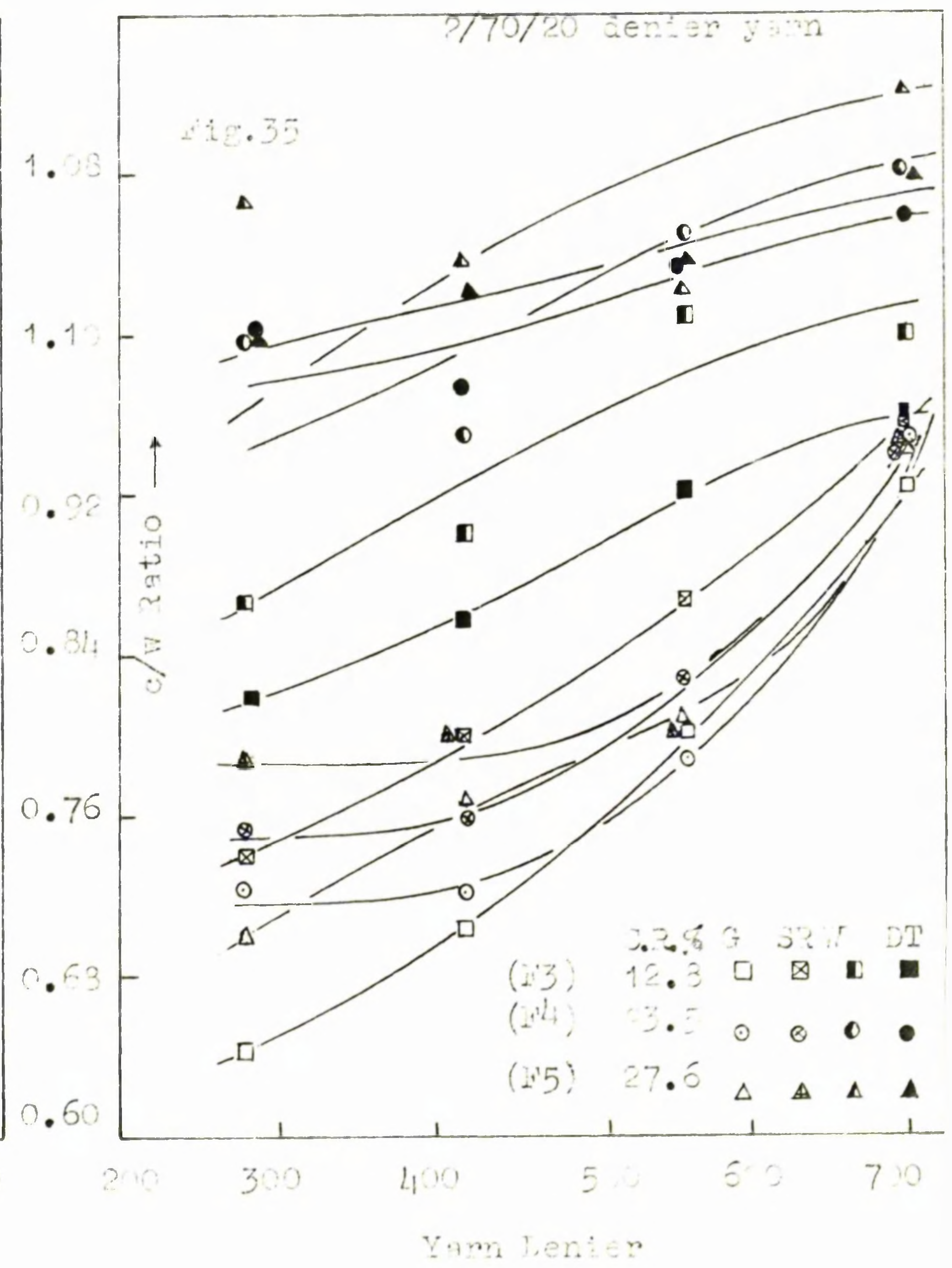


Fig. Effect of yarn denier and yarn crimp rigidity on c/w ratio of fabrics knitted from false twist crimped yarns.

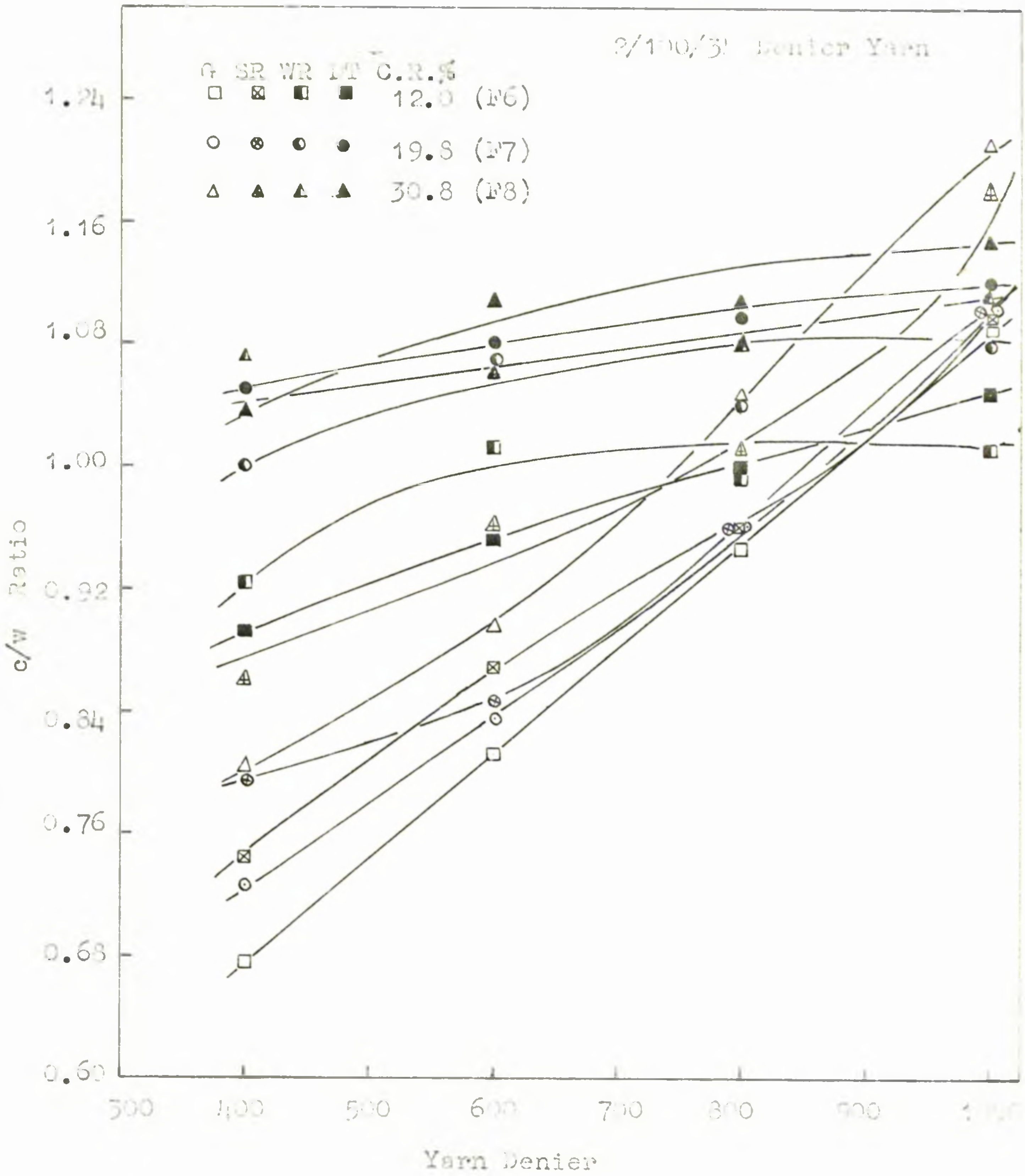


Fig.36. Effect of yarn denier and yarn crimp rigidity on c/w ratio of fabrics knitted from false twist crimped yarns.

whereas wet relaxing and dry tumbling the fabric does bring an increase in c/w ratio, the values for steam relaxed fabrics are very close to those for greige fabrics. This is because treating a fabric by steam on a Hoffman press bed achieves very little relaxation due to a lack of physical agitation.

When the values of c/w ratio obtained in this work are compared with the results of Cotton and Bladon[75] for 1x1 rib fabrics made from 2/70 denier false twist crimped nylon 6.6 yarn, it is seen that their results are much higher. It appears that they have not taken into consideration the rows of loops on the back of 1x1 rib fabric and thus their wales per inch values are only half that actually possessed by the fabric.

There does not appear to be much information published on this particular aspect of the work and therefore the results cannot be compared with any previous work. The results of Fitton and Hopkinson[73] and Eggleston and Cox[77] for plain knitted fabrics from bulked yarns show an increase in c/w ratio with an increase in cover factor. It should be pointed out that Fitton and Hopkinson defined the cover factor as the ratio of loop length to the square root of the yarn denier whereas the reciprocal of this ratio was used by Eggleston and Cox to represent cover factor. However, from their results it follows that for a constant stitch length, the ratio c/w will increase with an increase in yarn denier. This is in agreement with the results obtained in this investigation for 1x1 rib fabrics. For wool fabrics, Munden[57] has shown that after wet relaxation, the loop shape is independent of yarn count, a fact which cannot be applied to fabrics made from bulked yarns.

3.51 Effect of Yarn Crimp Rigidity on c/w Ratio

It is commonly understood that the crimp rigidity of a yarn governs the dimensions of a knitted fabric. In figures (34-36) the effect of yarn crimp rigidity on c/w ratio for fabrics knitted from false twist crimped yarns is shown and which demonstrates that this ratio increases with an increase in yarn crimp rigidity. This indicates that yarn retraction in fabric form brings about a proportionately greater change in the courses per inch than in the wales per inch, or alternatively more in fabric length than in fabric width.

Though the relationship between yarn crimp rigidity and c/w ratio is shown for fabrics from false twist crimped yarns, it is expected that the same relationship would be applicable to fabrics knitted from other types of bulked yarns. Fitton and Hopkinson[73] have shown this to be true for plain and interlock fabrics knitted from Banlon (stuffer box bulked) and false twist crimped yarns. Cotton and Bladon[75] have not analysed their data for 1x1 rib fabrics from Courtolon (false twist nylon 6.6 yarn) to show the relationship between c/w ratio and yarn crimp rigidity, but it can be seen from their results that a similar trend as obtained in this work exists.

Previous work[57] employing conventional types of yarns knitted to a wide range of loop lengths has shown that c/w ratio is equal to 1.3 and is independent of yarn count and knitting stiffness. The results for fabrics from bulked yarns indicate that this ratio changes not only with yarn denier and knitting stiffness[75], but also with yarn crimp rigidity.

3.6 Effect of Yarn Denier on Fabric Shrinkage

The term fabric shrinkage is used here to imply the changes in fabric dimensions as a result of yarn collapse in the fabric, since the fabric shrinkage is not caused by changes in the length of yarn in the loop but by a change in the configuration of the knitted loop which causes the adjacent loops and rows of loops to assume a more compact structure.

When the values of area shrinkage as shown in tables (6 - 11) for fabrics from Textralised yarns were plotted against their respective yarn deniers, a very irregular behaviour was found. A similar random variation of area shrinkage with yarn denier was also observed for fabrics made from false twist crimped yarns (tables 12 - 19). This probably reflects the difficulty in obtaining these fabrics in a completely relaxed form.

The results can, however, be interpreted in another way. From the concepts of fabric geometry it has been well established[57] that the dimensions such as stitch density, courses per inch, wales per inch of a plain knit fabric in its relaxed state are uniquely determined by the length of yarn knitted into a loop, the fabric having been knitted from dimensionally stable yarn. The bulked yarns such as were used to produce the fabrics considered in this work, however, are not stable in dimensions because they are tension sensitive. These yarns are knitted in an extended form but subsequently they collapse in the fabric, this being the major contributing factor for changes in fabric dimensions.

The amount of yarn collapse will be determined by:

(a) the available space in the fabric. This space is governed by the loop length and yarn diameter, the ratio of the two being the cover factor[97]. Because yarn diameter is proportional to the square root of the denier, cover factor can be expressed as $\sqrt{\text{denier}}/\ell$.

(b) the collapsing power of the filaments to adopt their crimped configuration and of the yarn to retract.

The amount of yarn retraction for fabrics from Textralised yarns may be seen in Figure (37) in which $k_s = (S \times \ell^2)$ is plotted against yarn denier. The figure includes results for fabrics made from yarns T3 and T6 and in general the same behaviour exists for fabrics from other yarns used. It will be observed that a decrease in k_s value occurs with increase in yarn denier. The particular value of k_s for any value of yarn denier represents a degree of collapse of that fabric, since previous work using conventional yarns has shown this value to be 19.0 for plain knit

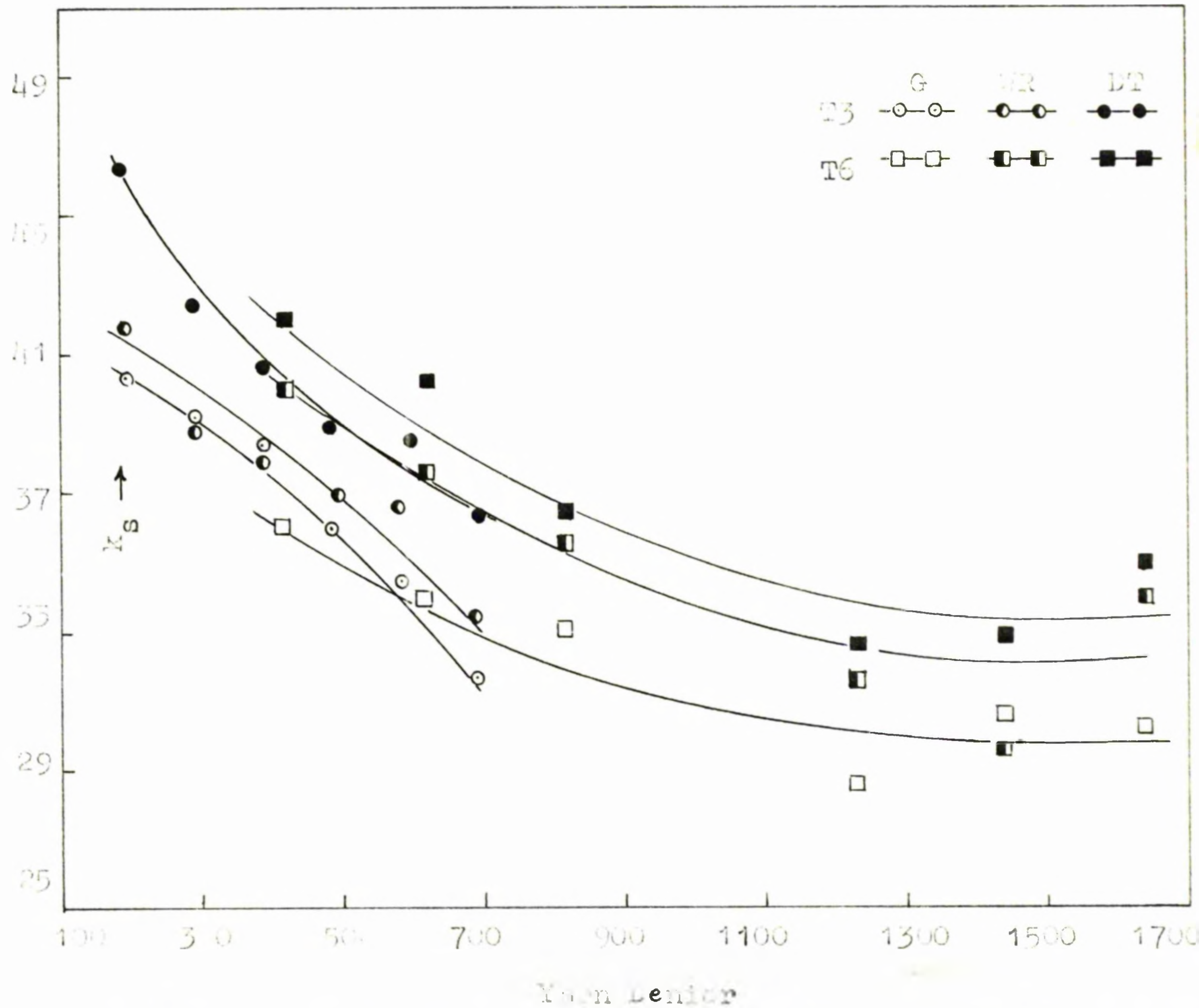


Fig. 37. Effect of yarn denier on k_s values for fabrics knitted from Texturalised yarns.

structures and 32 for rib knit structures, these indicating no yarn collapse at all. It is evident therefore, that as the yarn denier increases there is an improvement in the dimensional stability of a fabric knitted from that yarn. It will also be noted that a fabric relaxed by dry tumbling shows higher k_s values when compared with those of the wet relaxed fabric. The values for steam relaxed fabric not shown in the figure are only slightly more than those for the relaxed greige fabrics. The dry tumbling process produces a state of maximum collapse in the fabric.

Figures (35 - 40) are for fabrics produced from false twist crimped yarns (F1 - F8) and show results similar to those obtained from fabrics knitted from Textralised yarns. As can be expected it is seen from these figures that a greater change in k_s values between the greige and finished state occurs at low yarn deniers when the fabrics are more open, and with an increase in yarn denier there is a tendency to level off. For fabrics from false twist crimped yarns, there does not appear to be any significant difference in k_s values between dry tumbled and wet relaxed fabrics as that noticed for fabrics made from Textralised yarns.

On comparing these results with those previously published[69,73] for plain knitted fabrics, there is a general agreement. If the results of Cotton and Bladon[73] for 1x1 rib fabrics knitted from false twist crimped yarn of one particular denier to a wide range of loop lengths are analysed on similar lines as has been

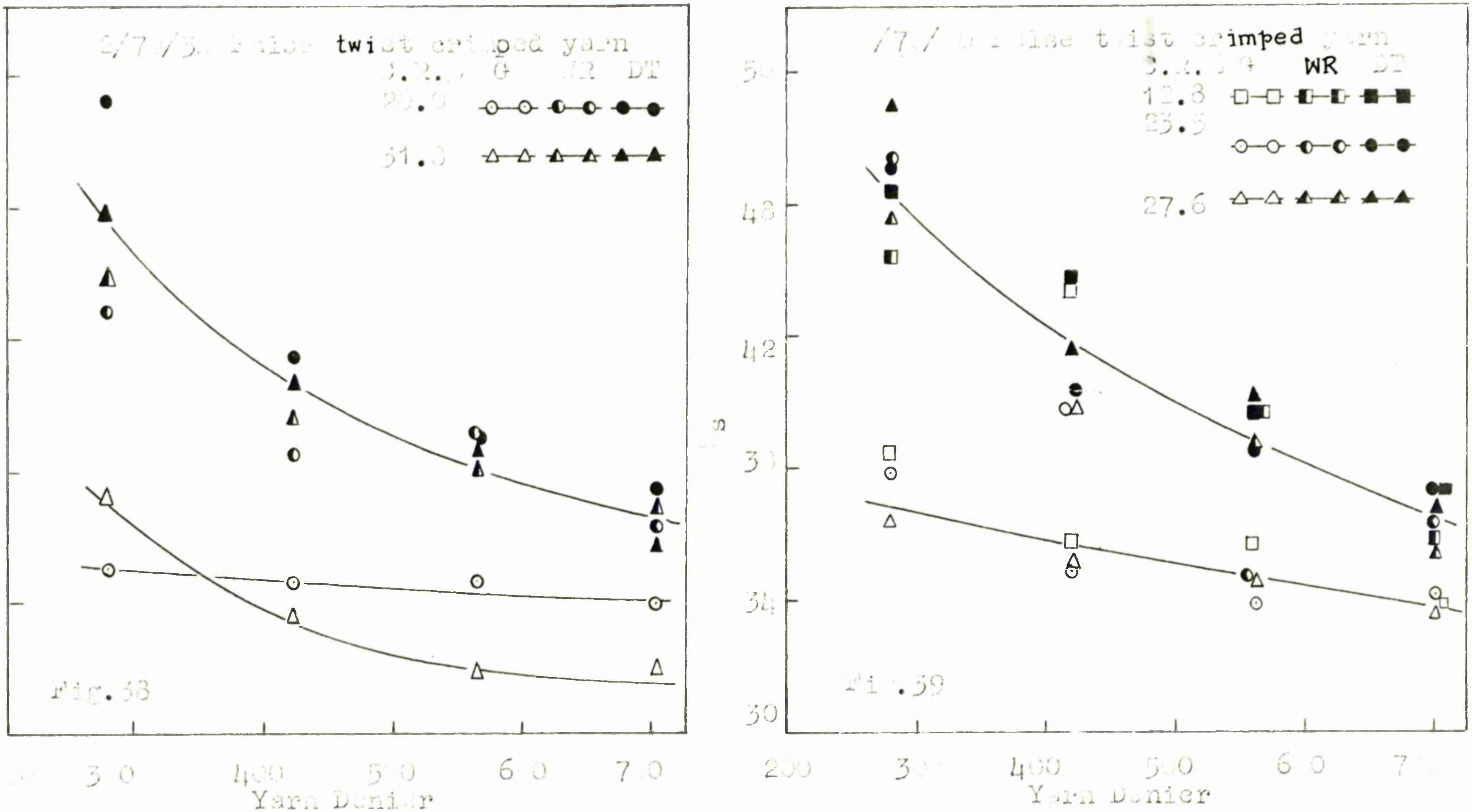


Fig. Effect of yarn denier and yarn crimp rigidity on K_s values for fabrics knitted from 2/70/34 and 2/70/20 false twist crimped yarns.

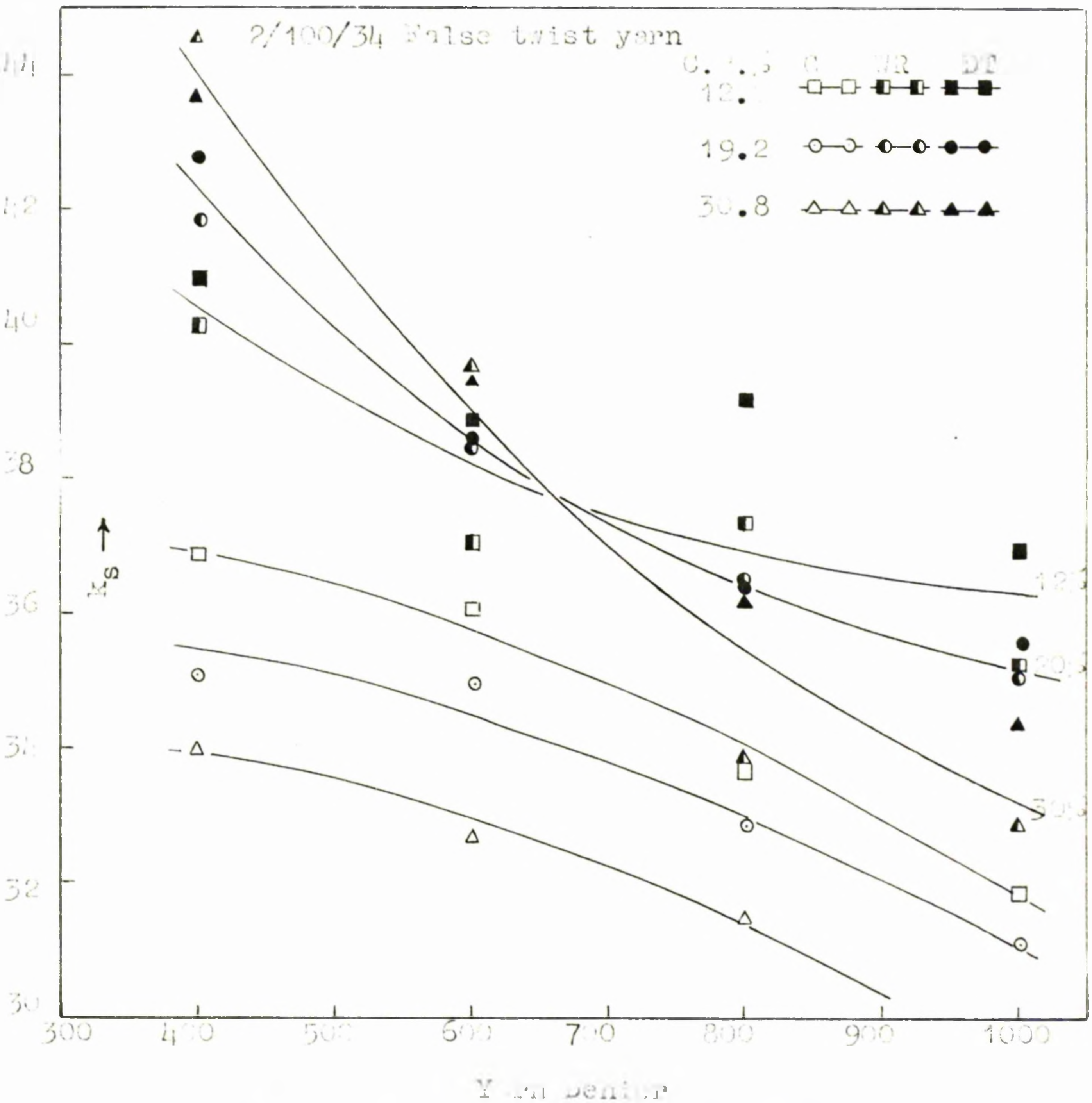


Fig. [illegible] Influence of yarn denier and yarn crimp rigidity on K_s values for fabrics knitted from 2/100/34 false twist crimped yarns.

attempted here, it will be noticed that the amount of yarn collapse as indicated by the value of k_s increases as the loop length increases. From the results obtained and showing the effect of yarn denier on knitted loop length, it has already been indicated (section 3.4) that as yarn denier increases, there is a progressive decrease in loop length. Thus there is some similarity between the present results and those of Cotton and Bladon. In the previous studies by other workers, fabrics were considered after one treatment only, namely, wet relaxation. It was thought desirable in this work to investigate the effect of other relaxation processes on fabric dimensions.

3.61 Effect of Yarn Crimp Rigidity on Fabric Shrinkage

It was stated in the previous section that the amount of yarn collapse in the fabric depends upon the collapsing power of the filaments to adopt crimped configuration. Thus one would expect some relationship between yarn crimp rigidity and fabric shrinkage.

From Figures (38 - 40) for fabrics from false twist crimped yarns, it is seen that no indication of the influence of yarn crimp rigidity on collapsing values is observable, though some evidence is provided by k_s values for fabrics from yarns F6, F7 and F8. Fitton and Hopkinson[73] have shown that for fabrics from false twist and stuffer box bulked yarns, the yarn contraction in fabrics increases with increase in yarn crimp rigidity and work on 1x1 rib fabrics[75] also indicated the same trend. These authors, however, performed their work on fabrics which were produced under controlled conditions of yarn feed. The knitted loop length was thus maintained constant for fabrics knitted from yarns of different crimp rigidities. In contrast to this, in the present experiments no such control method was employed to ensure constant stitch length, the amount of yarn contraction in the fabric being therefore, a result of the interaction of changes in stitch length and yarn crimp rigidity.

Figure (4) shows that for more open fabrics, the amount of yarn contraction increases as the yarn crimp rigidity increases as expected but for tighter fabrics, this trend is reversed. This is possibly due to the fact that for such tight fabrics from yarns of higher crimp rigidity, the decrease in loop length ultimately gives rise to a situation whereby there is not sufficient space available within and about the loop to enable any marked amount of yarn collapse in the loop to occur.

It is interesting to note that for relaxed greige fabrics, the increase in yarn crimp rigidity has an adverse effect on yarn contraction. It is pertinent to recall that the same situation was found to exist when the relation between fabric stitch density and yarn crimp rigidity was considered. The explanation then offered could also be used to explain this decrease in yarn contraction with increase in yarn crimp rigidity. This observation also emphasises the fact that any measurement taken on a fabric not thoroughly relaxed may be highly misleading.

3.7 Effect of Yarn Denier on Fabric Thickness

A knowledge of the change in dimensional area of the fabric is important during fabric or garment manufacture, but this change like that of fabric thickness is a consequence of yarn relaxation when in fabric form. This relaxation causes an increase in yarn bulk and imparts loftiness, warmth and cover to the fabric.

It is reasonable to assume that the thickness of the knitted fabric produced from a bulked yarn will be a function of the loop length, yarn diameter and yarn crimp rigidity.

For a yarn of a given crimp rigidity, the influence of the changes in yarn denier (which is proportional to the square of the diameter) on thickness of fabrics knitted from Textralised yarns T2, T3 and T6 is shown in Figure (41). As would be expected, the fabric thickness increases with an increase in yarn denier and the rate of this increase appears to be higher for changes in yarn denier up to a certain value above which the rate of change in fabric thickness reduces. This behaviour could be ascribed to several reasons, the simplest being that the method used for measuring fabric thickness was not sensitive enough to record changes that occurred with a progressive increase in yarn denier. Whilst this may be partly true, the more feasible explanation lies in the complicated interaction of yarn properties within a knitted fabric. It would appear that when the yarns are knitted into a fabric, the interlocking of the loops causes the effective diameter to be restricted to an upper limit which may be a

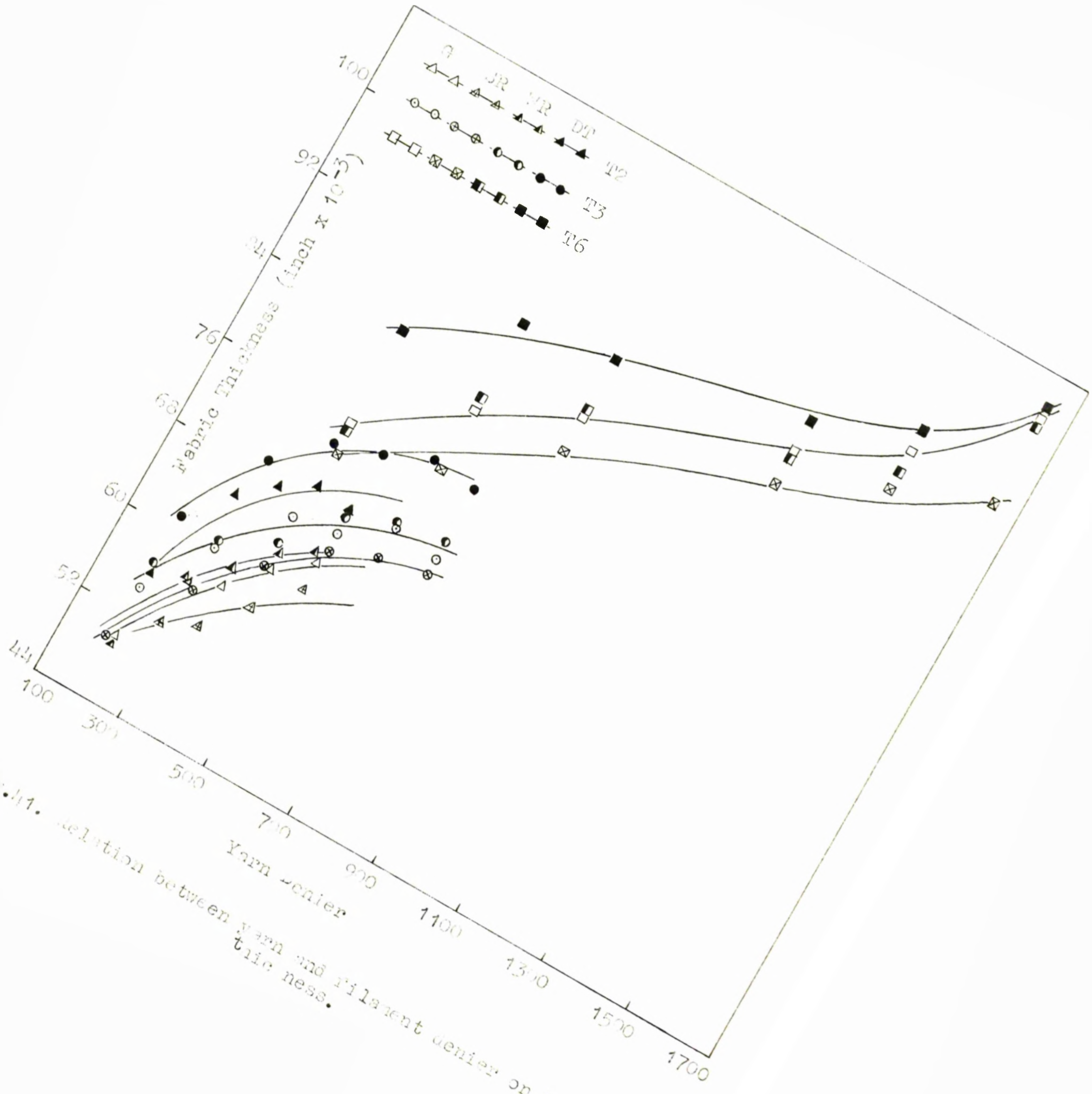
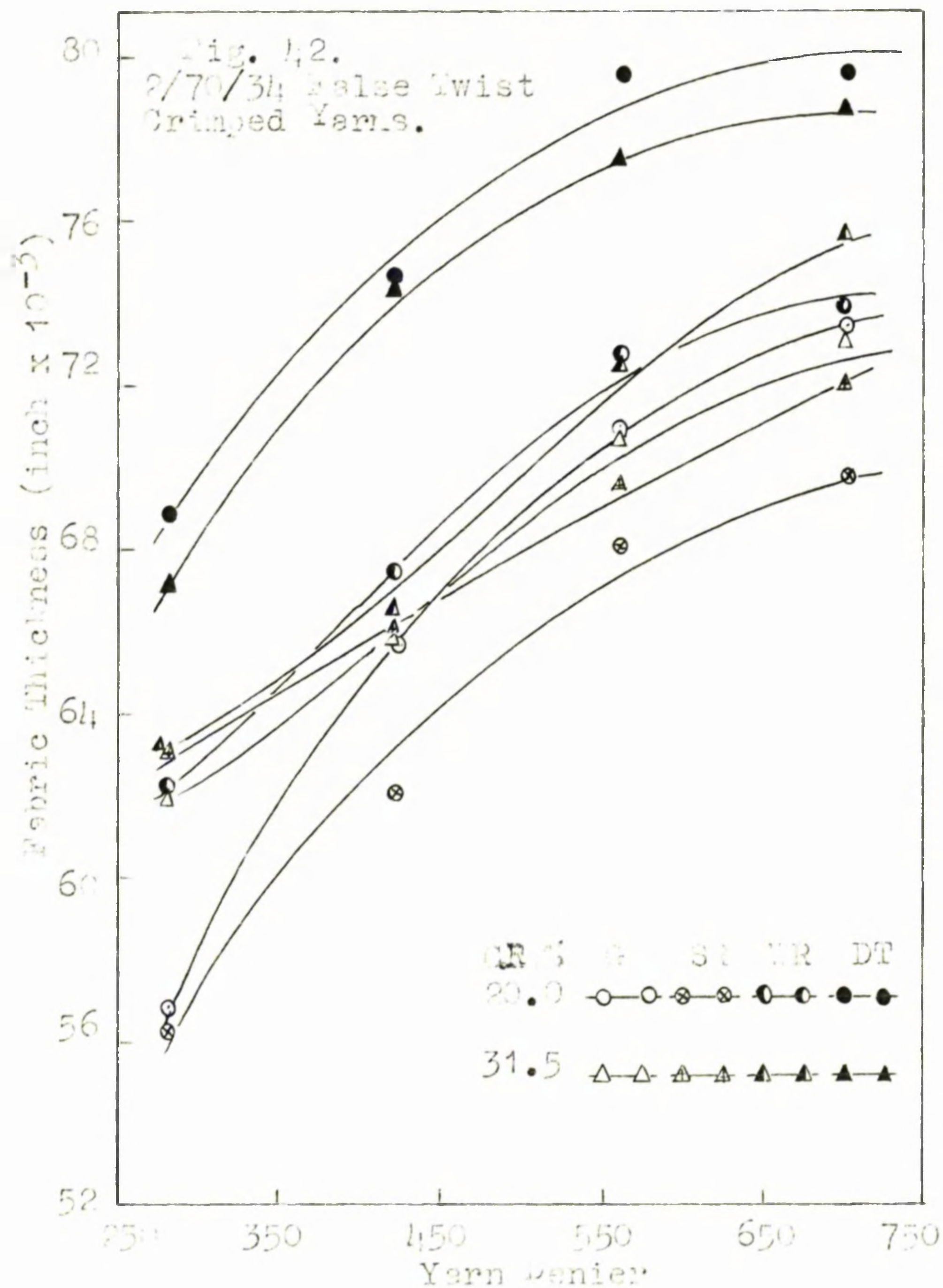


Fig.41. Relation between yarn and filament denier on fabric thickness.

function of free yarn diameter, crimp rigidity and knitted loop length. It should also be noted that for a given stitch cam setting and for a given yarn count, the yarn comprised of the heavier denier filaments will produce fabric of the greatest thickness.

The relationship between fabric thickness and yarn denier for fabrics produced from false twist crimped yarns (F1 to F8) is shown in Figures (42 - 44) and it will be noted that the trend remains the same as for the fabrics knitted from Textralised yarns.

Of the relaxation processes, dry tumbling causes fabrics made from Textralised and false twist crimped yarns to achieve maximum thickness at all yarn denier values. The thickness of the wet treated fabric appears to be very nearly the same or only slightly more than that of the relaxed greige fabric whereas relaxing fabric in steam reduces its thickness below that of the greige level. It is usually assumed that wet treatment of a fabric produced from bulked yarns brings about a nearly complete relaxation and as such should result in an increase in fabric thickness. It is felt that the resistance to compression of the fabric after wet relaxation decreases which appears to account for only small changes in fabric thickness. A subjective examination of the fabrics supports this as it was observed that wet treated fabrics were much softer than those relaxed by dry tumbling. Steam relaxation however, imparted a very limp and soft appearance to the fabric and therefore their



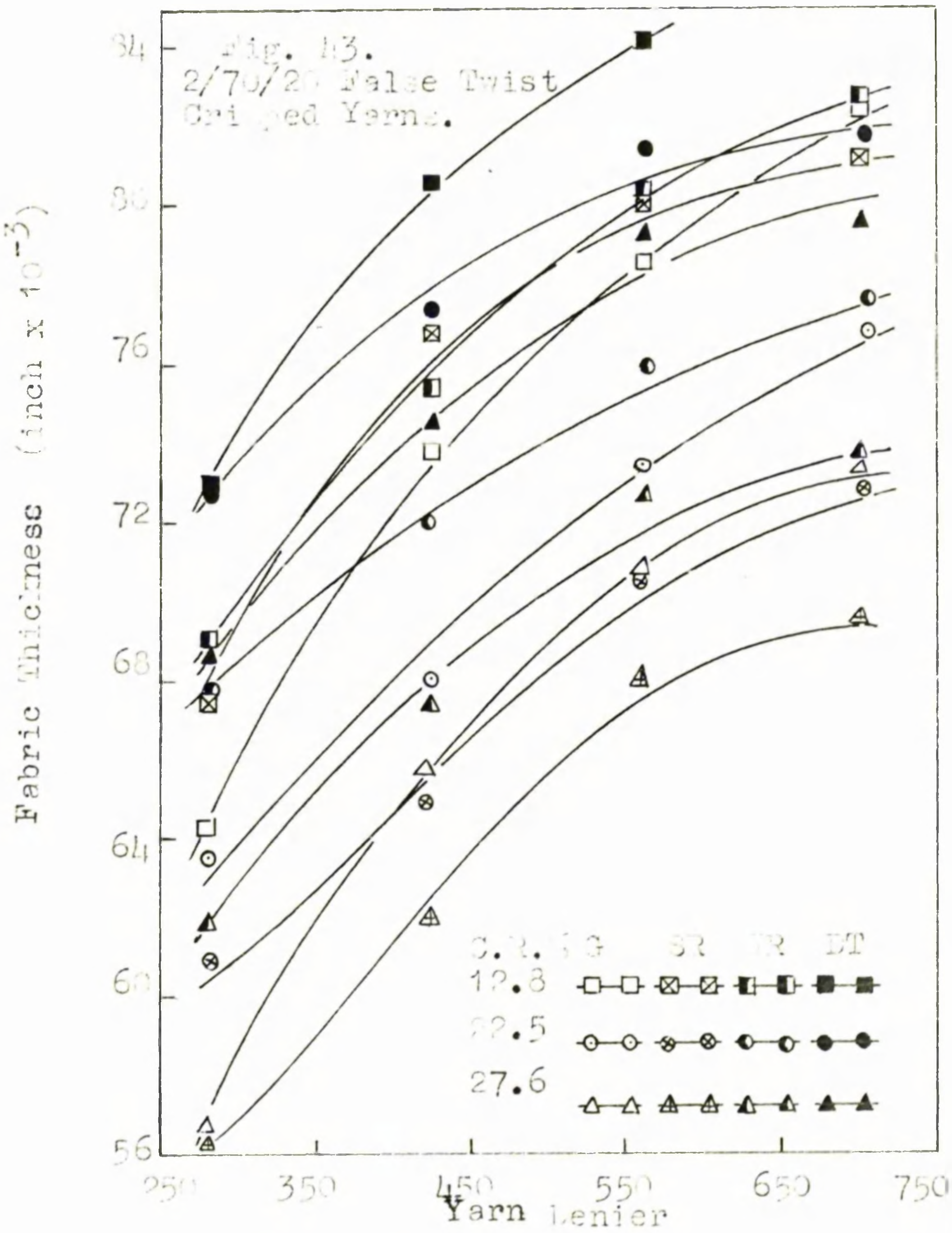


Fig. Effect of yarn denier and yarn crimp rigidity on fabric thickness.

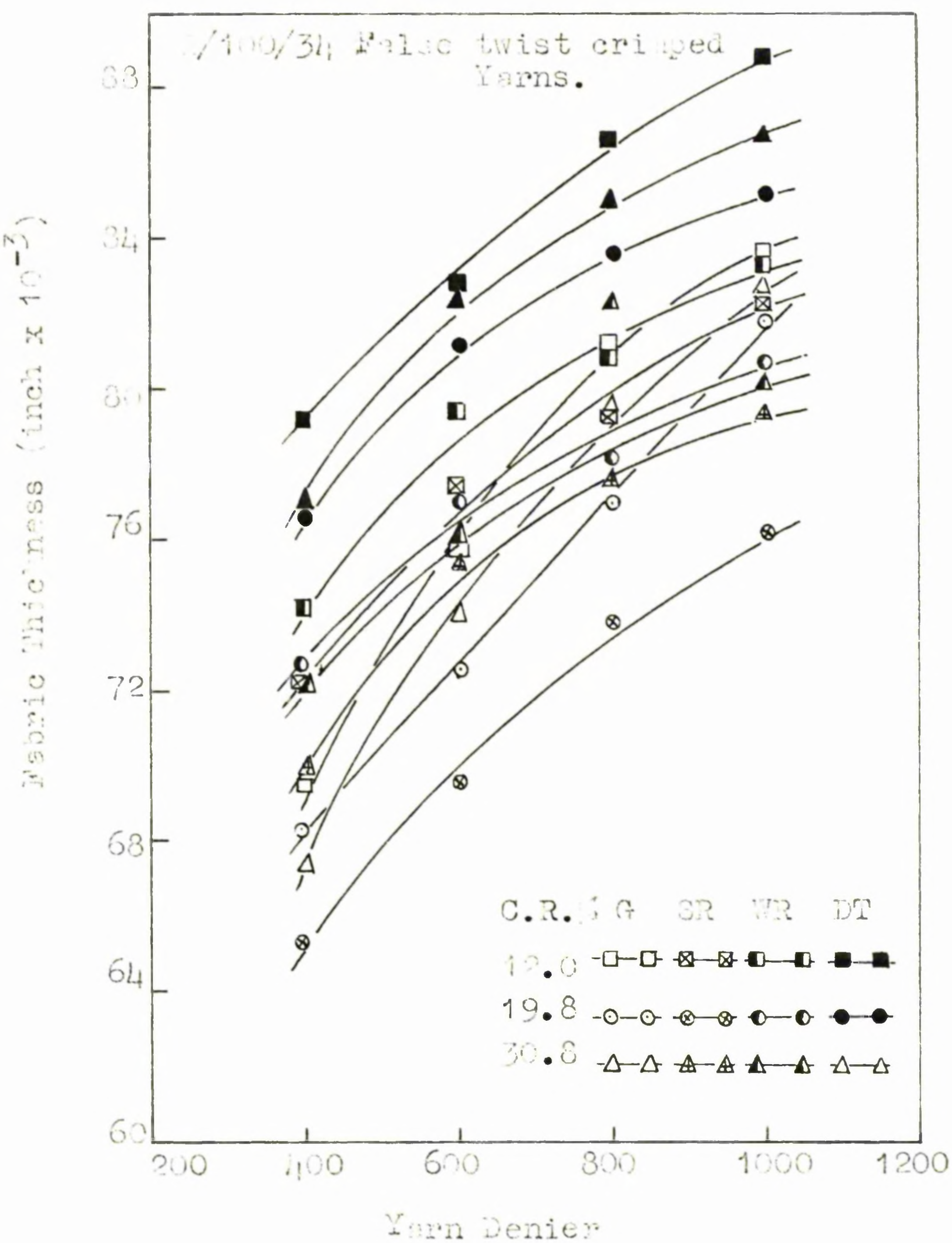


Fig. 44. Effect of yarn denier and yarn crimp rigidity on fabric thickness.

decrease in thickness is not surprising. This decrease was further enhanced by the fact that filament adhesion was noticed for these fabrics, this reducing the effective yarn diameter and hence the fabric thickness.

It has been already stated that an increase in fabric thickness is caused by relaxation of the yarn in a fabric. When a fabric is knitted from a given count of yarn of any crimp rigidity value and subsequently subjected to various finishing treatments, it is suggested that the measurement of fabric thickness if carefully carried out under standardised loading conditions, should give a reasonable estimate of yarn bulk in the fabric. When however, yarn bulk in fabrics of different constructions knitted to varying stitch lengths is compared, the effect of these variables will need to be considered.

3.71 Effect of Yarn Crimp Rigidity on Fabric Thickness

It is usually expected that fabric thickness would increase with an increase in crimp rigidity of a bulked yarn. There is little experimental evidence available in literature to support this, though the results of Fitton and Hopkinson[73] and Cotton and Bladon[75] for fabrics knitted from false twist crimped nylon yarns of differing crimp rigidities appear to indicate this trend, as can be seen from their data for fabric weights. For a given yarn denier, the weight of fabrics knitted to a constant stitch length increases with an increase in yarn crimp rigidity, this increase in fabric weight being related to an increase in fabric thickness. Similarly, the results of McCann and Sturley[72] demonstrate that the fabric compression decreases as the heater temperature increases during yarn processing, i.e. yarn crimp rigidity increases. As fabric compression is expressed as the ratio of fabric thickness measured at two different pressures, it follows that the fabric thickness increases as the yarn crimp rigidity increases.

The results of the present work showing the effect of yarn crimp rigidity on fabric thickness for 1x1 rib fabrics produced from false twist crimped yarns (F1 - F8) are plotted in Figures (42 - 44). It will be noted in Figure (42) that the fabric thickness is higher for fabrics produced from yarn of lower crimp rigidity with the exception of the fabrics in their steam relaxed state in which case higher crimp rigidity yarn shows higher fabric thickness. Similarly, in Figures (43 - 44) it will be noted that generally the same trend exists. There are, however, certain anomalies e.g. while in Figure (43) the fabrics made from yarn F5 (highest crimp rigidity within the group) appear to be of the lowest thickness, the fabrics from yarn F8 (again the highest crimp rigidity within the group) in Figure (44) are only of the intermediate thickness. From this confusing type of behaviour it is evident that the results obtained for the fabrics do not appear to be capable of simple interpretation and supports the view already expressed in the previous section that the changes in fabric thickness are the result of the complicated inter-action of yarn properties in a knitted fabric. It has been shown previously (section 3.41) that for the same stitch cam setting and without using a yarn feeding device, the fabric stitch length decreases with an increase in yarn crimp rigidity. This would appear to account partially for the greater thickness of fabrics knitted from yarns of lower crimp rigidity as the space available in such fabrics for yarn collapse will be greater.

The influence of the finishing treatments on fabric thickness has been considered in the last section. In this respect, it is rather surprising to note the results of MacDonnell and Kilby[98] who have shown that the thickness of plain knit fabrics made from false twist crimped nylon yarns is approximately the same in the unrelaxed and relaxed states of the fabrics, the thickness being measured at pressures of 0.1 p.s.i. and 0.6 p.s.i. At this latter pressure, one fabric knitted from 2/100/24 denier yarn and relaxed by wet treatment at 40°C actually exhibited a lower thickness as compared with the fabric in its unrelaxed state. Conversely, the results of the thickness measurements of plain knit fabrics produced from stuffer box bulked nylon yarns as reported by Lennie[99] show that the fabric thickness after relaxation increases, his measurements being made at 0.02 p.s.i. This apparent difference in the results arises because the degree of loading in the measurement of thickness has a pronounced effect and if proper loading conditions are not established, could lead to false results.

3.8 Fabric Stitch Density and Stitch Length

A series of 1x1 rib fabrics were knitted from yarns listed in Table (3c, chapter 2) at all the stitch cam settings on the power flat machine used in this work. These fabrics were then given relaxation treatments as described earlier and various measurements made.

Graphs of S_b against $1/\ell_b^2$ for fabrics from false twist crimped yarns FT1 and FT2 and Textralised yarns TX1 and TX2 are given in Figures (45) and (46). It will be noted from these graphs that the straight lines obtained can be represented by

$$S_b = k_{sb}/\ell_b^2 + S_2 \text{ ------------------ } (1)$$

where k_{sb} is the slope of any given line and S_2 the corresponding intercept on the Sb axis, the actual values of k_{sb} and S_2 depending on the particular relaxed state of the fabric. Thus k_{sb} and S_2 are constants for a given bulked yarn in a fabric relaxed by a given method.

Graphs of S_u against $1/\ell_u^2$ for fabrics from unbulked yarns U1 and U2 are similarly given in Figure (47). The best fit lines are drawn through the points but because of a considerable amount of scatter, calculation of separate lines for fabrics relaxed by different treatments was considered unnecessary. The correlation coefficients of the lines for fabrics from yarns U1 and U2 were found to be 0.97 and 0.98 respectively. These lines can be represented by

$$S_u = k_{su}/\ell_u^2 + S_1 \text{ ------------------ } (2)$$

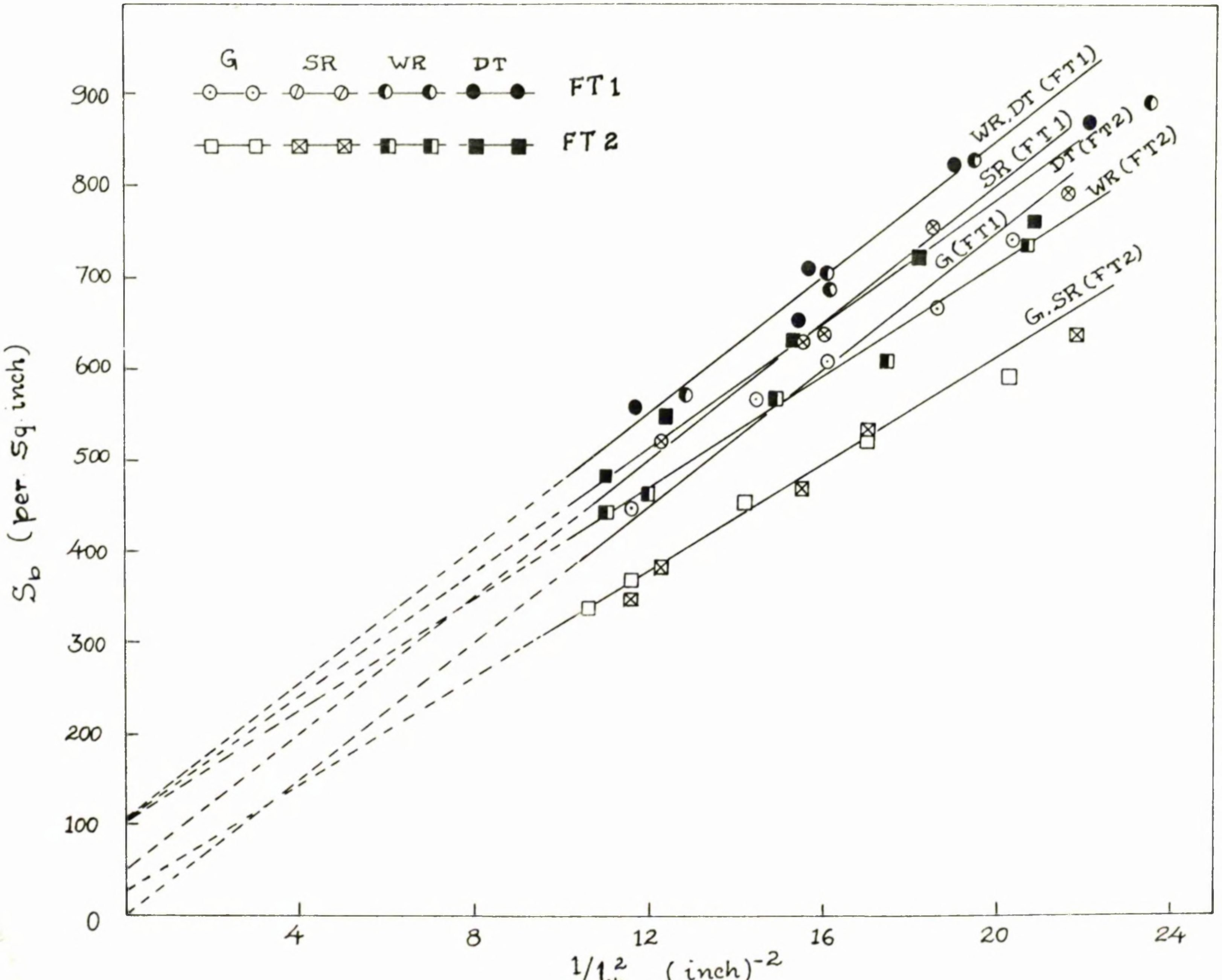


Fig. 45. Stitch density plotted against $1/l_b^2$ for fabrics knitted from false twist crimped yarns.

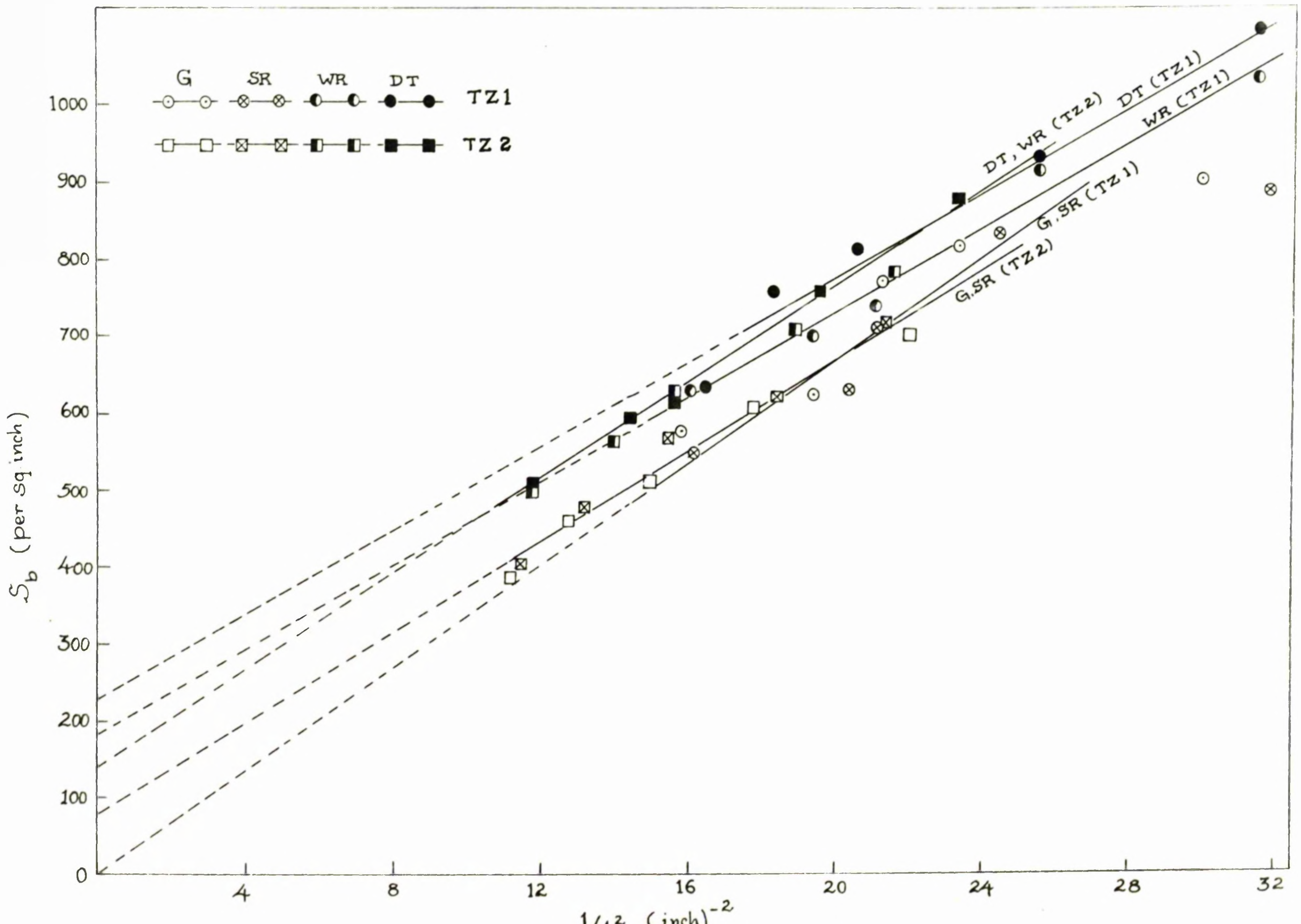


Fig. 46. Stitch density plotted against $1/l_b^2$ for fabrics knitted from Textralized yarns

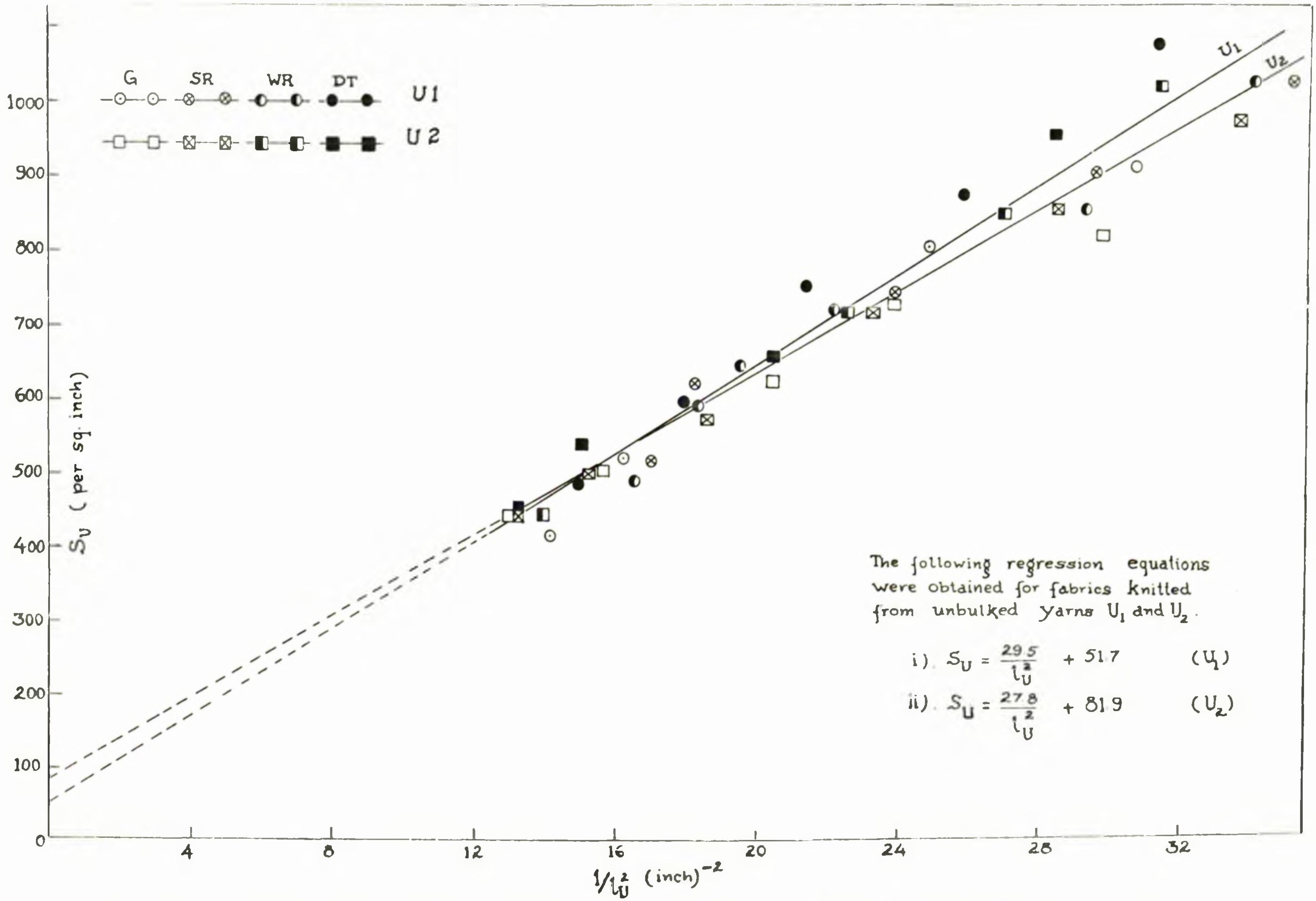


Fig 47 Stitch density plotted against $1/l_U^2$ for fabrics knitted from unbulked nylon yarns

where k_{ga} and S_1 are the slope and intercept respectively.

The significance of the intercepts S_1 and S_2 lies in the fact that they permit the mathematical expression of the trends obtained over experimentally accessible stitch lengths, and it is to be expected that at very low values of $1/\ell^2$ the lines must curve so as to meet at the origin[77]. Equations (1) and (2) which are of the same form as given by Cotton and Bladon[75] for 1x1 rib fabrics and Eggleston and Cox[77] for plain knit fabrics from bulked yarns are preferable to the form $S_b\ \ell_b^2 = k_{gb}$ employed by Munden et al.[69] and Fitton and Hopkinson[73] because k_{gb} is not constant for all bulked yarn fabrics but varies with stitch length.

The values of the slopes k_{gb}, k_{ga} and the intercepts S_1, S_2 for all the fabrics under consideration were found and reported in table (20). It will be observed from the table that k_{gb} values are not affected unduly by the yarn bulking process or fabric finishing treatments which do, however, affect the values for the intercepts S_1 and S_2. The k_{gb} values appear to be in close agreement with those quoted by Cotton and Bladon[75] (a slope of 13.8) for 1x1 rib fabrics produced from false twist crimped nylon yarns. They considered loops on one side of the rib structure only and hence their slope value is approximately half that reported in the present work. The values for the intercepts as given by Cotton and Bladon appear to be high, ranging from 130–375 for fabrics knitted from yarns having crimp rigidities values between 8 per cent and 33 per cent.

3.81 Relaxation Ratio and Stitch Length

It is known that the stitch density of bulked-yarn fabric compared with unbulked-yarn fabric and knitted to the same measured stitch length is higher and that this is due to the difference in the sensitivity to tension of these two types of yarn in relation to the method of measuring stitch length. It is already indicated earlier that the stitch length cannot be measured directly in knitted fabrics because of the complexity of the knitted loop. The method used to measure the stitch length involves the unroving of yarn from a knitted course over a known number of wales and its length measured under a tension T which is sufficient to remove yarn crimp. This measured course length is then divided by the number of wales to give the stitch length.

Unbulked yarns generally extend very little between zero tension and the tension T, with the result that their measured stitch lengths are virtually the same as their stitch lengths in relaxed fabrics. The bulked yarn, however, increases considerably in length between zero tension and the tension T. When this type of yarn is considered in relaxed fabric form, it is held by the fabric structure at some intermediate tension, so that the relaxed stitch length of a bulked-yarn fabric is less than its measured stitch length.

To calculate the relation between the relaxed and measured stitch lengths of fabrics knitted from bulked yarns, the approach used in this work is the same as that used by Eggleston and Cox[77] for plain knit fabrics produced from false twist nylon yarns. This calculation involves the assumption [69,75] that the relaxed stitch length of a bulked-yarn fabric is equal to the measured stitch length of a fabric having the same stitch density but knitted from a yarn which does not extend appreciably between zero tension and the tension used to measure the stitch length. This assumption is not completely valid because it has been shown earlier that the ratio of courses to wales per unit length for a bulked-yarn fabric varies with yarn denier and that the latter also affects the length of yarn knitted into the stitch when no yarn feeding device is employed. From this it follows that the stitch shape (c/w ratio) varies with stitch length. Munden[57] has shown that the stitch density of fabrics from unbulked yarns varies to some extent with stitch shape for the same stitch length. As it is extremely difficult to separate the effect on stitch density of a change in stitch length from that of a change in stitch shape, a single figure for yarn relaxation which incorporates both of these effects is considered sufficient to calculate the fabric dimensions for a given stitch length.

If a bulked-yarn fabric with a measured stitch length ℓ_b has relaxed stitch length ℓ_r, then ℓ_b/ℓ_r is defined as the relaxation ratio and the following equations for this ratio can be derived:

(a) Fabrics from bulked and unbulked yarns will have the same stitch density $S_b = S_u$ at measured stitch lengths ℓ_b and ℓ_u respectively. According to the assumption made earlier, $\ell_r = \ell_u$ when $S_b = S_u$

$$\ell_b/\ell_r = (\ell_b/\ell_u) \quad S_b = S_u \text{------------} (3)$$

(b) ℓ_r can be calculated from S_b and the line for unbulked-yarn fabric which is given by equation (2), i.e. $S_u = k_{su}/\ell_u^2 + S_1$

From assumption, $\ell_r = \ell_u$ when $S_b = S_u$

$$\therefore S_b = k_{su}/\ell_r^2 + S_1$$

$$\text{and } \ell_r = \sqrt{\left[k_{su}/(S_b - S_1)\right]} \qquad (4)$$

$$\therefore \ell_b/\ell_r = \ell_b\sqrt{\left[(S_b - S_1)/k_{su}\right]} \qquad (5)$$

ℓ_b/ℓ_r can be calculated from $_b$ and S_b once k_{su} and S_1 have been determined.

(c) A more general expression for ℓ_b/ℓ_r is obtained by squaring (5) and substituting the value of S_b from (1)

$$(\ell_b/\ell_r)^2 = (\ell_b^2/k_{su})\left[(k_{sb}/\ell_b^2) + S_2 - S_1\right]$$

$$(\ell_b/\ell_r)^2 = \left[(S_2 - S_1)/k_{su}\right]\ell_b^2 + k_{sb}/k_{su} \qquad (6)$$

A few suggestions have been offered as to the significance of the intercepts on the S axis for graphs of S against $1/\ell^2$. Munden et al.[69] ascribed the difference between the intercepts for fabrics from bulked and unbulked yarns to the greater relaxation occurring at longer stitch lengths. Cotton and Bladon[75] interpreted the intercept S_2 as being related to the crimp rigidity of the bulked yarn. Equation (6) however appears to favour the former interpretation.

To verify the above theory, the values of k_{sb} and S_2 for each fabric (1x1 rib) listed in table (20) were substituted in equation (6), with the corresponding values of k_{su} and S_1 for the whole range of ℓ_b values. The resulting data of $(\ell_b/\ell_r)^2$ is plotted against $(\ell_b)^2$ in Figure (48) for fabrics produced from yarns FT1 and TZ1 and in Figure (49) for those fabrics knitted from yarns FT2 and TZ2 in their griege and various finished states. As would be expected from equation (6) which is in the standard form for a straight line, y = mx+c, where $(\ell_b/\ell_y)^2 = y$ and $(\ell_b)^2 = x$, a number of straight lines are obtained with the slopes and intercepts equal to $(S_2 - S_1)/k_{su}$ and k_{sb}/k_{su} respectively. From Figures (48) and (49), the following points may be noted:

(i) The relaxation for fabric in all its states from yarn FT1 (Fig. 48) starts at the same intercept on $(\ell_b/\ell_y)^2$ axis. As k_{su} is constant for a given yarn denier, the value of this intercept is dependent on the value of k_{sb}. From table (20), it will be noted that the value of k_{sb} is also the same for this fabric in all its states. When fabric produced from yarn FT2 is considered, the k_{sb} values are different for the fabrics in the griege, wet treated and dry tumbled states and hence the relaxation starts at different intercepts (Fig. 49). For the same reason, relaxation for the fabrics from yarns TZ1 and TZ2 start at two different intercepts, one for griege and steam relaxed fabrics, and the other for wet treated and dry tumbled fabrics.

(ii) For fabrics from yarns TZ1 and TZ2, the relaxation starts at lower values of $(\ell_b/\ell_y)^2$ than in the case of fabrics from yarns FT1 and FT2 except in the case of fabrics from yarn TZ2 in the griege and steam relaxed states where the relaxation of fabrics in the corresponding

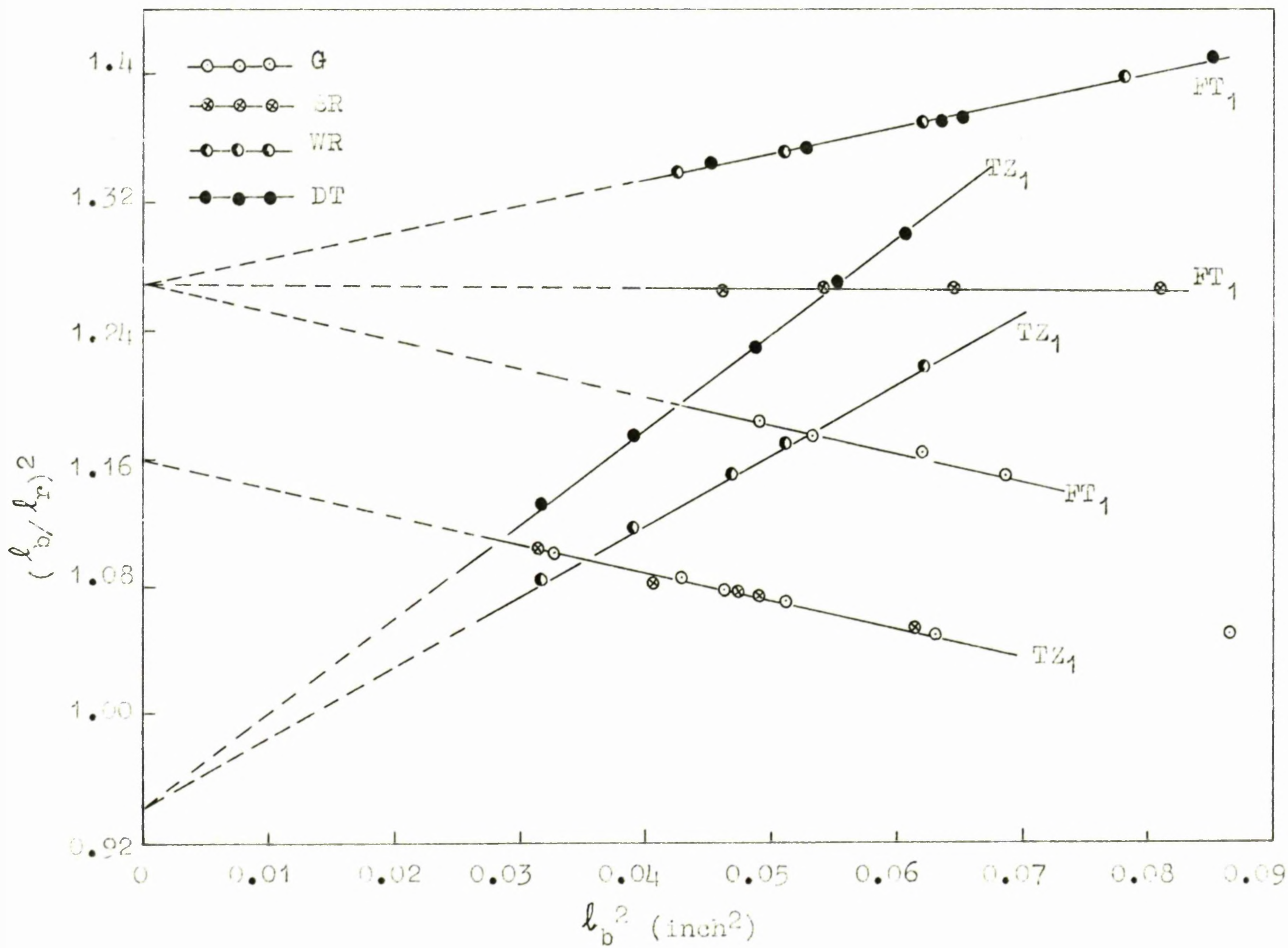


Fig.45. Relation between relaxation ratio and stitch length for false twist crimped and Textralized yarns.

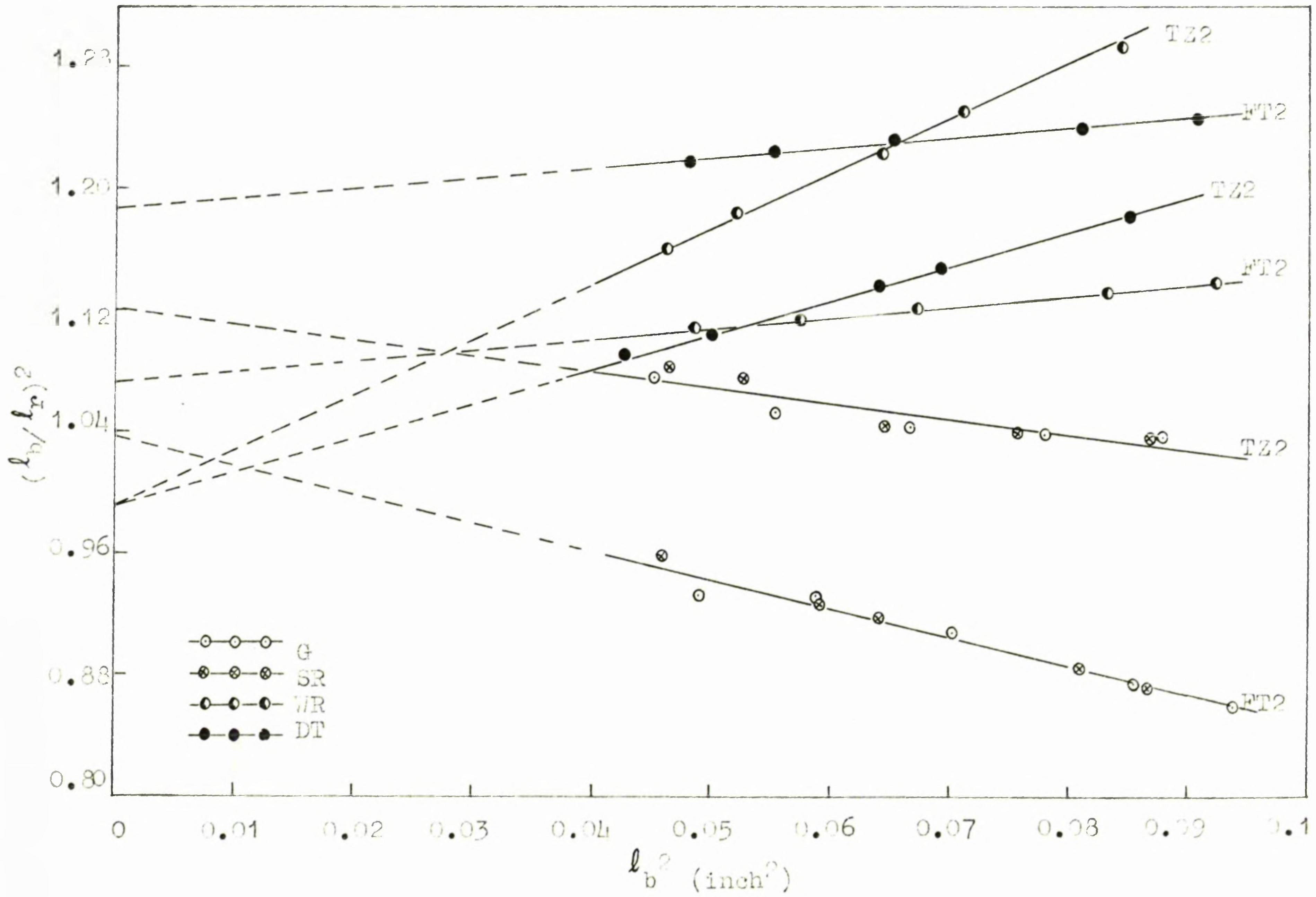


Fig. 49. Relation between relaxation ratio and stitch length for false twist crimped and Textralized yarn fabrics.

states from yarn FT2 starts at a lower value of $(\ell_b/\ell_r)^2$.

(iii) The rate of increase in the relaxation ratio with an increase in $(\ell_b)^2$ is much greater with wet treated and dry tumbled fabrics from yarns TZ1 than those from yarns FT1 though at any given value of $(\ell_b)^2$ the amount of relaxation is smaller with the former fabrics within the range of $(\ell_b)^2$ values considered. (Fig.48).

(iv) Whereas the relaxation for fabrics from yarn FT2 starts at lower values of $(\ell_b/\ell_r)^2$ when compared with fabrics from yarn FT1, this difference is not so marked with fabrics from yarns TZ1 and TZ2. The yarns FT1 and FT2 and TZ1 and TZ2 differ in their filament denier and crimp rigidity values, FT1 and TZ1 being of the lower filament denier and lower crimp rigidity value.

(v) With an increase in $(\ell_b)^2$, most griege and steam relaxed fabrics exhibit a decrease in the relaxation ratio. It is unlikely that this behaviour is correct and as such there must be some reason for this peculiar behaviour. Analysis of equation (6) would indicate that the relaxation ratio $(\ell_b/\ell_r)^2$ is dependent primarily on the values of S_1 and S_2. For all the fabrics from unbulked yarns U1 and U2, the values of S_1 (table 20) are fairly high and whereas values of S_2 for the wet treated and dry tumbled fabrics from bulked yarns are large, those for the griege and steam relaxed fabrics are small. This indicates that the factor $(S_2 - S_1)$ used in equation (6) is negative for griege and steam relaxed fabrics and is responsible for this peculiar behaviour. Referring to Figure (47) for the plot of S_u against $1/\ell_m^2$, it will be observed that though regression equations have been computed which give high values for intercepts S_1, it would be logical to draw the lines to pass through the origin or very near to it so that S_1 values will become minimal and the expected behaviour would then be obtained for the griege and steam relaxed fabrics. After this modification in the values of S_1, the trend for the wet treated and dry tumbled fabrics would still remain the same, the values for the relaxation ratio becoming higher. Also, the intercept S_1 for fabrics from yarns U1 and U2 would be the same and therefore in agreement with Eggleston and Cox[77], the constants S_1 and k_{su} would require to be determined once only and should hold good for all the fabrics of a given construction from unbulked yarns of differing deniers.

The fact that the relaxation ratio depends on the measured stitch length can be explained by the observation that tight fabrics restrain the development of crimp more than loose fabrics due to the increased number of yarn crossings per unit area. The intercept and slope of the graphs of $(\ell_b/\ell_r)^2$ against $(\ell_b)^2$ bear the following significance[77]

(a) The intercept k_{sb}/k_{su} which is an extrapolation to $(\ell_b)^2=0$ represent the lowest value of $(\ell_b/\ell_r)^2$ obtained from the tightest fabrics for which a linear relationship exists between S_b and $1/\ell_b^2$. As k_{su} is constant as indicated previously, the intercept k_{sb}/k_{su} would depend on K_{sb}.

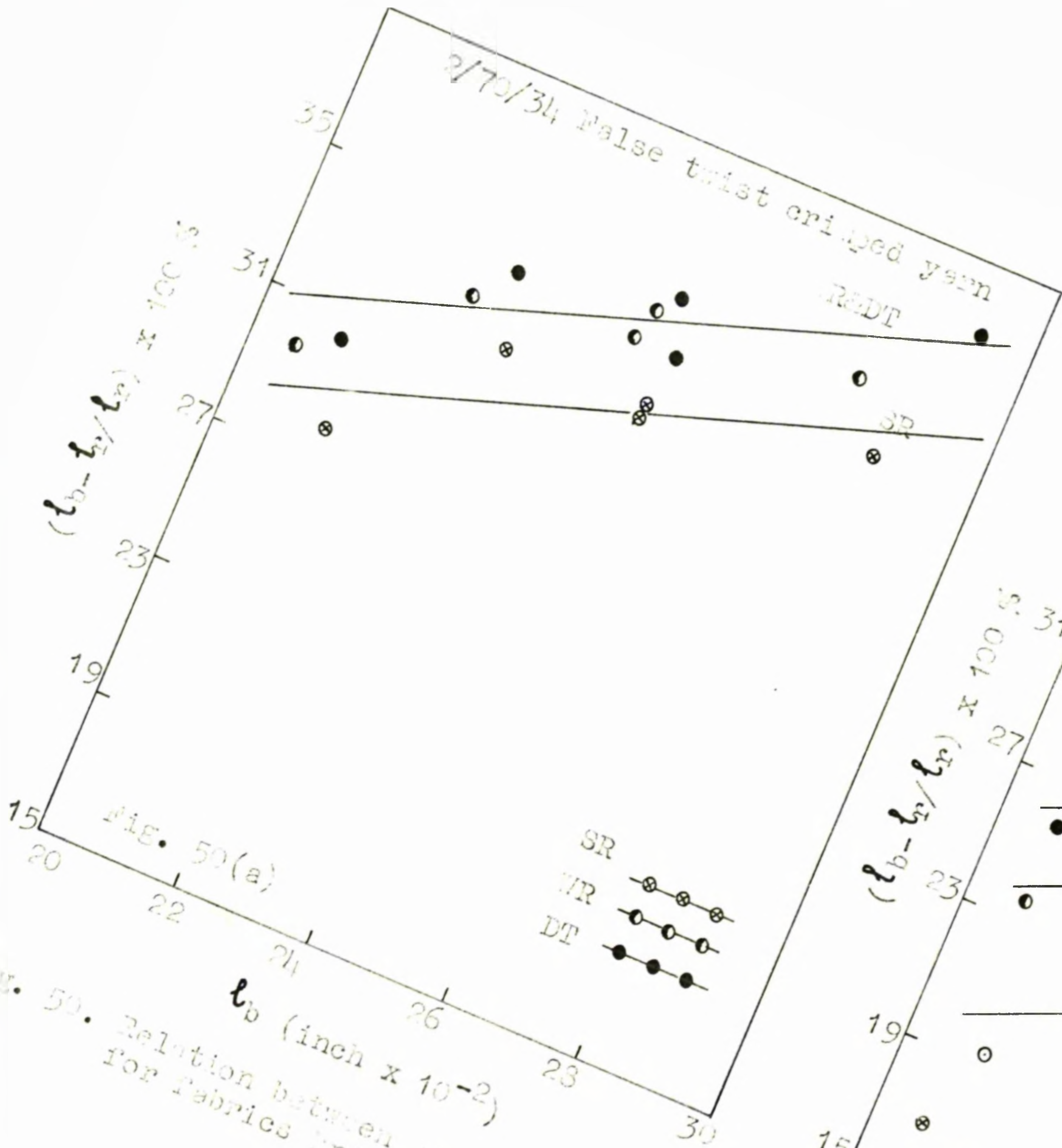
(b) The slope $(S_2 - S_1)/k_{su}$ represents the rate of increase of $(\ell_b/\ell_y)^2$ as $(\ell_b)^2$ increases. As explained previously S_1 and k_{su} are constants, this rate of increase therefore depending on S_2 and supporting the interpretation put forward by Munden et al.[69].

It may be concluded from this work that the theory developed by Eggleston and Cox[77] for plain knit fabrics from bulked yarns is also generally applicable to 1 x 1 rib fabrics from those yarns. The difference in the relaxation ratio for fabrics from yarns FT1, FT2 and TX1, TX2 would indicate that a factor for filament denier requires to be incorporated whereby the theory could be used for fabrics made from yarns of differing filament deniers. However, further work is needed to establish this fact as the yarns of differing filament deniers used in this work also varied in crimp rigidity values, FT1 and TX1 being of approximately 10% crimp rigidity whereas FT2 and TX2 were of about 15% crimp rigidity. It is important to note that a single figure such as yarn crimp rigidity which describes the yarn property is not capable of explaining the behaviour of the yarn in the fabric form. Textralised and false twist crimped nylon yarns of similar crimp rigidities used in this work show different relaxation behaviours when knitted into fabrics (Figs. 48, 49).

The theory discussed empowers a more detailed understanding of the behaviour of bulked yarns in fabric form, but because of its complicated character, would be of little use in routine control of fabric production. For this reason a simple way of estimating yarn relaxation in fabric form is to use the method suggested by Munden et al.[69] and later used by Cotton and Bladon[75]. Percentage yarn collapse in a fabric is defined as

$$(\ell_b - \ell_r)/\ell_r \times 100 \text{ ——————————— } (7)$$

where ℓ_r is calculated from $\sqrt{19}/S_b$ for all the corresponding values of ℓ_b. The constant 19 is used for plain knit fabrics and it is realised that the use of this factor for 1x1 rib fabrics is possibly not justified but somewhat similar conclusions would result from any other reasonable value. The calculated percentage yarn collapse is plotted in Figures 50 (a) and (b) for fabrics knitted from yarns FT1, TX1 and in Figures 51 (a) and (b) from yarns FT2 and TX2. It will be noted that fabrics from false twist crimped yarns (FT1 and FT2) exhibit greater yarn collapse than those from Textralised yarns (TX1 and TX2). Hence when fabrics from these two types of yarns are required to be finished to the same size, these will require different stitch lengths or a difference in the number of courses. The slope of the lines would indicate that a greater yarn collapse occurs at longer stitch lengths. In general, these results exhibit the trend described earlier in this section. An additional feature of interest from these graphs is that most of the lines for fabrics in their various states are of the same slope, which implies that the rate of increase of yarn collapse is similar for these fabrics for the range of stitch lengths considered here. A greater yarn collapse occurs when the fabrics are dry tumbled and that there is



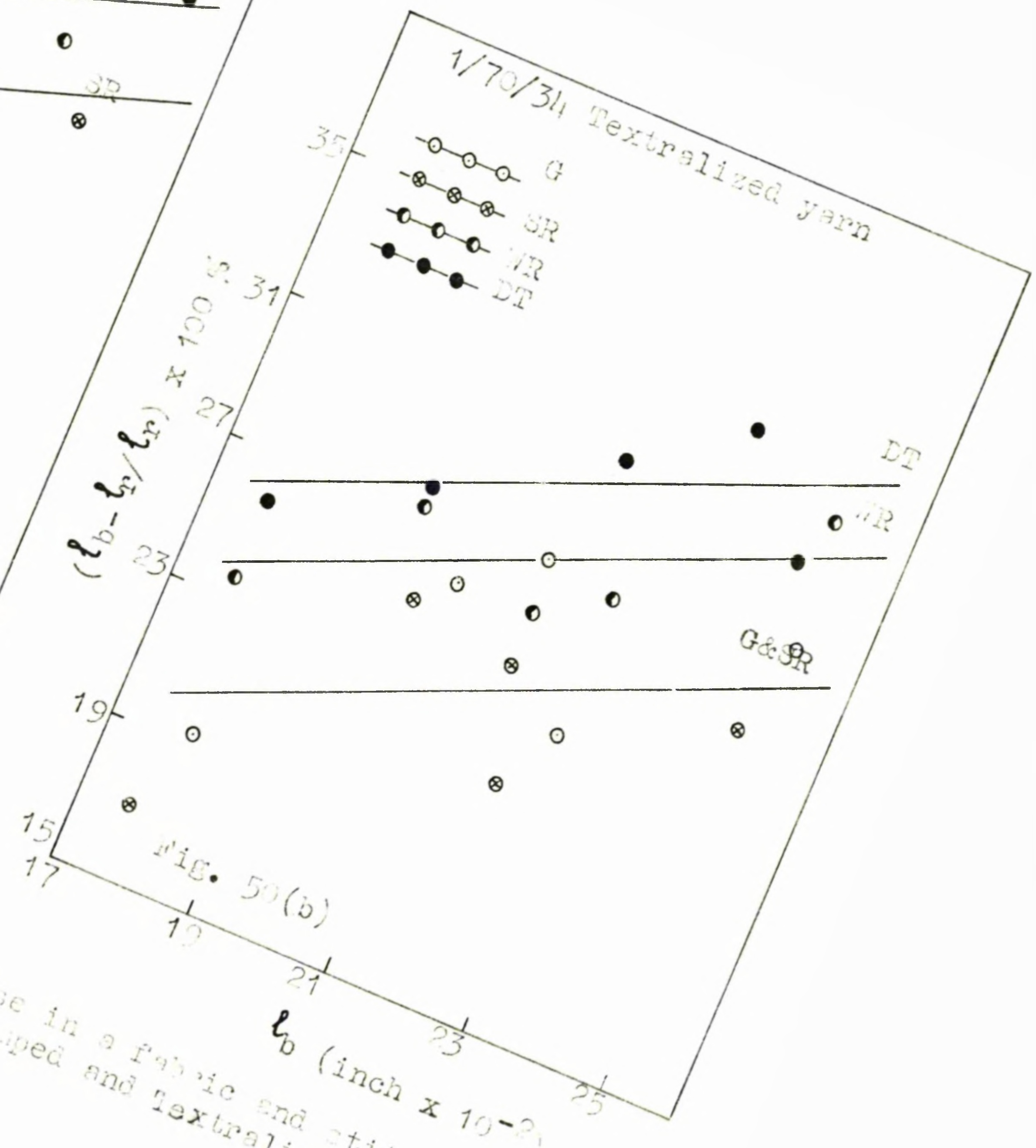


Fig. 50. Relation between percentage yarn collapse in a fabric and stitch length for fabrics knitted from false twist crimped and Textralized yarns.

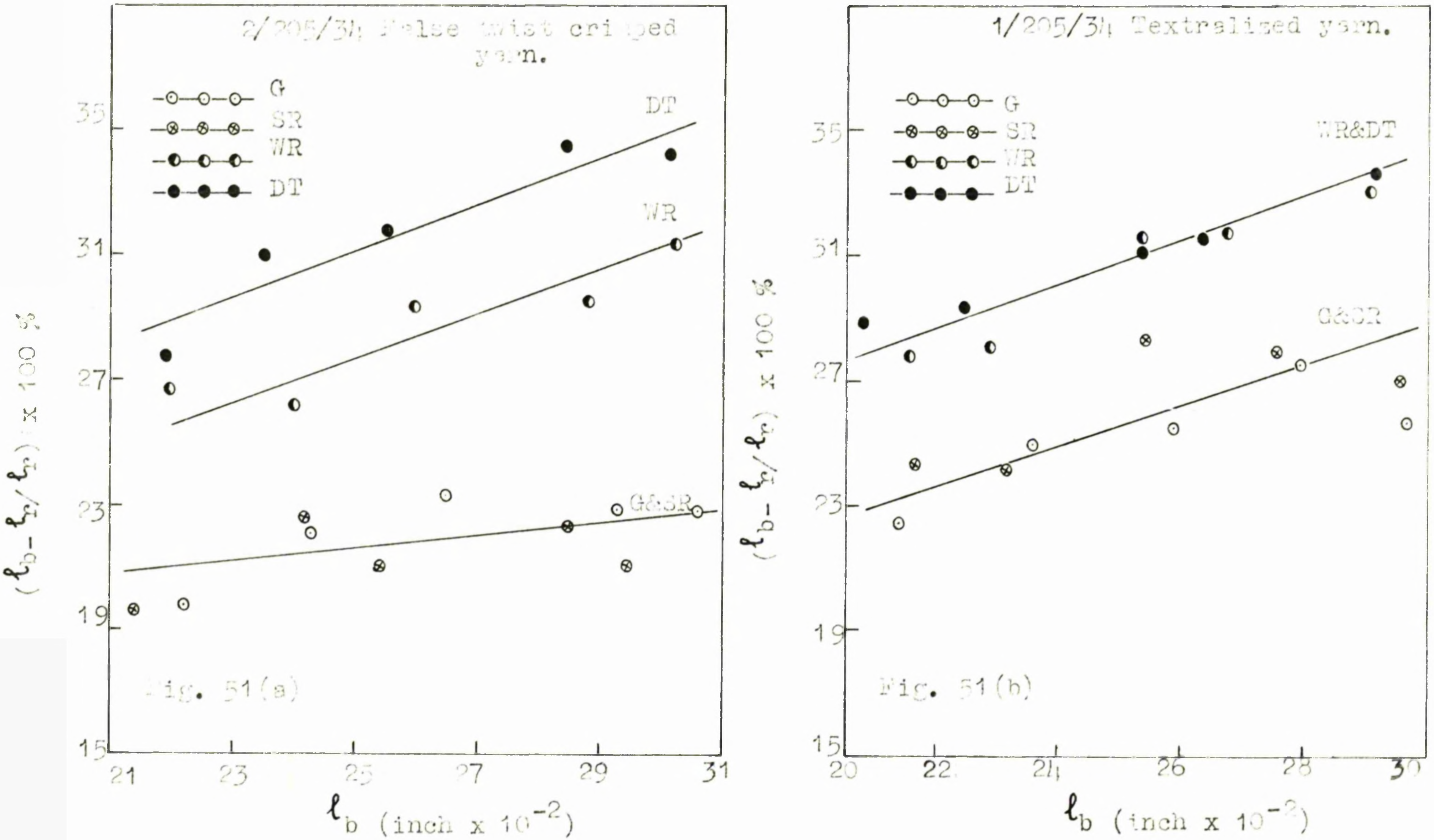


Fig. 51. Relation between percentage yarn collapse in a fabric and stitch length for fabrics knitted from false twist crimped and Textralized yarns.

little difference in the yarn collapse of the griege and steam relaxed fabrics, indicating that steam relaxation alone is not sufficient to develop filament crimp appreciably.

3.62 Measured and Calculated Yarn Collapse

The results of measurements of yarn collapse in terms of crimp rigidity and percentage yarn collapse were presented and discussed in section (3.1) and it was indicated that those results would be further considered in relation to the retraction behaviour of the yarn when it is knitted into a fabric.

It was stated in the last section that the amount of yarn collapse or retraction in the fabric can be determined from relation (7). Munden et al.[69] have shown that the amount of yarn retraction in a fabric is a function of (1), $\ell_b/\sqrt{D}$, where ℓ_b is the measured stitch length and D the yarn denier, and (2), the yarn collapsing property, i.e. percentage yarn retraction in a fabric is proportional to measured yarn retraction x $\ell_b/\sqrt{D}$.

An indication of the usefulness of the measured yarn retraction properties may be obtained by plotting the following:

$$\left[\frac{\text{Calculated percentage yarn retraction in a fabric}}{\text{measured yarn retraction}}\right] \text{ against } \ell_b/\sqrt{D}$$

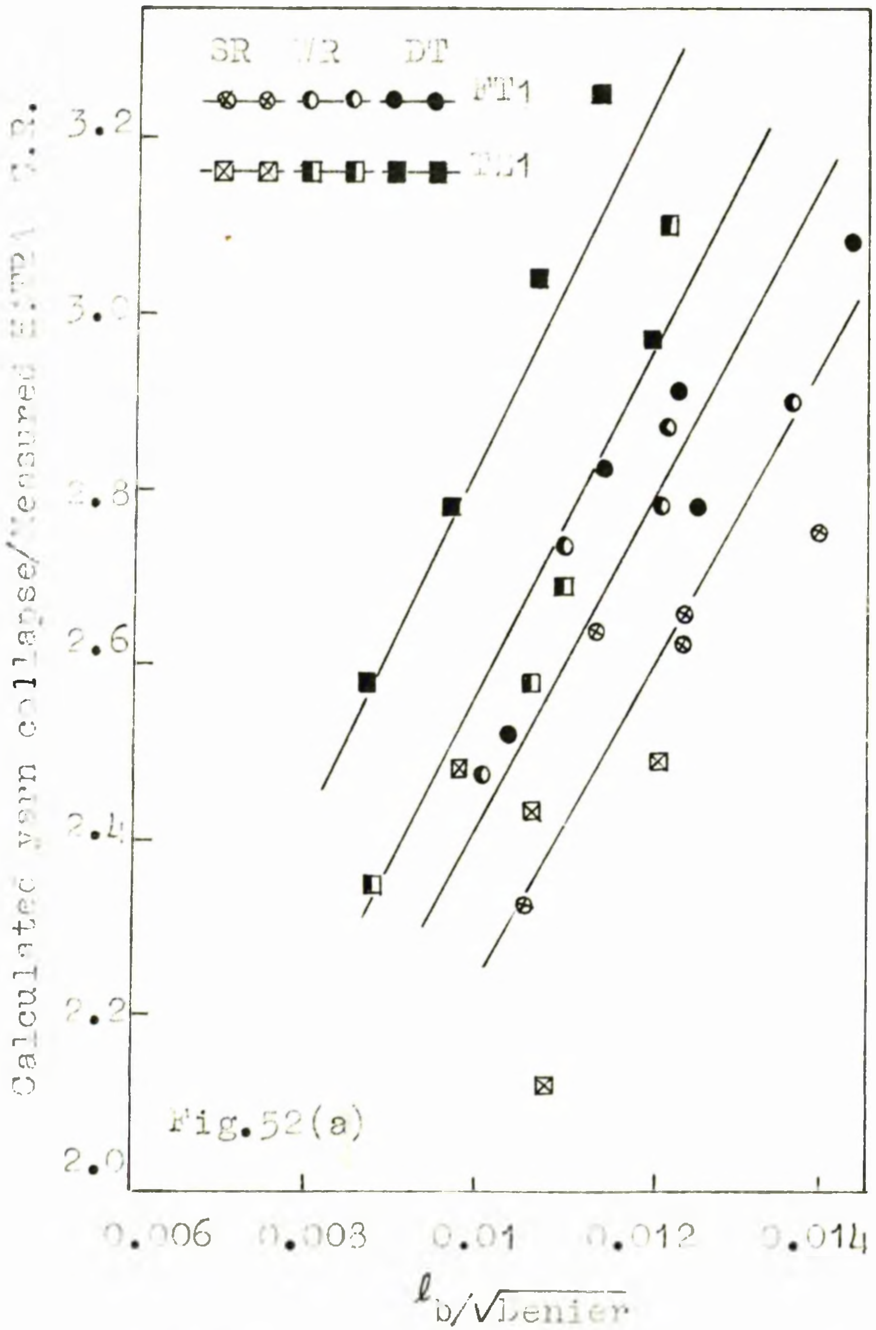
If the measured yarn retraction value represents a reasonable estimate of its potential retraction in fabric form, the results for the various yarns will fall on a line. Any spread of these results would indicate a lack of agreement between the measured yarn retraction in yarn form and the retraction of that yarn when in fabric form.

The amount of yarn retraction was calculated from relation (7) for 1x1 rib fabrics made from yarns FT1, FT2 and TZ1, TZ2 (table 3c, chapter 2) for the whole range of ℓ_b values and the results presented in a series of graphs. Results for two fabric states only are given in the figures, namely (a) wet treated and (b) dry tumbled since it is considered that these are the most useful relaxation treatments for fabrics produced from bulked yarns. The following information will be observed from the figures:

(1) The H.A.T.R.A. crimp rigidity results (Figures 52a and b) give a reasonable indication of the behaviour of yarn in fabrics when these are relaxed by wet treatment but for the fabrics in the dry tumbled state, the H.A.T.R.A. crimp rigidity test fails to predict yarn behaviour.

(2) The results for yarn crimp rigidity measured after the yarns were relaxed in water at 45°C show a lower spread than the H.A.T.R.A. crimp rigidity results for fabrics from yarns FT1 and TZ1 (Figure 53a) and give a good estimation of the behaviour of the yarns in fabrics relaxed by dry tumbling. When however, fabrics from yarns FT2 and TZ2 (Figure 53b) are considered, a greater spread is obtained in this case than with H.A.T.R.A. crimp rigidity values and a very poor indication of the behaviour of these yarns in such fabrics is obtained.

(3) The crimp rigidity values for yarns relaxed in steam on a Hoffman



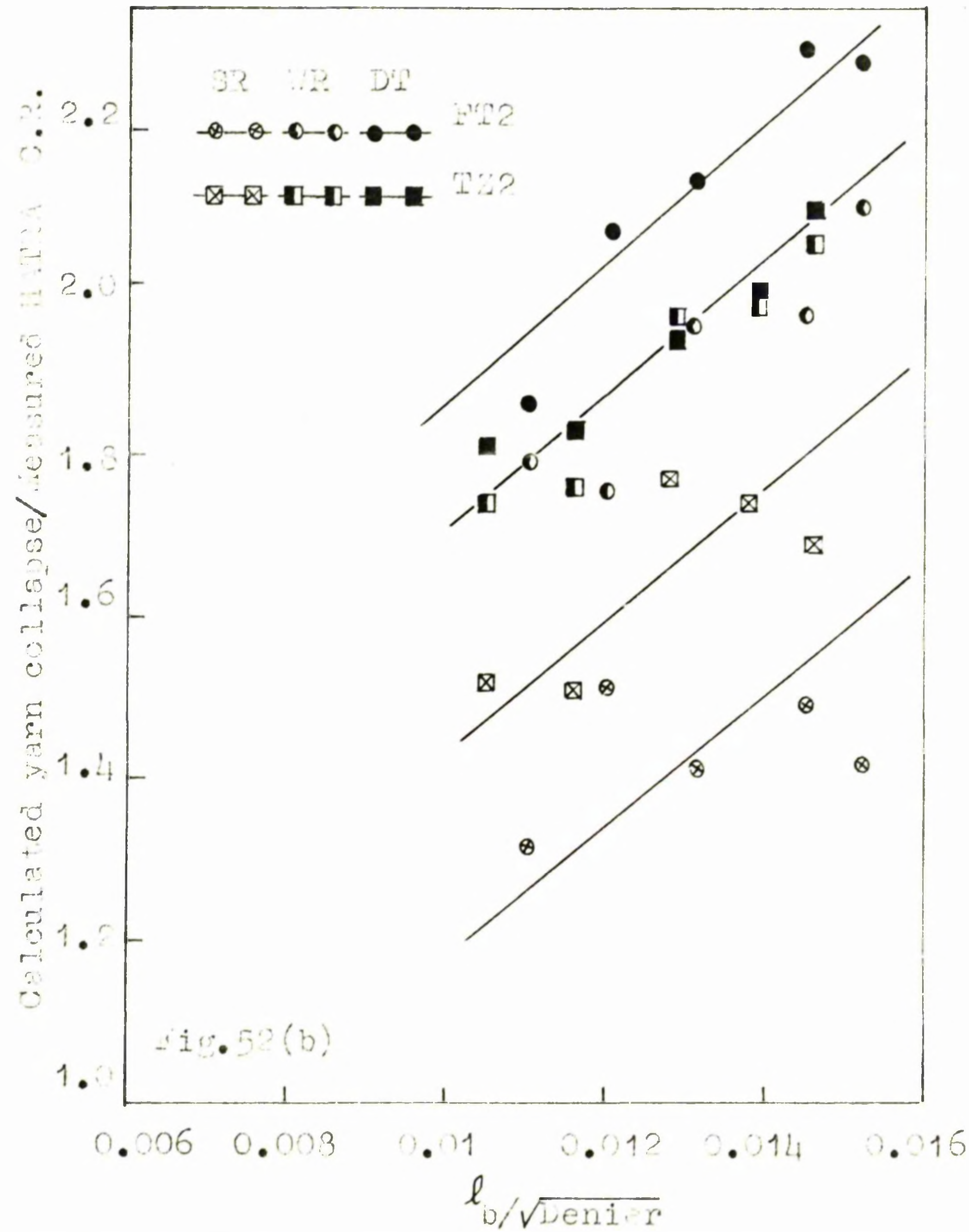
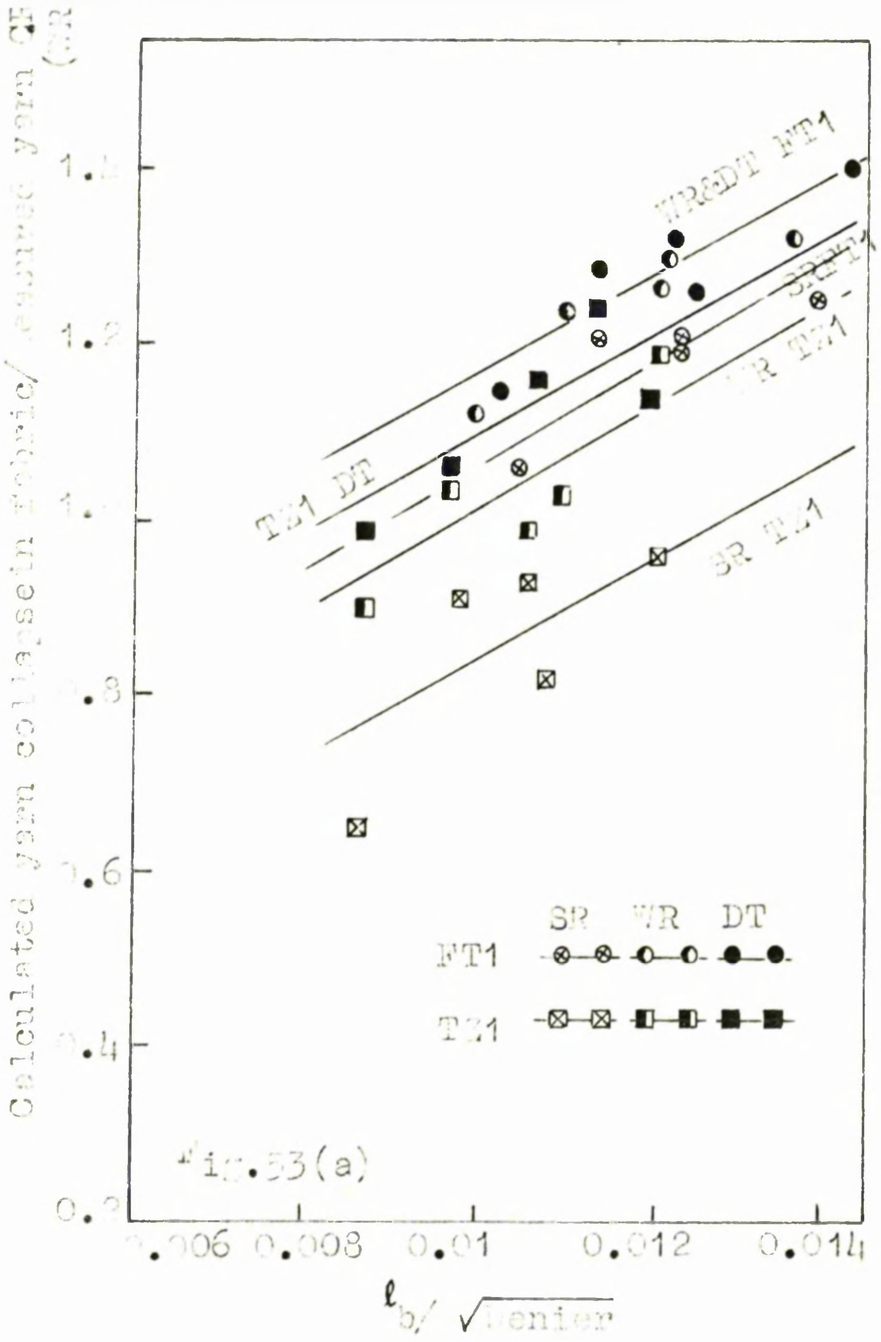


Fig.52. Relation between $l_b/\sqrt{\text{denier}}$ and calculated yarn collapse in fabric/measured H.A.T.R.A. crimp rigidity for fabrics knitted from false twist crimped yarns.



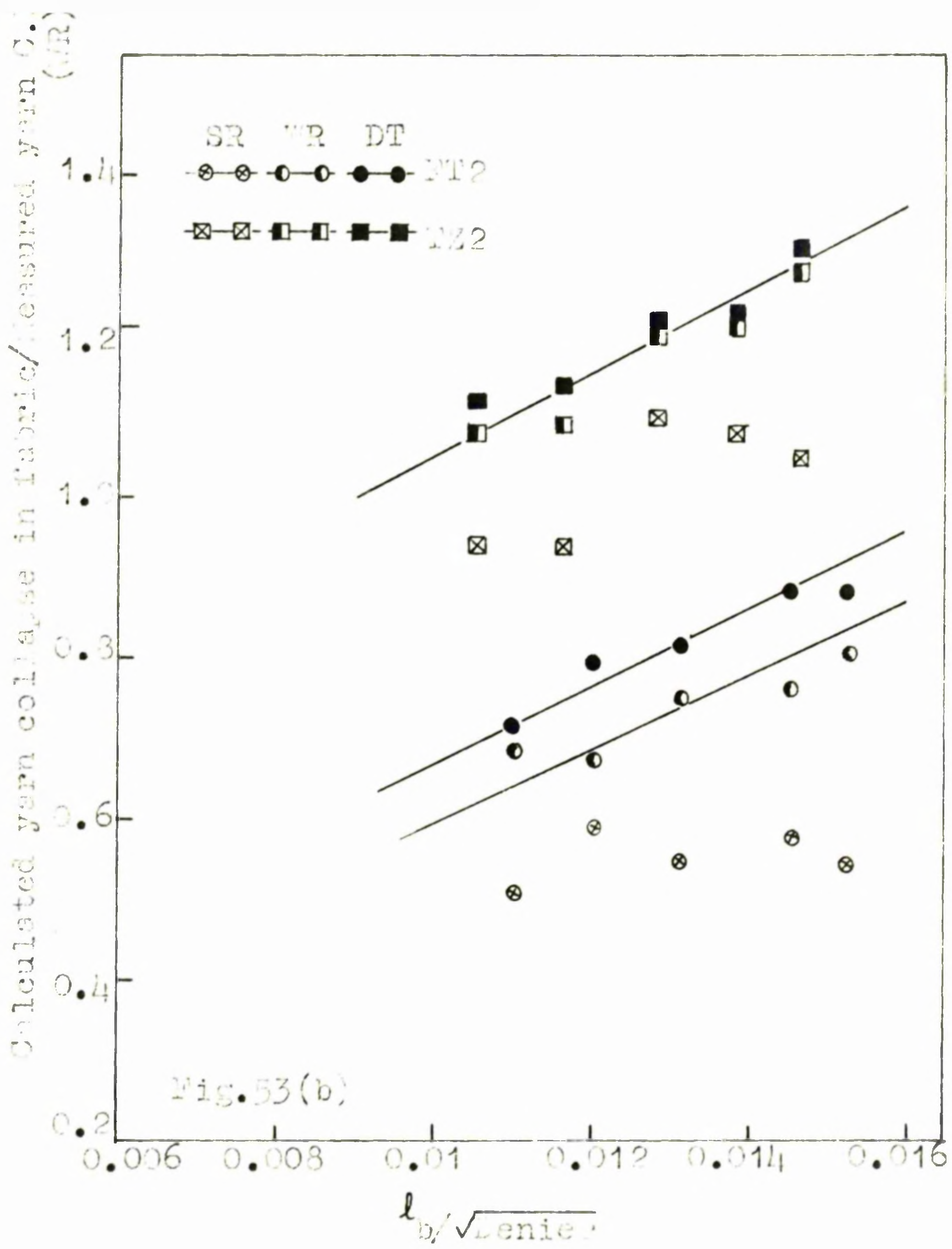


Fig.53. Relation between $\ell_b/\sqrt{\text{Denier}}$ and calculated yarn collapse in fabric/measured yarn crimp rigidity (wet relaxed) for fabrics knitted from false twist crimped and textralized yarns.

bed show poor correlation with their behaviour in the fabrics under consideration (Figures 54a and b).

(4) When the yarns are relaxed by a dry heat treatment at 90°C, the resultant crimp rigidity measurements indicate a reasonable correlation for fabrics from yarns FT1 and TZ1 (Figure 55a) when those fabrics are dry tumbled but for the wet relaxed fabrics, yarn crimp rigidity measured in this manner over-estimates the yarn collapse by a small amount. For the fabrics knitted from yarns FT2 and TZ2 (Figure 55b), poor correlation is noted.

(5) The values for the measured percentage yarn collapse after the yarns were relaxed in water at 45°C demonstrate the same behaviour as did the crimp rigidity (modified method) values determined on the yarns in the same state. It will be noted from Figures (56a and b) that whereas the yarn retraction in fabrics from yarns FT1 and TZ1 is reasonably correlated, no such correlation exists for the fabrics from yarns FT2 and TZ2.

(6) The measured percentage yarn collapse after relaxing yarn in steam on a Hoffman bed does, like the corresponding crimp rigidity (modified method) results, exhibit little correlation with those fabrics (Figures 57a and b).

(7) A reasonable correlation for the yarn retraction in fabrics from yarns FT1 and TZ1, particularly in the wet relaxed state, can be obtained from measured percentage yarn collapse for yarns dry relaxed at 90°C (Figure 58a). However, for fabrics from yarns FT2 and TZ2

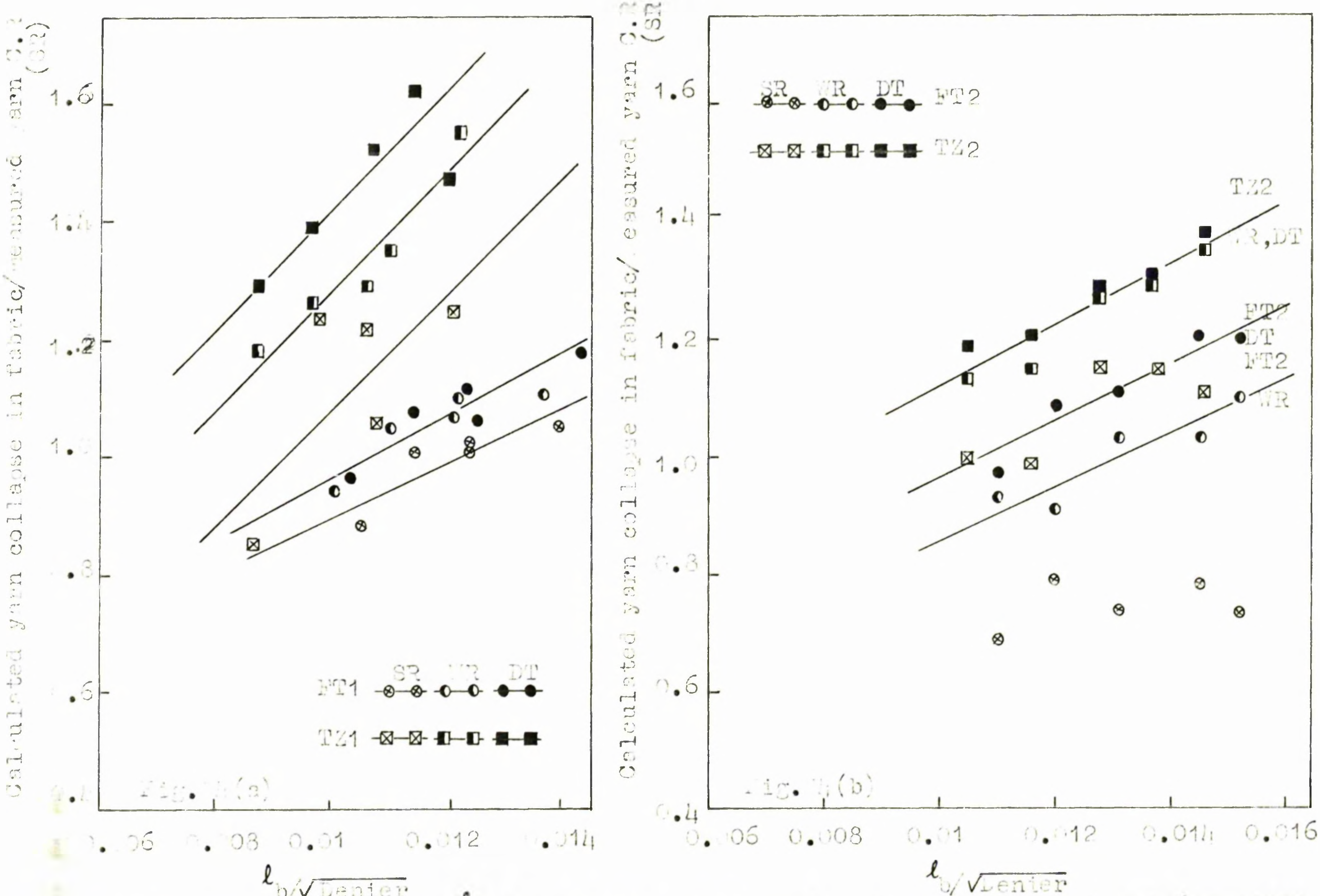


Fig. 54 Relation between $l_b/\sqrt{denier}$ and calculated yarn collapse in fabric/measured yarn crimp rigidity (steam relaxed) for fabrics knitted from false twist crimped and textralized yarns.

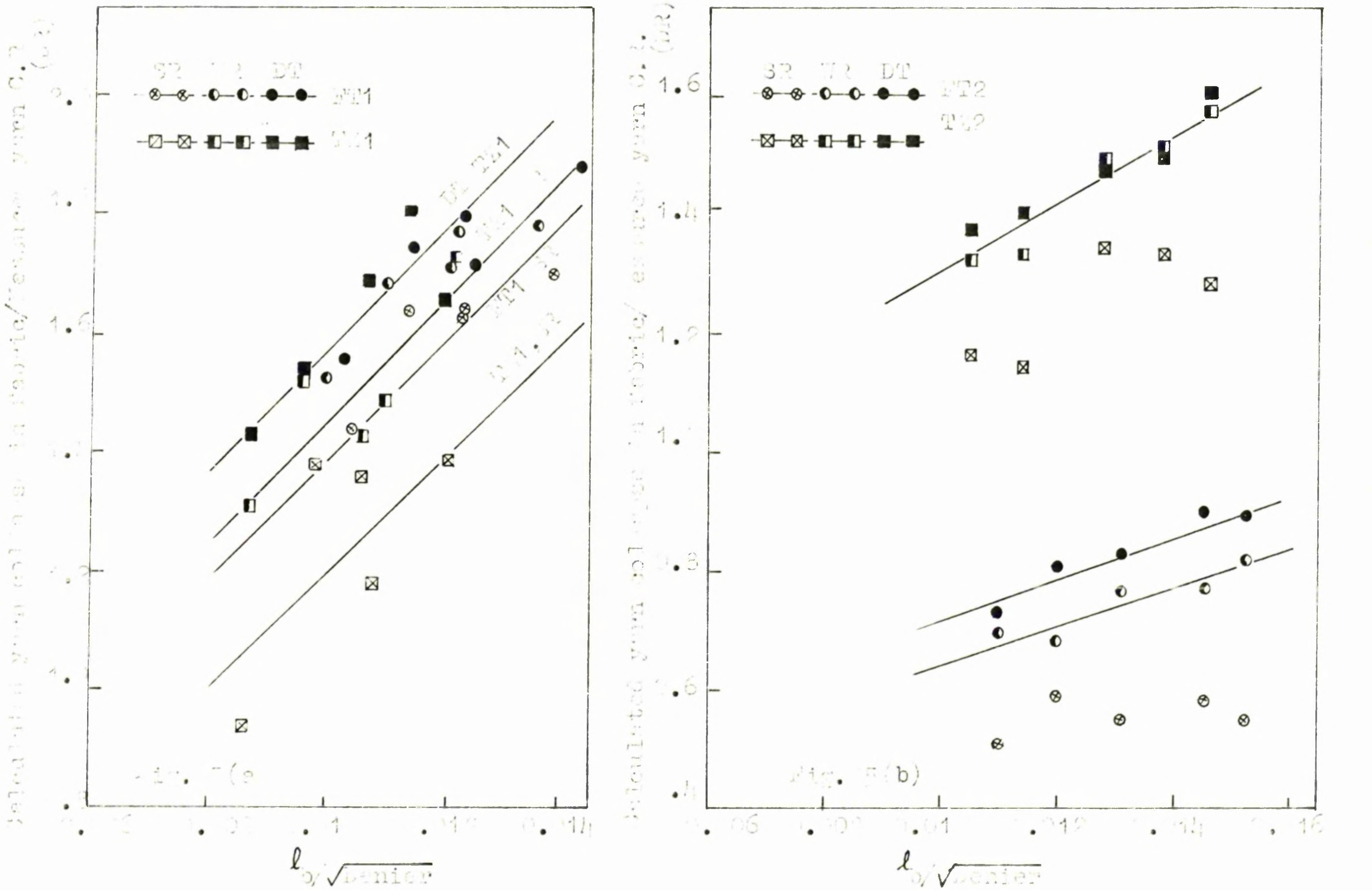
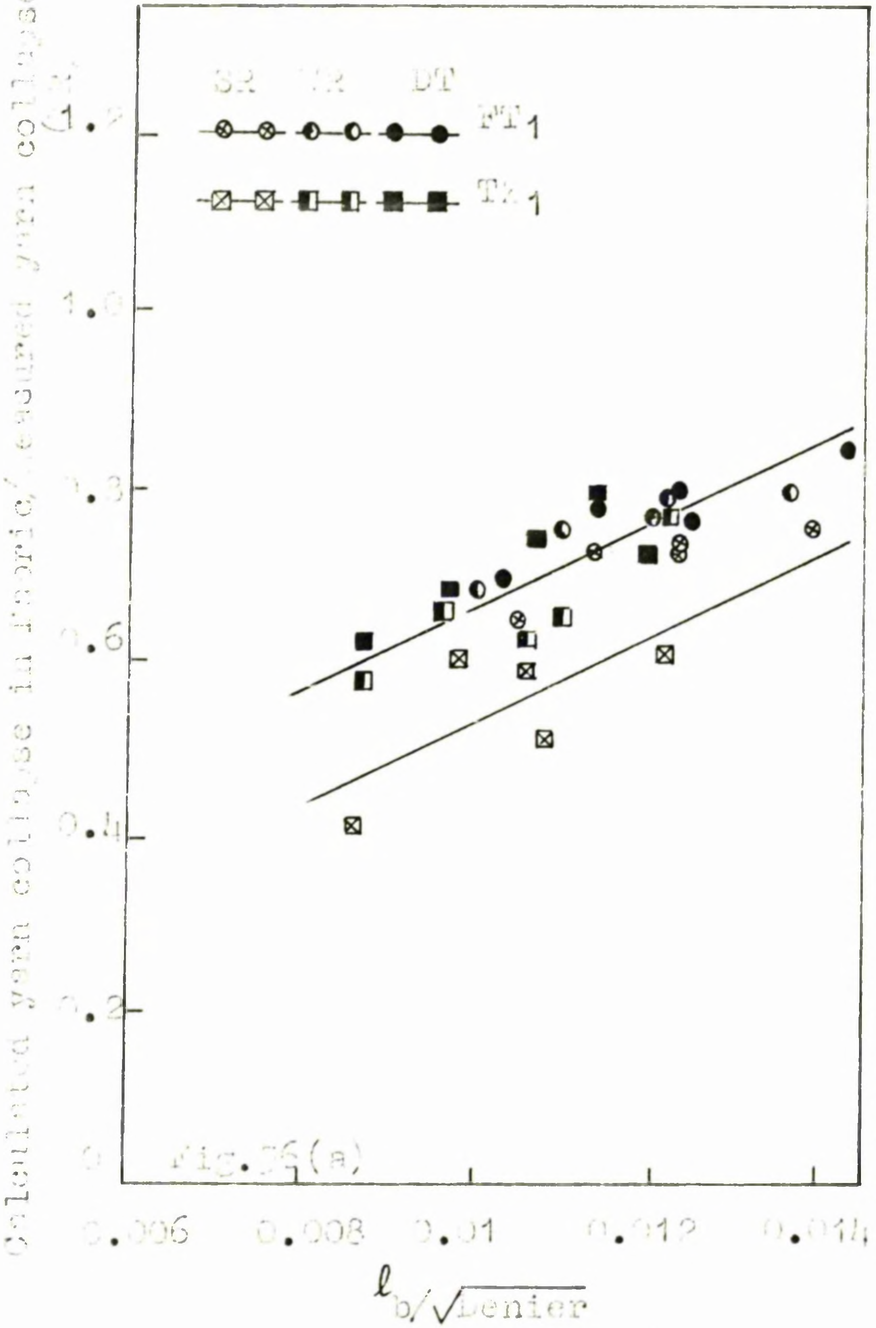


Fig.55. Relation between $l_o/\sqrt{\text{denier}}$ and calculated yarn collapse in fabric/measured yarn crimp rigidity (dry relaxed) for fabrics knitted from false twist crimped Terylene yarns.



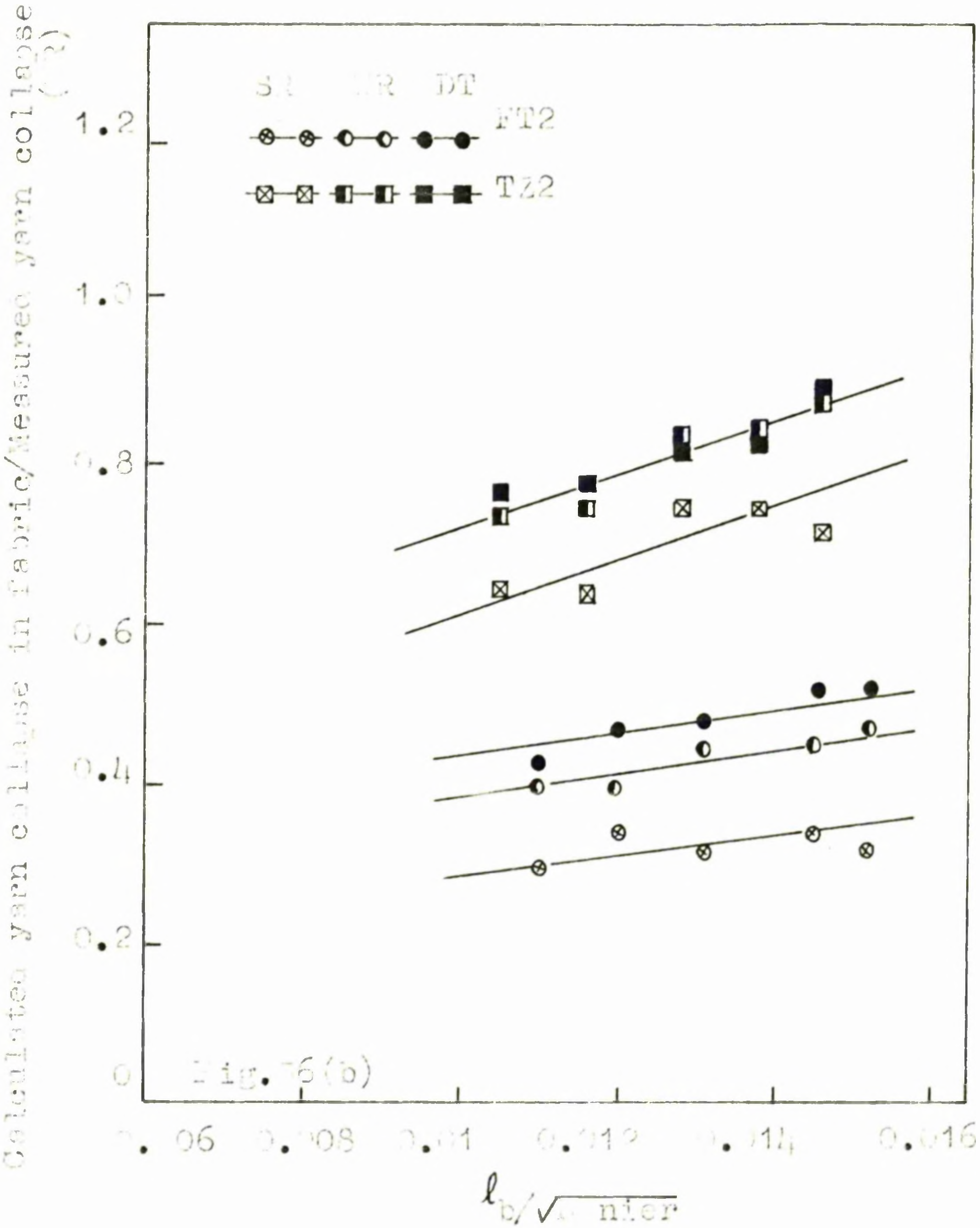


Fig56. Relation between $l_b/\sqrt{denier}$ and calculated yarn collapse in fabric/measured yarn collapse (wet relaxed) for fabrics knitted from false twist crimped and Textralized yarns.

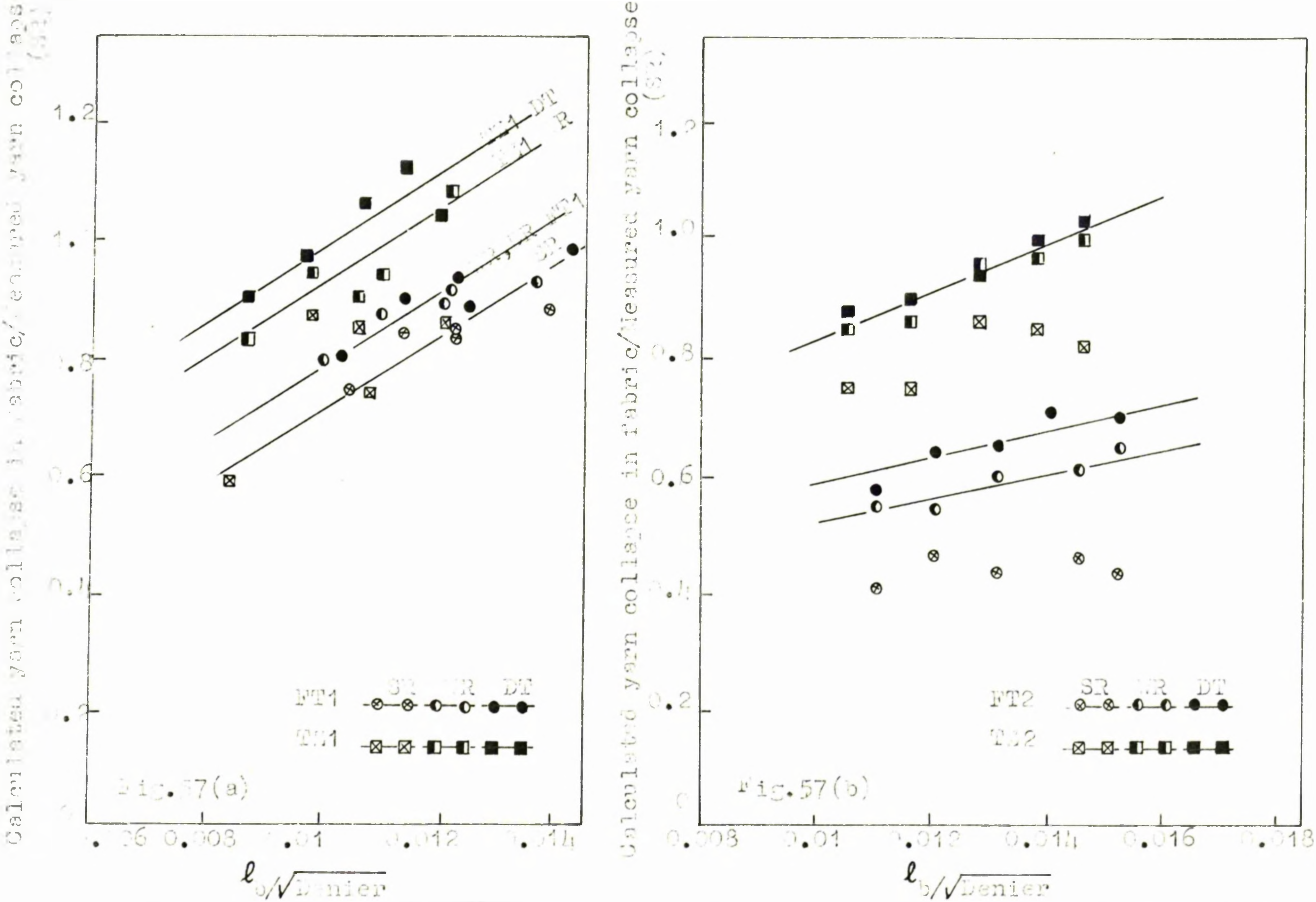


Fig.57. Relation between $\ell_b/\sqrt{denier}$ and calculated yarn collapse in fabric/ measured yarn collapse (steam relaxed) for fabrics knitted from false twist crimped and Textralized yarns.

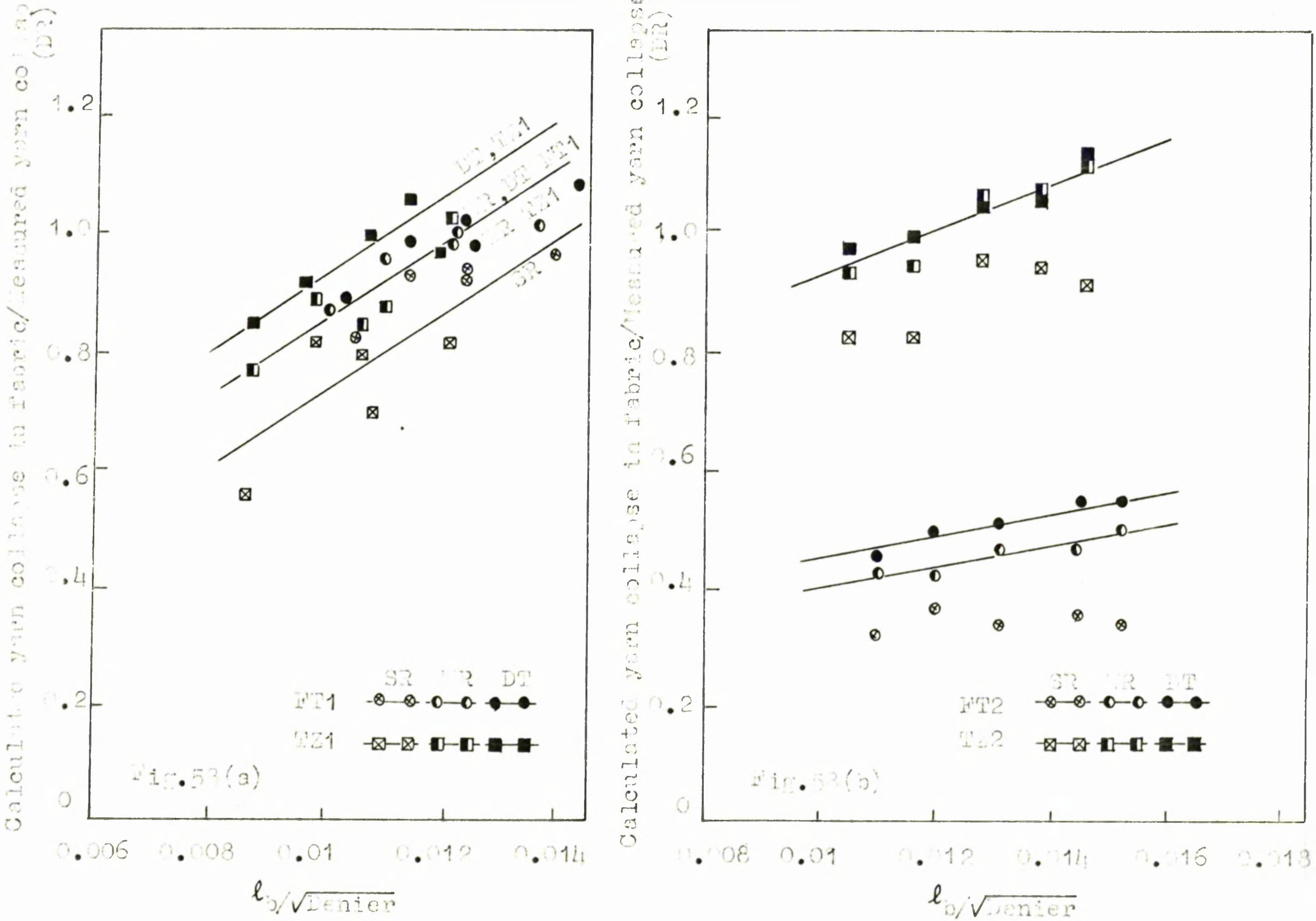


Fig.53. Relation between $l_b/\sqrt{Denier}$ and calculated yarn collapse in fabric/ measured yarn collapse (dry relaxed) for fabrics knitted from false twist crimped and Textralized yarns.

(Figure 58b), the lines are widely separated, indicating poor correlation.

From these results it may be concluded that

(a) the H.A.T.R.A. crimp rigidity test gives a reasonable measure of agreement between measured and calculated yarn retraction for fabrics relaxed by wet treatment but does not do so for yarn retraction in dry tumbled fabrics

(b) the yarn retraction properties measured in terms of crimp rigidity (modified method) and percentage yarn collapse give a similar correlation with yarn retraction in fabrics

(c) the results for the crimp rigidity (modified method) and percentage yarn collapse measured after the relaxation of the yarns in steam on a Hoffman bed have no correlation with the performance of those yarns in fabric form

(d) a number of methods such as the H.A.T.R.A. crimp rigidity test or crimp rigidity and percentage yarn collapse, determined after relaxation of the yarns in water at 45°C and dry heat treatment at 90°C, predict reasonably well the behaviour of yarns FT1 and TZ1 when knitted into fabrics but none of these methods appear suitable to predict the behaviour of yarns FT2 and TZ2 in their fabric form. For those yarns only the H.A.T.R.A. crimp rigidity test has shown any correlation. Therefore, for yarns composed of higher denier filaments a method is required to measure yarn retraction properties which would correlate with the actual collapse of yarn in fabric form.

3.83 Fabric Bulk and Stitch Length

The changes in area dimensions of a fabric due to bulked yarn relaxation have been investigated by several workers, but little attention has been devoted to the associated changes in fabric bulk due to this yarn relaxation. Attempts have been made to determine diameters[76] of free bulked yarns but as these are not necessarily the same in fabric form, such information is not of much help in this context. The thickness and specific volume of bulked-yarn fabrics have been assessed by several authors[38,69,76] but have proved to be not capable of simple interpretation.

The fabric bulk has been defined as the volume per unit weight of a fabric and is given by,

Fabric bulk = t/A, where t is the fabric thickness and A is the fabric area density. Fabric bulk as concerned in this work has been calculated from these measurements.

Fabrics were knitted at various stitch cam settings from yarns FT1, FT2 and TX1, TX2 and their fabric area densities determined in the griege and relaxed states by weighing known areas of the samples. The thicknesses of the samples were determined by the use of a Shirley Thickness Tester at a range of pressures. Thickness-pressure data were plotted but it was found difficult to extrapolate the resultant curves to zero pressure in order to obtain ideal fabric thicknesses under zero load conditions. However, plotting the data on a log-log scale resulted in a linear relation between thickness and pressure to a limiting value and from these plots, fabric thicknesses at 0.05 p.s.i. were determined and utilised in the calculation of fabric bulk.

The results of measurement of fabric bulk plotted against their respective measured stitch lengths revealed that fabric bulk increases with an increase in stitch length as would be expected, but this method of analysing results failed to demonstrate any changes in fabric bulk due to bulked yarn relaxation (e.g. for fabrics from yarns TZ1 and TZ2) or indicated an unexpected behaviour for fabrics from yarns FT1 and FT2 in that their fabric bulk for a given stitch length decreased after relaxation treatments. This peculiar indication of bulk probably arises due to the fact that the quantities used in the measurement of fabric bulk namely, thickness and area density are measured on fabrics in the relaxed state whereas stitch lengths are determined after straightening the yarns and hence do not represent the true values of the loop lengths as they lie in the fabrics. It therefore, appears that this method of presenting data is not proper and indicates the reason why Lennie[99] did not get a difference in fabric bulk values before and after relaxation of fabrics from stuffer box bulked yarns. For the same reason, the results of Munden et al.[38] indicating the same value of fabric bulk for a given stitch length for fabrics knitted from bulked yarns of different types appear doubtful. It is, therefore suggested in this case that fabric bulk should be related to the relaxed stitch length (ℓ_r). However, a better approach appears to be to use a two dimensional quantity such as 'Cover Factor'[97] which is used as a measure of the thightness of a knitted fabric. It has been shown for plain knit fabrics from bulked yarns that fabric thickness factor is related to cover factor and it is expected that cover factor will have some connection with fabric bulk.

The cover factor is defined as the ratio of $\sqrt{\text{denier}}$ to measured stitch length (i.e. $\sqrt{D_b}/\ell_b$) for the reason that $\sqrt{\text{denier}}$ is proportional to the yarn diameter. It has, however, been shown[77] that fabric thicknesses for bulked - and unbulked- yarn fabrics with the same measured deniers and stitch length are different, indicating that $\sqrt{D_b}$ is inadequate as a measure of yarn diameter. Hence a more general expression for cover factor would be to use,

Cover factor $= \sqrt{D_r}/\ell_r$, i.e. cover factor is the ratio of the average yarn denier and stitch length, both in a relaxed state in fabric form, D_r being calculated from the relation

$$D_r = D_b\ (\ell_b/\ell_r),$$

where D_b is the measured mass per unit length of the straightened yarn, and ℓ_b/ℓ_r is the relaxation ratio as indicated previously and is calculated from the equation

$$\ell_b/\ell_r = \ell_b \sqrt{\left[(S_b - S_1)/k_{su}\right]} \quad \text{(equation 5 in section 3.81)}$$

From the above equation,

$$\ell_r = \sqrt{\left[k_{su}/(S_b - S_1)\right]}$$

In calculating ℓ_b/ℓ_r and ℓ_r, the value of $k_{su} = 31$ and $S_1 = 0$ have been used and were obtained from Figure (47) for the graph of S_u against $1/\ell_u^2$ the reason for using these values being discussed in section (3.81). Cover factors were calculated for all the fabrics in their various states and the results of fabric bulk measurements are plotted against cover factors in Figure (59) for fabrics from yarns FT1 and TX1 and in Figure (60) for those from yarns FT2 and TX2. It will be noted that the fabric bulk decreases as the cover factor increases for which the physical explanation is that there would be less space available in tight fabrics for yarn relaxation. Examination of these figures would further reveal that for a given cover factor, fabric bulk is greater for the wet and dry tumbled fabrics as compared with that of greige and steam relaxed fabrics and that this trend is observable with fabrics knitted from both false twist and Textralised yarns. Relaxing fabric in steam on a Hoffman bed does not bring about any significant change in fabric bulk. It is also interesting to note the differences in fabric bulk for false twist and Textralised yarn fabrics. For any given cover factor, the fabric bulk is less in all states for fabrics from Textralised yarn (TX1) as compared with fabrics from false twist yarn (FT1). This is probably the result of the difference in the nature of the crimp in these two types of yarn. However from Figure (60) it will be seen that after a dry tumbling treatment, the fabric bulk is the same for fabrics from yarns FT2 and TX2 but in the griege and steam

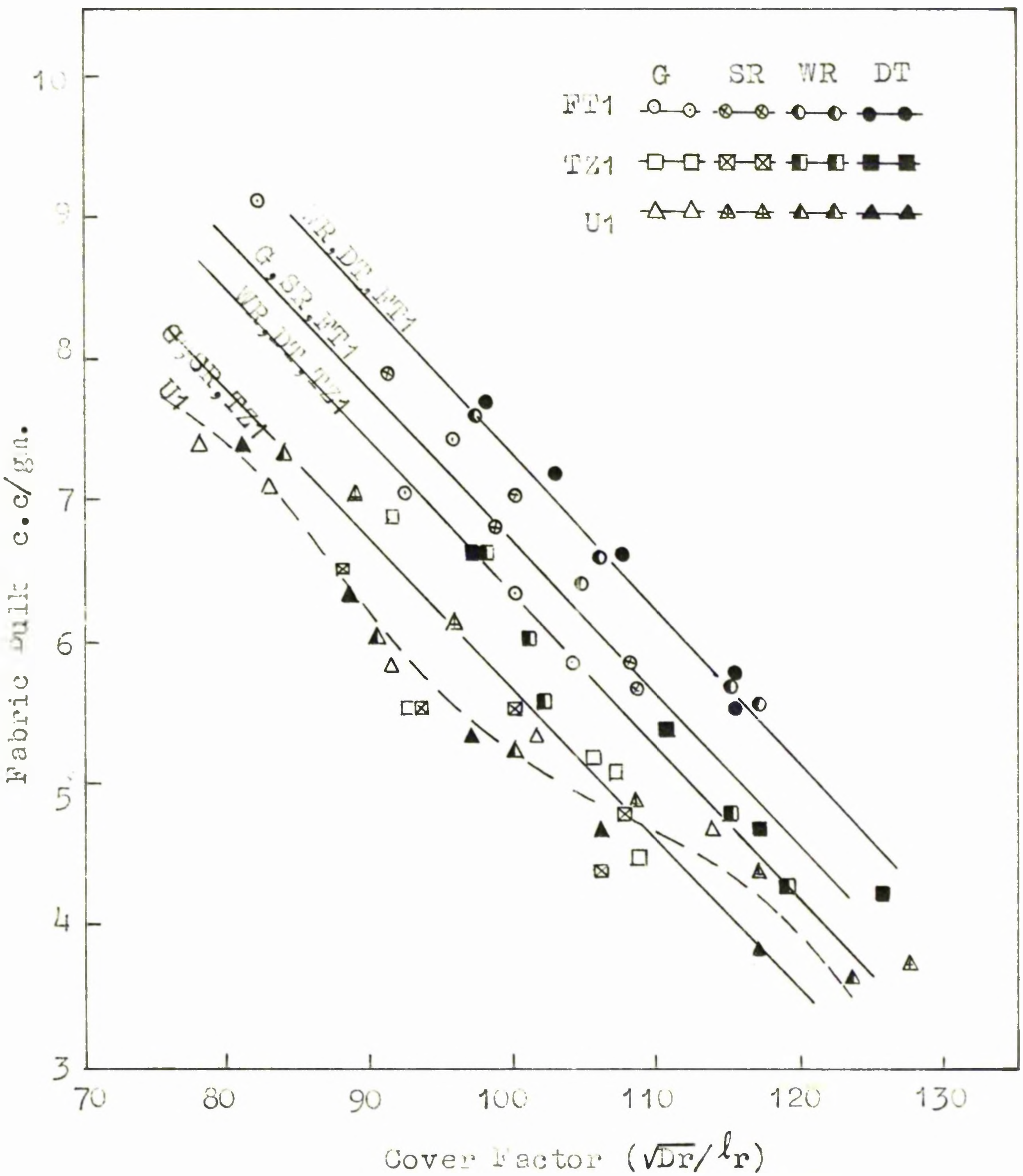


Fig.59. Relation between cover factor and bulk of fabrics knitted from bulked and unbulked yarns and finished by different treatments.

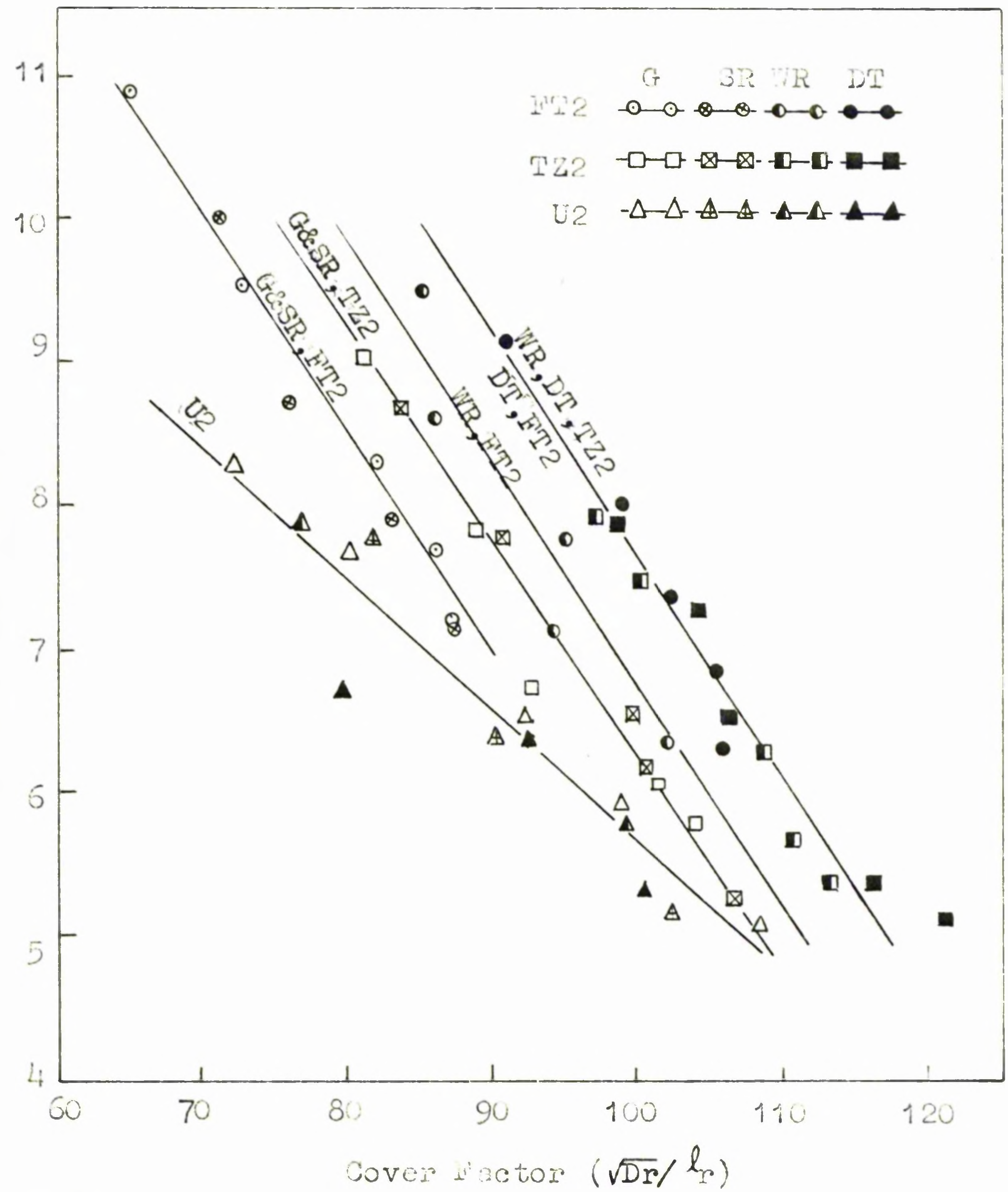


Fig.60. Relation between cover factor and bulk of fabrics knitted from bulked and unbulked yarns and finished by different treatments.

relaxed states, the fabric bulk is more for fabrics from yarn TZ2. The yarns TZ1 and TZ2 vary essentially in their filament denier as also do the yarns FT1 and FT2. Thus the contribution of filament denier to fabric bulk appears to alter the trend but more work is required to establish exactly the role of this yarn variable. Also included in the figures are the data for fabrics from unbulked yarns U1 and U2. It is clear that after relaxation these fabrics do not increase their bulk though in most cases a considerable amount of yarn shrinkage was observed which resulted in an increase in mass per unit length. It follows that it is only the yarn relaxation which is responsible for the increasing fabric bulk.

It is thus shown that fabric bulk when plotted against fabric cover factor does indicate differences in the expected manner and hence the extreme view expressed by Eggleston and Cox[77] that this method of measuring fabric bulk is not sensitive as a means of detecting changes in yarn bulk is not supported by this work. An alternative method for estimating yarn bulk as suggested by these authors is based on the comparison of bulked - and unbulked-yarn fabrics knitted at the same stitch length and mass per unit length, employing the relaxed values for the unbulked-yarn fabrics. Thus the fabric weights per unit area are the same and the effect of fabric construction on its thickness is cancelled out. Therefore, any changes in fabric thickness are assigned to the difference in bulk between the bulked and unbulked yarns. Theoretically this method is superior to any other so far used, nevertheless it involves a considerable amount of material, experimental work and calculation, and as such would not be of great practical utility.

3.64 Fabric Bulk and Air Permeability

The measurement of air permeability of fabrics produced from false twist crimped and Textralised nylon yarns knitted at various stitch cam settings was carried out to determine whether this test could be used as a simple means of estimating fabric bulk.

The air permeability (P_a) of a fabric is expressed as the rate of flow (cubic centimeters per second) of air (65% r.h. and 70°F) through a unit area (one square centimeter) of the fabric under a pressure differential (equivalent to a one centimeter head of water). With the instrument used in the present work to measure air permeability of fabrics, it was not always possible to obtain air permeability (P_a) at a pressure drop across the fabric of 1 cm head of water without incorporating more flow meters in the instrument. Therefore, to ascertain the relationship between the flow in c.c./cm^2/sec (F) and the pressure drop in centimeters of water (Δp) so that tests could be performed at values of Δp lower than 1 cm of water and yet be able to extrapolate to the required value of 1 cm, the rate of flow was measured on fabrics under consideration at values of Δp up to the range to which it was possible to record flow.

In Figures (61) and (62) the rate of flow (F) is plotted against pressure drop (Δp) for fabrics produced from yarns FT1, TX1 and FT2, TX2 respectively. In each figure the data plotted for fabrics from false twist crimped yarns represents the flow values for fabrics of the same measured stitch lengths as for fabrics from Textralized yarns. The flow values for fabrics from false twist crimped yarns were obtained from separate plots of F against ℓ, (loop length), at various values of Δp. Thus the flow characteristics as demonstrated in Figures (61) and (62) for fabrics from false twist crimped and Textralised yarns are directly comparable. It will be noted from these figures that whereas the relation between F and Δp is linear for wet treated and dry tumbled fabrics within the range of Δp considered here, this is not true for fabrics in their greige and steam relaxed states. It is not, however, intended here to attempt a complete account or explanation of the relation between flow and pressure drop. The maximum resistance to air flow for any given pressure drop is offered by the dry tumbled fabrics and the minimum by steam relaxed fabrics. This is due to the greater collapse of the fabric in its dry tumbled state. The greige and steam relaxed fabrics, in addition to their openness, are more easily deformed and hence allow more air to pass through, the difference

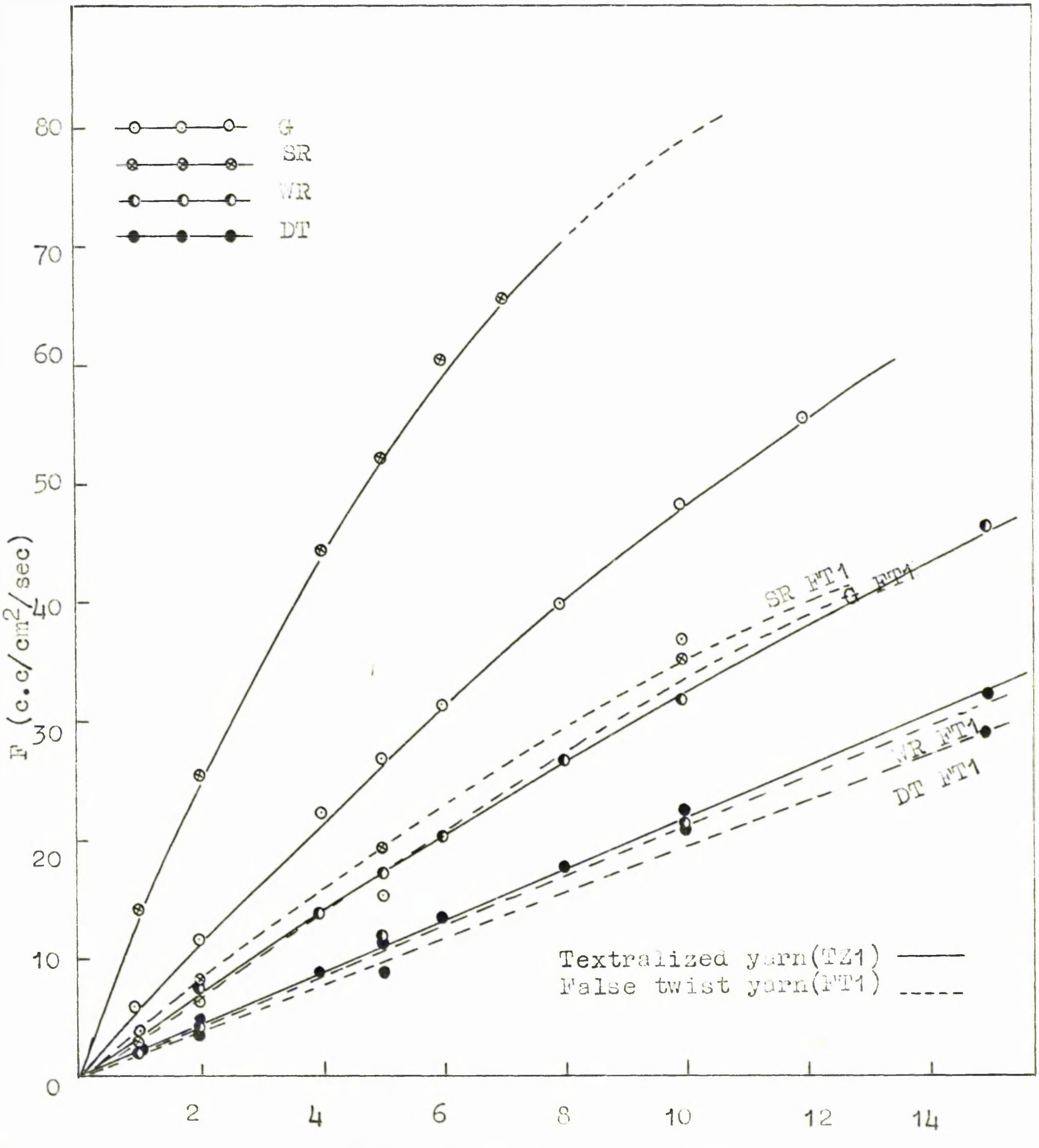


Fig.61. .elation between pressure drop (Δp) and .ir flow(F) of fabrics knitted fro. false twist crimped and Textralized yarns.

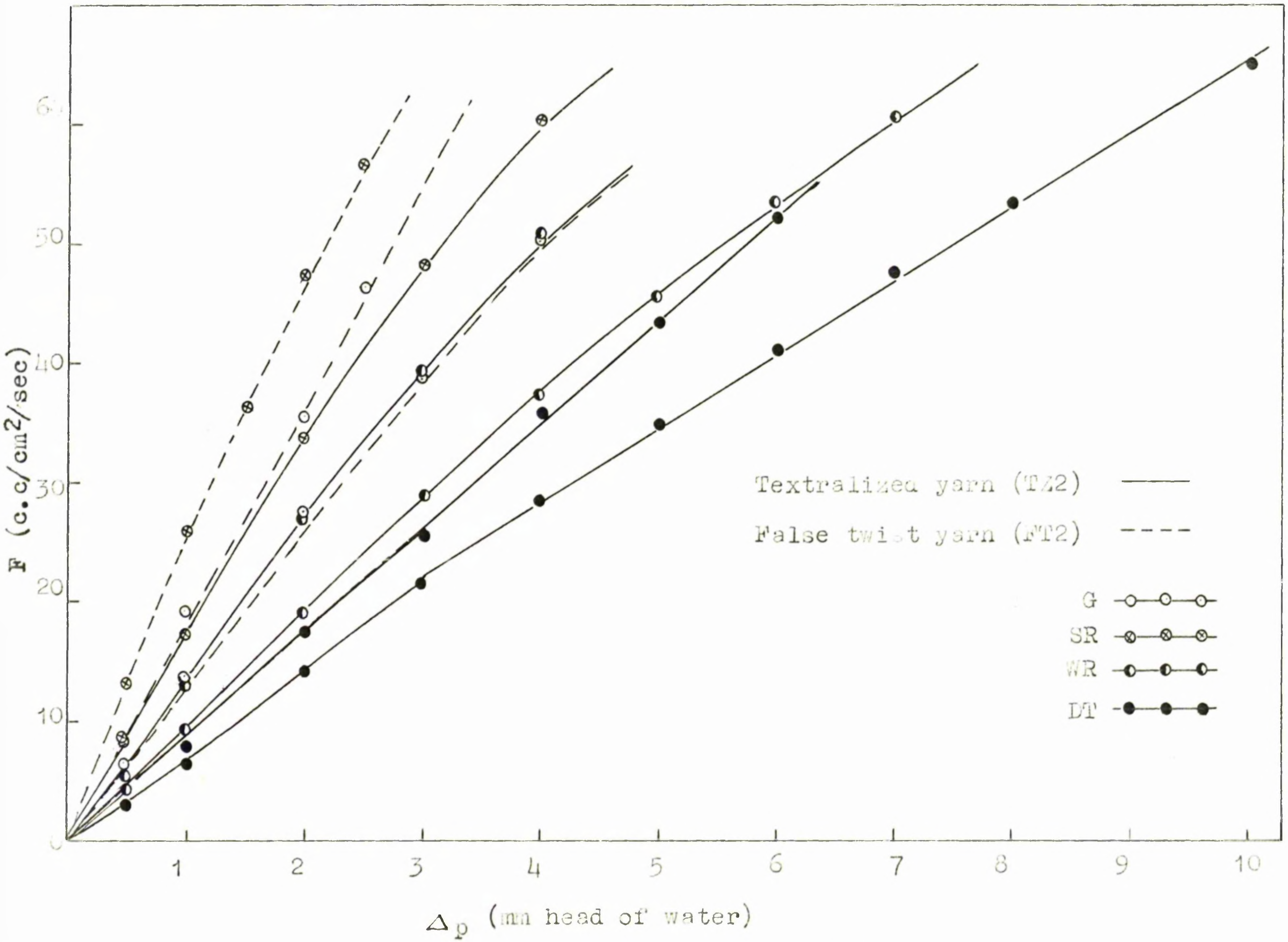


Fig.62. Relation between pressure drop(Δp) and air flow(F) of fabrics knitted from false twist crimped and Textralized yarns.

in air flow increasing with an increase in pressure drop across the fabric. It may also be stated that the standard deviations calculated from sets of ten readings were found to be high for greige and steam relaxed fabrics when compared with those of wet treated and dry tumbled fabrics. This reflects the greater variability of the fabrics in their greige and steam relaxed states. Furthermore, the standard deviations increased with an increase in pressure drop.

The test of air permeability of plain knitted fabrics from bulked nylon was performed by Maxwell et al.[100] for comparison with cotton and wool fabrics and they found that at low pressure differentials, the bulked-nylon fabric was the least permeable. At high pressure differentials a large increase in air flow resulted, which was ascribed to the greater distortions of bulked-nylon fabric and opening of their interstices.

It will also be observed from Figures (61) and (62) that whereas fabric produced from false twist yarn FT1 in any of its four states is more resistant to air flow at any given pressure drop when compared with corresponding fabric from Textralised yarn TX1 (Fig.61), this trend is reversed for fabrics from yarns FT2 and TX2 (Fig.62).

In order to demonstrate the relation between fabric air permeability and fabric bulk, the data are plotted in Figures (63-66). Fabric bulk was measured as already indicated in the previous section. Since air permeability (P_a) of fabrics from

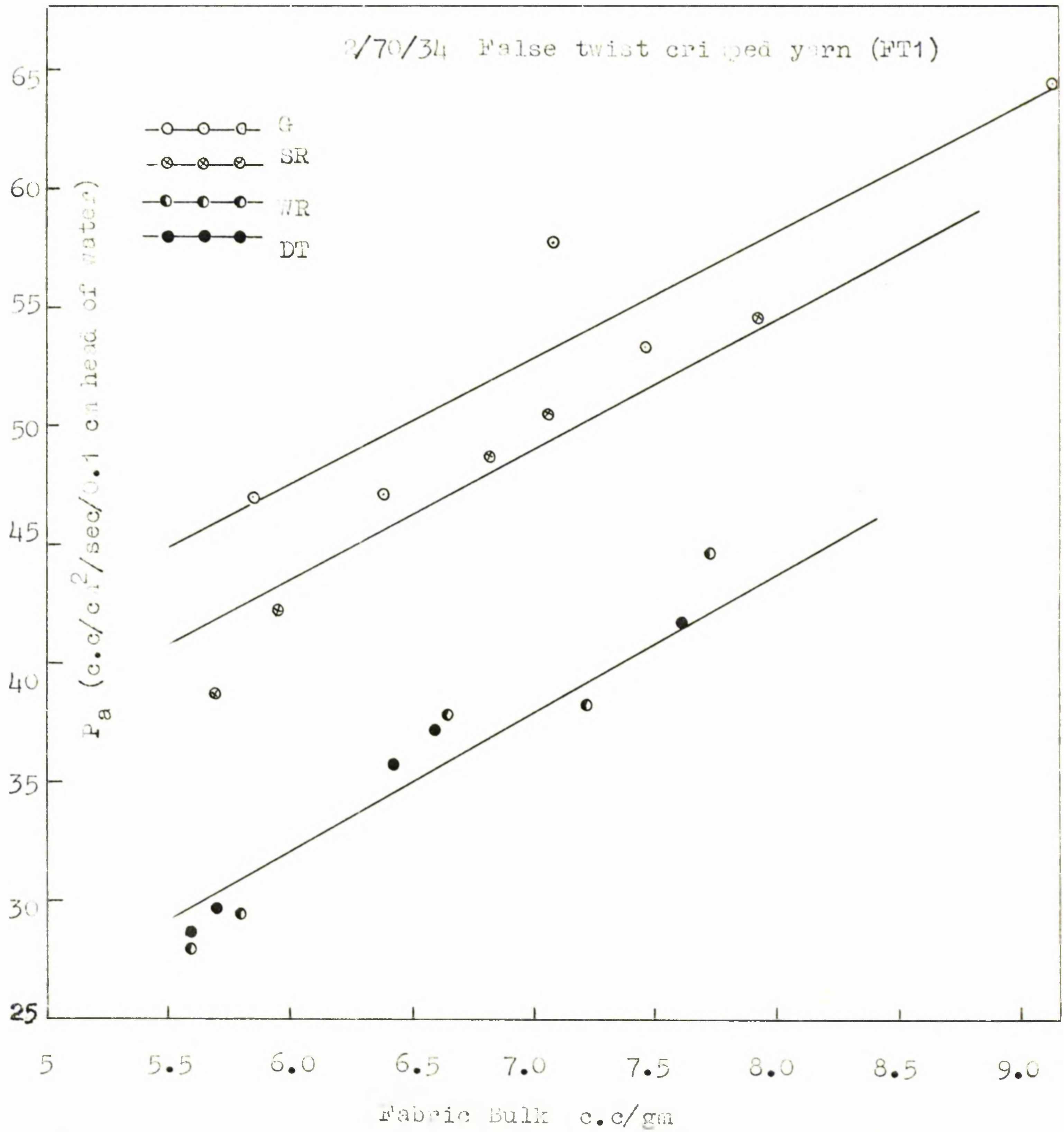


Fig.63. Relation between fabric bulk and air permeability(Pa) for the fabric in its greige and relaxed states.

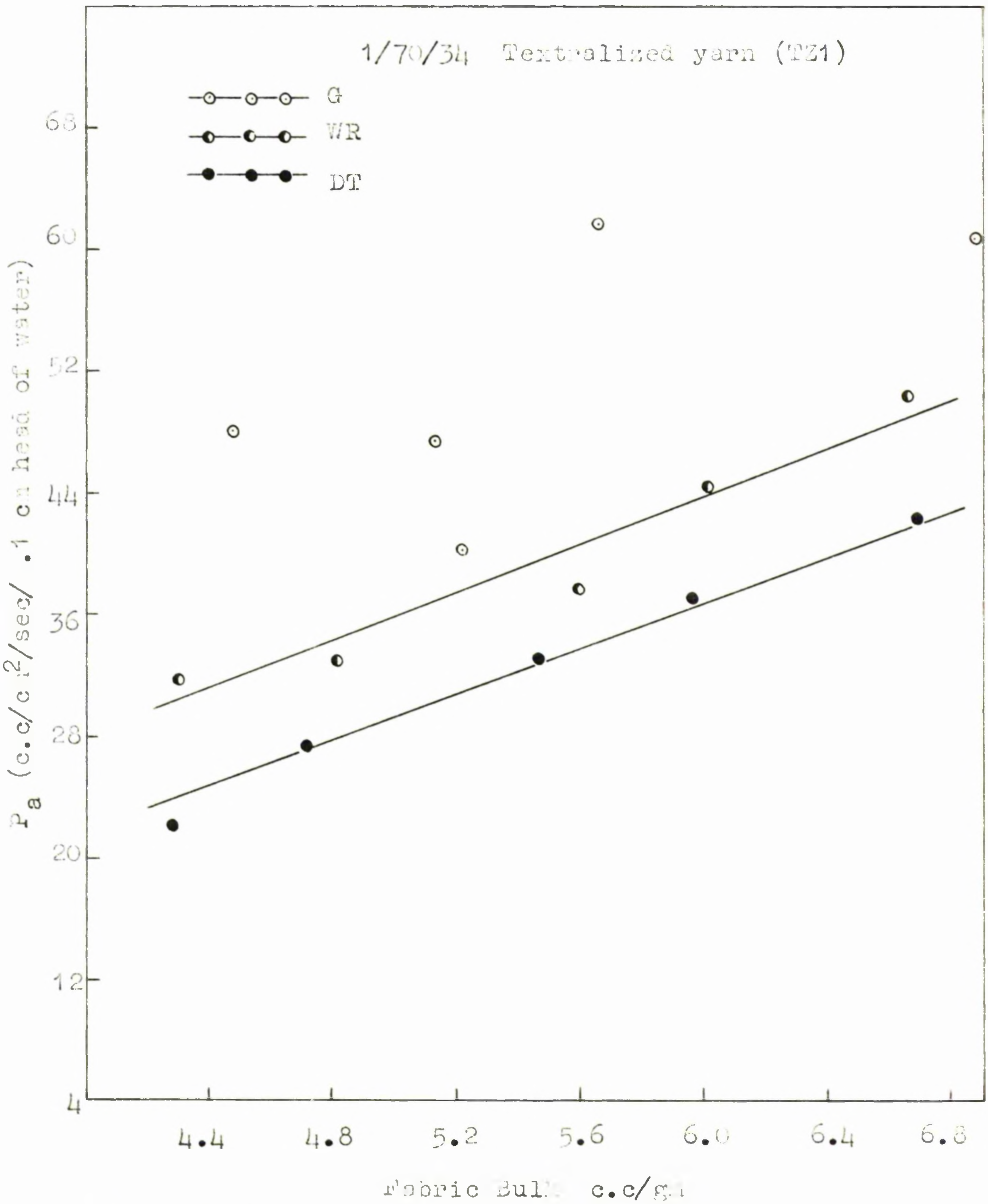


Fig. 64. Relation between fabric bulk and air permeability(Pa) for fabric in its greige and relaxed states.

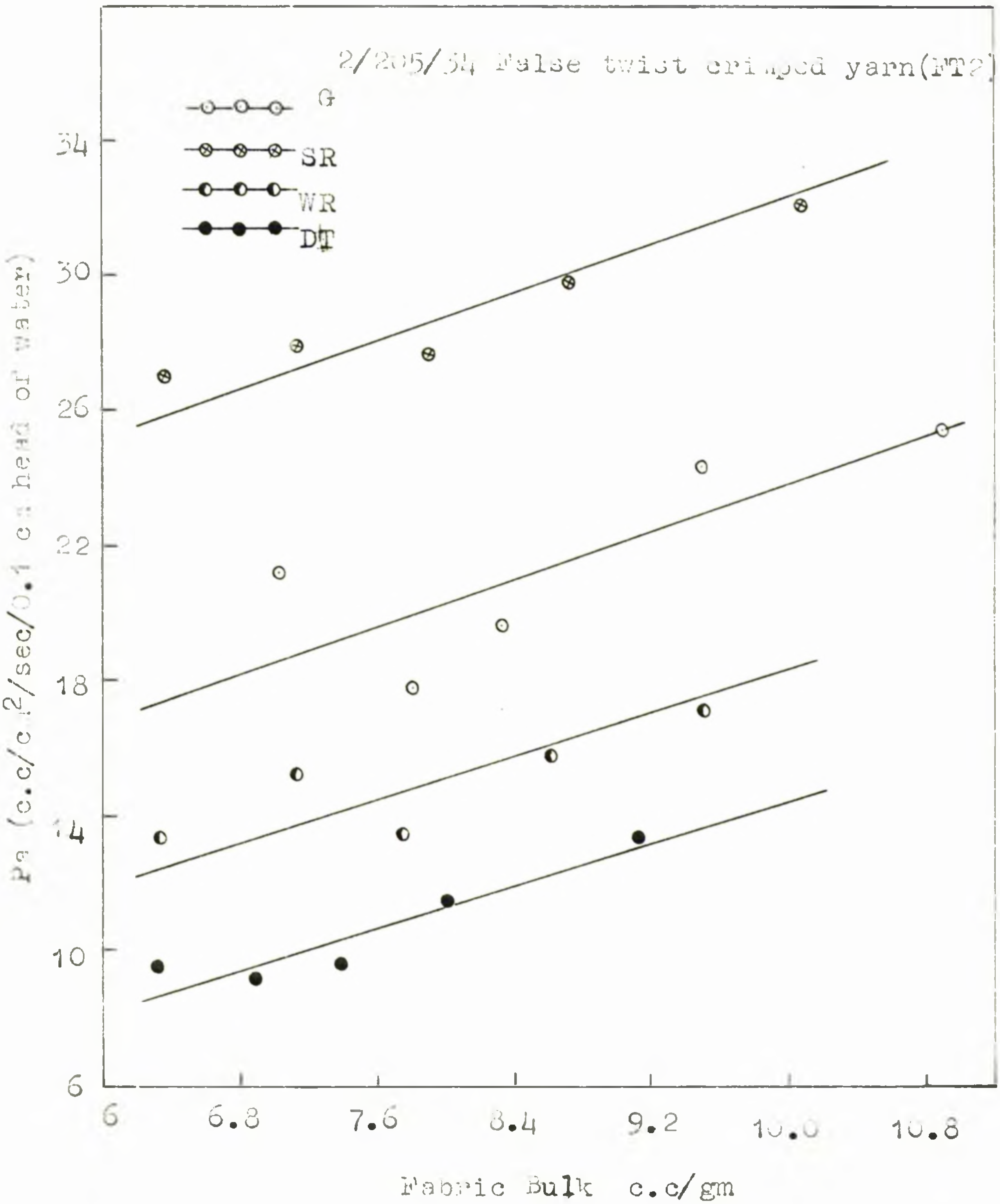


Fig.65. Relation between fabric bulk and air permeability for the fabric in its greige and relaxed states. (Pa)

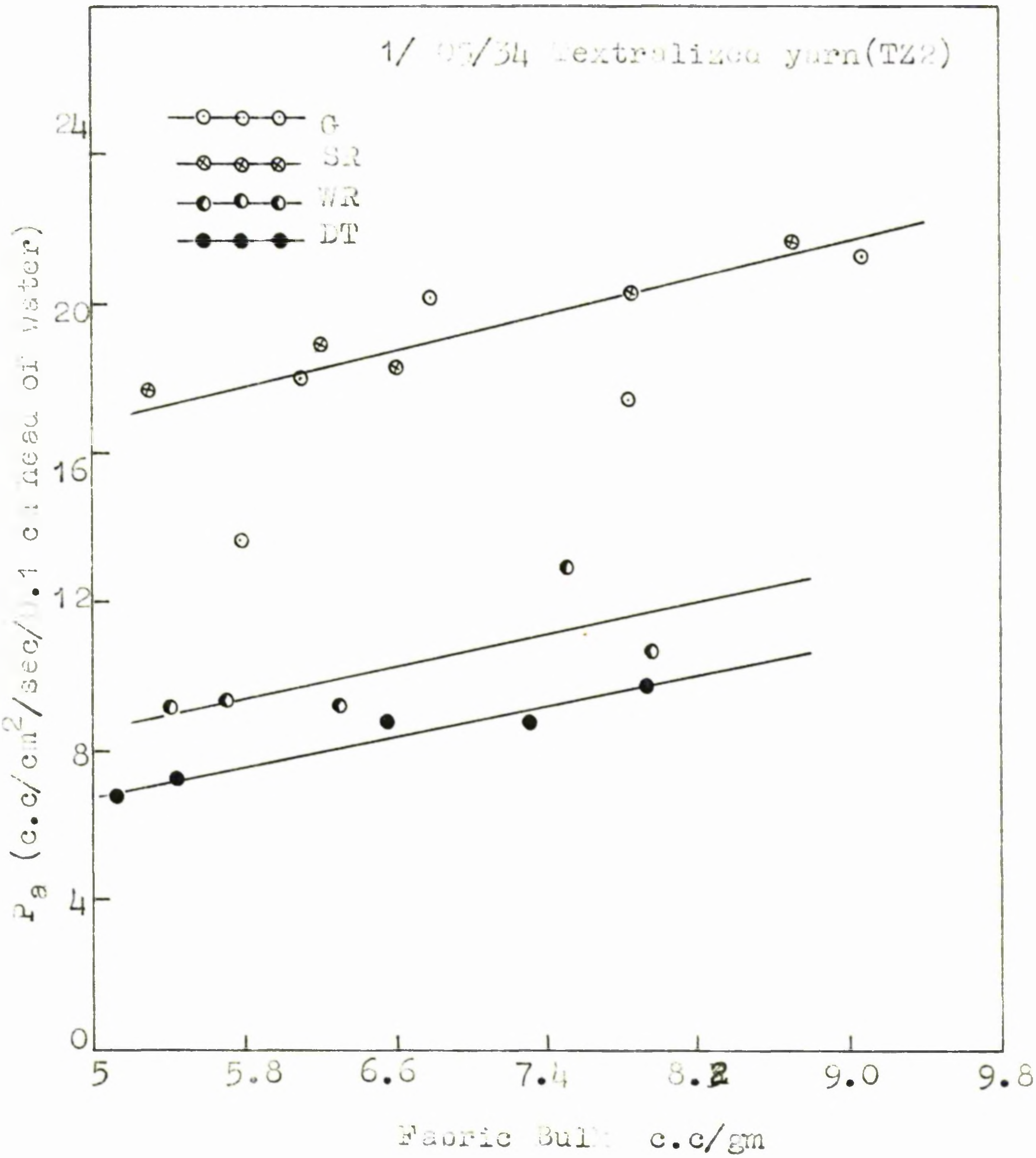


Fig.66. Relation between fabric bulk and air permeability (P_a) for fabric in its greige and relaxed states.

yarns FT2 and TZ2 could not be measured at 1 cm head of water, the values plotted are for 0.1 cm head of water and the fact that air permeability values for fabrics knitted from yarns FT1 and TZ1 (using an appropriate number of ends to give the resultant yarn denier, the same as that for yarns FT2 and TZ2) could be obtained at 1 cm head of water indicates that fabrics produced from lower denier filament yarns and therefore of a greater number of filaments, are less permeable. It will be seen from Figures (63-66) that the air permeability increases with an increase in fabric bulk as would be expected and that the increase is linear within the range of fabric bulk considered here. The slopes of the lines for a given fabric in its various states appear to be similar which implies that for a given increment in fabric bulk, the amount of increase in air permeability would be similar for those fabric states.

For a given fabric bulk the amount of air flow varies according to the particular state of the fabric. Thus when a group of fabrics which may vary in their constructional and processing details are tested for air permeability and different values of F_a are obtained, it does not seem possible to grade those fabrics according to their fabric bulk by air permeability methods alone. In this respect the air permeability test does not appear to be promising but when a given fabric is finished by different treatments, it might be possible to indicate its bulk characteristics by air permeability tests, the lower the permeability of the fabric, the greater the fabric bulk, and use the air permeability factor as a method of size prediction in fabric and garment manufacture.

TABLE 4(a)

(Crimp rigidity values for Textralized yarns)

Code No.	Yarn denier	Crimp rigidity, %
T_1	1/70/20	13
T_2	1/70/34	10
T_3	1/100/34	12
T_4	1/140/68	11
T_5	1/150/30	16
T_6	1/205/34	16

TABLE 4(b)

(Crimp rigidity values for false twist crimped nylon yarns)

Code No.	Yarn denier	Crimp rigidity, %
F_1	2/70/34	20.0
F_2	2/70/34	31.8
F_3	2/70/20	12.8
F_4	2/70/20	23.5
F_5	2/70/20	27.6
F_6	2/100/34	12.0
F_7	2/100/34	19.8
F_8	2/100/34	30.8

TABLE 5(a)

(Yarns pre-relaxed by wet treatment at 45°C)

Code No.	Yarn denier	Yarn collapse, %	Yarn crimp rigidity, %	Yarn shrinkage, %
T_1	1/70/20	41.4	26.9	0
T_2	1/70/34	41.1	26.1	0.13ø
T_3	1/100/34	38.7	25.9	0.3ø
T_4	1/140/68	33.9	22.8	0.5
T_5	1/150/30	34.6	28.1	0.3
T_6	1/205/34	37.8	25.0	0.27
F_3	2/70/20	60.5	58.8	0.47
F_4	"	82.8	66.3	1.077
F_5	"	84.8	70.2	0.77
F_6	2/100/34	60.4	36.4	0.37
F_7	"	72.9	59.5	0.85
F_8	"	79.8	68.6	0.67

ø indicates an increase in yarn length

TABLE 5(b)

(Yarns pre-relaxed by dry-heat treatment at 90°C)

Code No.	Yarn denier	Yarn collapse, %	Yarn crimp rigidity, %	Yarn shrinkage, %
T_1	1/70/20	44.9	25.7	0.95ǿ
T_2	1/70/34	30.8	18.0	0.60
T_3	1/100/34	32.5	17.4	0.67ǿ
T_4	1/140/68	24.5	17.1	0.25ǿ
T_5	1/150/50	29.9	17.8	0.07ǿ
T_6	1/205/34	29.0	21.1	0.1
F_3	2/70/20	61.0	34.7	0
F_4	"	85.1	63.3	0.17
F_5	"	85.0	66.8	0.20
F_6	2/100/34	52.9	28.4	0.10
F_7	"	75.3	54.6	0.13
F_8	"	84.3	63.2	0.13

ǿ indicates an increase in yarn length.

TABLE 5(c)

(Yarns pre-relaxed in steam on a Hoffman press bed at about 105°C)

Code No.	Yarn denier	Yarn bulking, %	Yarn crimp rigidity, %	Yarn shrinkage, %
T_1	1/70/30	34.1	25.1	0.25[d]
T_2	1/70/34	28.9	26.1	0.67
T_3	1/100/34	30.3	22.0	0.07
T_4	1/140/68	26.1	18.4	0.33
T_5	1/150/68	29.0	21.0	0.07[d]
T_6	1/200/34	33.1	24.4	0.33
R_3	2/70/30	40.7	27.0	0
R_4	"	60.6	43.0	3.07
R_5	"	71.3	56.2	2.33
R_6	2/100/34	47.7	34.2	0.67
R_7	"	59.7	40.5	2.33
R_8	"	76.7	56.1	1.33

d Indicates an increase in yarn length.

TABLE 6

(Using differing number of ends of 1/70/20 Textralized yarn (Z_1))

Yarn denier	Fabric state	t	w	S	1000 ℓ	Change in fabric length, % (decrease)	Change in fabric width, % (decrease)	Change in fabric area, % (decrease)	Fabric thickness inches x 10^{-3}
140	Greige	21.7	27.5	600	250	25.0	8.3 ø	18.3	-
"	SR	24.0	26.6	659	249	28.1	10.4 ø	29.5	-
"	WR	27.9	24.2	675	253	45.8	32.5 ø	32.5	-
"	DT	27.6	28.0	772	246	41.7	6.0 ø	38.5	-
210	Greige	21.5	30.4	654	239	19.8	4.2 ø	16.4	52.4
"	SR	23.5	29.5	695	243	28.1	10.4 ø	20.5	52.6
"	WR	27.2	26.8	729	236	38.5	21.9 ø	25	56.5
"	DT	27.6	28.2	778	238	40.6	12.5 ø	33.2	64.2
280	Greige	22.1	31.3	689	234	19.8	3.1 ø	17.2	60.4
"	SR	22.0	31.0	682	236	19.8	7.3 ø	13.9	59.6
"	WR	27.9	29.5	711	233	36.5	28.1 ø	18.6	60.6
"	DT	27.0	28.0	756	237	36.5	15.6 ø	26.7	67.0
420	Greige	23.0	29.4	676	224	7.3	0	7.2	66.1
"	SR	24.0	30.0	720	224	14.6	6.25 ø	9.2	62.4
"	WR	28.2	26.9	760	223	26.0	10.4 ø	18.5	60.1
"	DT	28.1	28.1	790	221	28.2	9.4 ø	21.7	73.0
560	Greige	25.3	27.9	704	218	5.2	5.2	10.3	68.3
"	SR	24.8	28.0	694	215	22.5	10.4	21.7	71.8
"	WR	29.0	27.5	792	215	17.7	0	17.8	69.0
"	DT	30.0	29.0	670	213	18.8	5.1	21.2	73.3

ø indicates an increase in fabric width.

TABLE 7

(Using differing numbers of ends of 1/70/34 Textralised yarn (T_2))

No. of ends	Yarn denier	Fabric state	c	w	S	1000 l	Change in fabric length % (decrease)	Change in fabric width % (decrease)	Change in fabric area % (decrease)	Fabric thickness inches $\times 10^{-3}$
[illegible]	140	Greige	23.2	26.7	610	245	32.5	15.0	18.3	-
	"	SR	19.0	24.6	666	243	29.1	25.0	11.4	-
	"	WR	18.9	22.8	601	243	47.0	45.0	22.5	-
	"	DT	28.8	28.0	506	241	40.6	8.5	34.4	-
[illegible]	210	Greige	21.8	30.7	669	233	21.9	4.2	18.6	49.7
	"	SR	22.2	28.5	633	231	20.8	11.5	11.7	42.9
	"	WR	27.7	25.3	646	237	39.6	45.[illegible]	13.1	49.6
	"	DT	28.1	28.1	790	235	38.5	14.6	29.5	56.0
[illegible]	280	Greige	22.5	30.6	689	231	20.8	0.1	19.2	57.0
	"	SR	22.2	30.7	602	225	17.7	6.5	12.5	52.5
	"	WR	26.8	24.1	646	231	35.4	30.2	15.8	57.2
	"	DT	18.3	18.0	792	229	37.5	13.6	28.9	65.2
[illegible]	350	Greige	[illegible]4.0	33.8	763	218	15.6	4.2	19.2	57.9
	"	SR	[illegible]2.4	30.9	698	217	11.5	1.1	12.8	54.1
	"	WR	28.1	27.4	770	218	28.1	14.6	17.5	59.7
	"	DT	[illegible]0.0	28.0	860	219	33.5	8.5	27.7	67.2
[illegible]	420	Greige	[illegible]9.0	31.2	774	215	12.5	5.2	16.9	61.3
	"	SR	[illegible]3.6	30.8	727	214	14.6	5.2	21.7	57.9
	"	WR	[illegible]9.0	27.8	606	216	25.0	5.2	21.1	62.5
	"	DT	[illegible]0.0	28.2	876	211	27.1	3.1	29.8	69.2
[illegible]	490	Greige	[illegible]5.4	30.5	775	211	9.4	10.4	16.1	60.9
	"	SR	[illegible]5.6	30.0	760	203	6.3	16.6	21.9	64.4
	"	WR	[illegible]0.4	27.7	642	204	20.8	5.2	25.0	64.6
	"	DT	[illegible]0.2	28.4	690	209	21.9	6.3	27.0	68.4

TABLE 8.

(Using differing numbers of ends of 1/100/34 Textralised Yarn (T_3)).

No. of ends	Yarn denier.	Fabric state	c	w	S	1000ℓ	Change in fabric length, % (decrease)	Change in fabric width, % (decrease)	Change in fabric area, % (decrease)	Fabric thickness $\times 10^{-3}$
2	200	Greige	22.9	28.4	630	249	29.2	10.4ø	21.7	53.5
	"	SR	22.8	26.4	602	248	28.0	19.6ø	13.9	49.7
	"	WR	26.6	25.4	676	249	40.6	28.2ø	22.5	54.5
	"	DT	27.3	27.2	743	250	38.5	25.6ø	28.9	61.4
3	300	Greige	22.3	30.3	676	241	21.5	7.3ø	16.1	60.4
	"	SR	21.6	29.5	637	236	18.8	8.3ø	11.9	56.7
	"	WR	26.0	26.6	692	237	33.3	18.8ø	20.8	60.7
	"	DT	27.6	27.9	770	235	37.5	15.6ø	27.8	69.0
4	400	Greige	22.9	30.2	692	236	18.8	3.1ø	16.1	65.9
	"	SR	22.2	31.3	694	233	14.6	0	14.4	61.3
	"	WR	25.2	27.1	683	236	28.1	15.6ø	17.0	63.5
	"	DT	27.0	28.0	756	232	31.3	8.3ø	25.6	73.1
5	500	Greige	23.4	29.4	688	229	11.5	6.3	17.5	66.4
	"	SR	24.0	28.4	682	221	11.4	6.3	17.5	65.0
	"	WR	26.7	28.0	748	223	21.9	8.3	28.4	68.1
	"	DT	28.0	27.6	773	225	26.0	3.1	28.6	74.0
6	600	Greige	24.3	27.8	676	226	6.3	11.5	18.9	69.3
	"	SR	24.4	28.0	683	216	7.3	12.5	18.9	66.6
	"	WR	26.9	27.1	729	224	17.7	8.3	24.7	69.3
	"	DT	28.8	28.0	806	219	21.9	14.6	33.4	76.2
7	700	Greige	26.0	26.0	676	217	3.1	17.7	20.6	68.5
	"	SR	26.0	26.4	686	209	4.2	14.6	18.1	67.4
	"	WR	27.6	27.0	745	212	8.3	14.6	21.6	70.8
	"	DT	29.0	27.0	783	216	14.6	17.7	30.0	75.5

ø indicates an increase in fabric width.

TABLE 9.

(Using differing numbers of ends of 1/140/68 Textralised yarn (T_4)).

No. of ends	Yarn denier	Fabric state	c	w	S	1000ℓ	Change in fabric length, % (decrease)	Change in fabric width, % (decrease)	Change in fabric area, % (decrease)	Fabric thickness inches x 10^{-3}
2	200	Greige	21.8	28.2	615	255	17.8	5.2ø	13.6	61.0
		SR	21.5	26.2	558	247	19.8	14.6ø	6.9	47.9
		WR	26.3	22.8	600	254	35.4	27.1ø	15.2	60.3
		DT	27.2	26.9	732	251	38.5	15.6ø	27.7	69.0
3	420	Greige	22.2	29.0	644	242	17.7	31.1ø	15.0	69.0
		SR	21.1	29.0	612	243	14.6	4.2ø	11.1	64.8
		WR	26.8	26.0	697	242	29.2	15.6ø	18.1	70.6
		DT	26.8	27.2	729	242	34.4	9.4ø	28.4	78.6
4	560	Greige	23.6	26.1	616	239	14.6	11.4	24.4	74.0
		SR	23.2	26.8	622	238	14.6	11.4	24.4	72.6
		WR	26.4	24.3	641	238	25.0	8.3	31.1	70.6
		DT	27.0	27.0	739	236	27.1	11.4	35.2	80.9

ø indicates an increase in fabric width.

TABLE 10.

(Using differing numbers of ends of 1/150/50 Textralized yarn (T_5)).

No. of ends	Yarn denier	Fabric state	c	w	S	1000 ℓ	Change in fabric length, % (decrease)	Change in fabric width, % (decrease)	Change in fabric area, % (decrease)	Fabric thickness inches x 10^{-3}
2	200	Greige	20.3	26.2	575	261	25.0	2.1 ø	23.3	66.8
		BR	21.0	27.7	582	259	24.0	4.2 ø	20.8	64.6
		WR	26.4	25.9	684	258	39.5	16.7 ø	29.5	67.8
		DT	27.1	26.8	726	261	42.7	4.2 ø	40.3	76.8
3	450	Greige	22.1	28.2	625	241	16.7	1.0 ø	15.8	74.1
		BR	21.8	28.8	628	244	12.5	2.1 ø	10.6	71.6
		WR	25.6	26.2	671	240	25.0	11.5 ø	16.4	70.8
		DT	27.0	27.0	729	240	33.0	3.1 ø	31.1	80.4
4	600	Greige	23.9	24.6	588	241	13.5	14.6	26.1	77.4
		BR	23.6	25.4	599	241	11.4	13.5	23.3	75.0
		WR	25.6	25.0	640	240	20.8	15.8	33.0	81.9
		DT								

ø indicates an increase in fabric width.

TABLE 11.

(Using differing numbers of ends of 1/205/34 Textralized yarn (T_6)).

No. of ends	Yarn denier	Fabric state	c	w	s	1000ℓ	Change in fabric length, % (decrease)	Change in fabric width, % (decrease)	Change in fabric area, % (decrease)	Fabric thickness inches X 10^{-3}
2	410	Greige	19.4	27.5	534	260	18.8	3.1ø	16.1	75.1
		SR	19.9	27.8	553	259	20.0	5.2ø	17.5	72.6
		WR	24.4	24.5	598	258	38.5	11.5ø	32.3	74.6
		DT	24.7	26.3	650	254	37.5	9.4ø	25.0	84.1
3	615	Greige	21.0	26.0	546	249	15.5	2.1	15.3	81.3
		SR	20.2	26.5	535	251	12.5	3.1ø	15.3	75.9
		WR	24.0	25.1	602	250	25.0	4.2ø	22.0	82.2
		DT	25.0	26.0	650	249	29.2	4.2	32.2	89.5
4	820	Greige	22.5	24.0	540	247	10.4	10.4	19.7	85.9
		SR	22.1	24.8	548	246	8.3	12.5	19.7	82.2
		WR	24.2	24.0	581	247	15.6	12.5	26.4	86.1
		DT	24.2	24.2	605	245	16.7	16.7	30.5	90.7
6	1230	Greige	27.0	18.0	502	236	4.2	2.1ø	1.8	91.3
		SR	27.6	18.0	524	238	4.2	0	4.2	88.6
		WR	27.0	20.6	556	238	14.6	0	14.5	91.7
		DT	27.0	22.0	594	234	17.7	0	17.8	94.1
7	1435	Greige	29.0	18.0	522	242	2.1	2.1ø	0	96.7
		SR	29.0	18.0	522	238	4.2	1.0ø	3.3	92.9
		WR	29.0	18.4	532	236	8.3	2.1ø	6.4	94.6
		DT	29.0	20.0	560	238	14.6	4.2ø	7.1	95.3
8	1640	Greige	30.0	18.0	540	236	1.0	1.0ø	0	104.0
		SR	30.0	18.0	540	234	2.1	1.0ø	1.4	96.0
		WR	31.0	19.0	588	240	7.3	2.1ø	5.3	104.0
		DT	21.0	20.0	620	237	12.5	4.2ø	8.7	105.0

ø indicates an increase in fabric width.

TABLE 12.

(Using differing numbers of ends of 2/70/34 false twist crimped yarn (F_1), C.R. 20%).

No. of ends	Yarn denier	Fabric state	c	w	S	1000 l	Change in fabric length, % (Decrease)	Change in fabric width, % (Decrease)	Change in fabric area, % (Decrease)	Fabric thickness inches $\times 10^{-3}$
2	280	Greige	21.6	29.6	639	234	16.6	1.0ϕ	16.1	56.7
		SR	23.6	29.5	698	231	22.9	0.	22.8	56.2
		WR	27.9	27.8	775	235	37.5	5.4ϕ	34.2	61.9
		DT	30.0	28.0	840	242	39.6	2.1	40.8	68.7
3	420	Greige	22.8	28.2	643	232	15.8	0	15.3	65.6
		SR	23.4	29.1	680	227	17.7	3.2ϕ	20.6	61.9
		WR	27.6	26.4	728	230	32.3	6.3ϕ	26.7	67.3
		DT	29.0	27.0	783	230	35.4	4.2ϕ	32.8	74.4
4	560	Greige	23.1	27.4	635	237	12.5	8.3	19.2	70.0
		SR	23.8	27.8	660	229	15.6	8.3	22.8	66.
		WR	27.9	25.9	720	232	28.1	1.0	28.9	72.7
		DT	28.0	26.0	728	331	29.2	8.3	34.7	79.5
5	700	Greige	24.3	26.0	632	232	11.5	8.3	19.2	73.4
		SR	24.7	26.0	643	229	10.4	7.3	17.2	69.7
		WR	27.8	24.4	680	231	26.0	6.3	32.3	73.7
		DT	28.0	25.0	700	231	25.0	12.5	34.5	79.5

ϕ indicates an increase in fabric width.

TABLE 13.

(Using differing numbers of ends of 2/70/34 false twist crimped yarn (T_2), C. F. 31.8%)

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No. of ends	Yarn denier	Fabric state	c	w	S	1000 l	Change in fabric length, % (decrease)	Change in fabric width, % (decrease)	Change in fabric area, % (decrease)	Fabric thickness inches 10^{-3}
2	280	Greige	22.2	28.5	630	243	20.8	5.4	25.0	61.9
		SR	24.9	29.3	750	236	30.2	7.6	35.4	62.8
		WR	28.5	28.8	815	235	38.5	6.3	42.5	62.9
		DT	29.0	28.4	824	238	39.6	8.3	44.8	67.0
3	420	Greige	25.5	25.5	615	235	14.6	12.5	25.3	65.6
		SR	25.5	27.0	675	228	24.0	16.7	36.6	65.9
		WR	28.9	27.6	796	223	31.2	19.8	45.0	66.3
		DT	30.0	27.0	810	224	33.4	17.7	45.5	74.2
4	560	Greige	25.0	24.6	618	227	12.5	12.5	23.6	69.6
		SR	25.1	24.6	670	230	19.8	18.7	34.8	70.5
		WR	28.6	24.2	750	225	25.0	17.7	38.6	72.4
		DT	29.0	26.0	755	226	29.2	14.1	42.5	77.3
5	700	Greige	26.0	24.0	625	226	8.3	13.6	20.6	73.0
		SR	26.4	23.3	612	228	15.3	15.3	28.9	71.9
		WR	28.0	25.0	728	225	16.7	15.3	30.0	75.6
		DT	29.0	25.0	725	222	21.8	16.7	35.0	78.6

TABLE 14.

(Using differing numbers of ends of 2/70/20 false twist crimped yarn (F_3), C.R. 12.8%)

- - - -

No. of ends	Yarn denier	Fabric state	c	w	S	1000 ℓ	Change in fabric length, % (decrease)	Change in fabric width, % (decrease)	Change in fabric area, % (decrease)	Fabric thickness inches 10^{-3}
2	280	Greige	19.2	29.8	572	259	17.8	1.0	18.6	64.3
		SR	22.1	29.7	656	241	29.2	2.1	30.5	67.7
		WR	24.4	28.0	683	255	36.5	6.3ϕ	32.5	69.3
		DT	23.9	29.1	695	258	34.4	1.0	35.1	75.1
3	420	Greige	19.3	27.5	531	259	12.5	4.2	16.1	74.1
		SR	22.6	28.0	633	251	23.0	4.2	26.2	76.9
		WR	24.9	27.6	687	251	30.2	2.1	31.6	74.4
		DT	24.0	28.0	672	254	28.6	4.2	32.2	80.6
4	560	Greige	21.5	26.7	574	249	10.4	8.3	17.8	78.7
		SR	23.4	25.9	629	224	17.7	10.4	25.5	80.3
		WR	26.1	25.8	673	222	26.1	9.4	32.8	80.4
		DT	25.0	27.1	676	223	25.0	15.6	34.8	84.1
5	700	Greige	22.8	24.6	561	245	8.3	12.5	19.7	82.4
		SR	24.0	25.0	600	244	12.5	13.5	24.5	81.2
		WR	25.0	26.0	625	259	17.7	14.6	29.7	82.4
		DT	25.0	26.0	650	240	17.7	15.6	30.6	86.2

ϕ indicates an increase in fabric width.

TABLE 15.

(Using differing numbers of ends of 2/70/20 false twist crimped yarn (F_4), C.V. 23.5%)

- - - -

No. of ends	Yarn Denier	Fabric state	c	w	S	1000 ℓ	Change in fabric length, % (dec.)	Change in fabric width, % (dec.)	Change in fabric area, % (dec.)	Fabric thickness inches x 10^{-3}
2	260	Greige	20.9	28.9	604	250	20.8	1.0ϕ	20.0	63.4
		SR	22.4	28.9	647	246	27.0	0	29.7	60.9
		WR	28.0	28.0	784	246	41.7	4.2ϕ	39.2	67.6
		DT	28.0	28.0	784	245	40.6	3.1ϕ	38.8	72.8
3	420	Greige	20.5	28.4	582	245	14.6	3.1	17.2	68.0
		SR	21.8	28.7	626	239	20.8	3.1ϕ	23.4	64.9
		WR	26.3	26.4	694	239	33.3	3.1ϕ	31.1	72.0
		DT	26.0	26.6	692	241	33.3	3.1ϕ	31.1	77.2
4	560	Greige	21.1	26.7	563	245	11.5	10.4	20.6	73.3
		SR	22.7	27.3	620	237	14.6	5.2	18.9	70.5
		WR	26.8	25.4	609	238	28.2	7.3	33.4	75.9
		DT	27.0	26.0	702	237	29.2	9.4	35.8	81.3
5	700	Greige	23.9	25.0	597	239	11.5	12.5	22.5	76.8
		SR	24.2	26.0	629	233	13.5	10.4	22.5	72.8
		WR	27.0	25.0	675	232	21.9	4.2	25.0	77.5
		DT	27.0	25.5	689	233	22.9	12.5	32.5	81.6

ϕ indicates an increase in fabric width.

TABLE 16.

(Using differing numbers of ends of 2/70/20 false twist crimped yarn (F_5), C.R. 27.6%)

No. of ends	Yarn Denier	Fabric state	c	w	S	1000 ℓ	Change in fabric length, % (dec.)	Change in fabric width, % (dec.)	Change in fabric area, % (dec.)	Fabric thickness inches 10^{-3}
2	280	Greige	20.5	28.1	576	251	27.0	2.1ø	26.7	64.1
		SR	22.6	28.6	646	247	27.0	2.1ø	26.7	63.3
		WR	28.6	26.8	766	244	43.8	6.3ø	41.4	67.6
		DT	28.0	28.0	784	250	43.8	0	43.7	73.7
3	420	Greige	21.5	28.0	602	241	17.7	5.2	21.9	69.9
		SR	22.8	28.6	652	236	20.8	1.0ø	21.7	67.1
		WR	27.0	26.0	702	232	34.4	3.1ø	32.2	72.8
		DT	27.7	27.0	748	236	37.5	0	37.5	78.6
4	560	Greige	21.6	26.7	577	244	13.5	8.3	20.8	76.3
		SR	22.1	27.4	603	239	16.7	10.4	25.3	71.3
		WR	26.9	26.2	705	234	29.0	8.3	36.1	79.0
		DT	27.0	26.0	702	239	29.0	7.3	35.3	83.0
5	700	Greige	23.1	24.8	573	240	9.4	10.4	18.9	78.1
		SR	24.0	25.3	607	234	14.6	13.5	26.2	74.1
		WR	26.9	24.3	654	233	24.0	10.4	32.0	78.8
		DT	27.0	25.0	675	233	21.9	8.3	28.3	83.6

ø indicates an increase in width.

TABLE 17.

(Using differing numbers of ends of 2/100/34 false twist crimped yarn (F_6), C.R. 125)

No. of ends	Yarn Denier	Fabric state	c	w	s	1000ℓ	Change in fabric length, % (decrease)	Change in fabric width, % (decrease)	Change in fabric area, % (decrease)	Fabric thickness inches 10^{-3}
2	400	Greige	19.9	29.4	585	251	10.4	3.1	13.3	69.6
		SR	21.6	29.0	628	243	17.7	4.2 ϕ	21.4	72.4
		WR	25.0	27.0	675	245	30.2	2.1 ϕ	28.9	74.1
		DT	25.0	28.0	700	242	28.1	1.0 ϕ	27.8	79.2
3	600	Greige	22.1	27.2	602	245	9.3	7.6	15.0	76.1
		SR	23.0	26.6	612	239	12.5	11.5	22.5	77.2
		WR	26.0	25.6	666	236	22.9	2.1	24.4	79.4
		DT	25.4	26.6	676	240	20.8	8.3	27.5	82.6
4	800	Greige	23.4	24.7	578	241	7.3	13.5	20.3	81.2
		SR	24.0	25.0	600	242	9.4	14.6	22.5	79.2
		WR	25.6	25.8	660	238	14.6	17.7	29.7	80.9
		DT	26.0	26.0	676	241	14.6	19.8	31.6	86.7
5	1000	Greige	24.9	22.6	563	238	3.2	14.6	17.2	83.7
		SR	25.0	23.0	575	238	4.2	14.6	20.8	82.3
		WR	25.5	25.3	645	234	6.3	17.7	22.7	83.3
		DT	26.3	25.0	658	237	9.4	20.8	28.0	88.7

ϕ indicates an increase in fabric width.

TABLE 10.

(Using differing numbers of ends of 2/100/34 false twist crimped yarn (P_7), C.R. 19.8%)

- - -

No. of ends	Yarn Denier	Fabric State	c	w	S	1000ℓ	Change in fabric length, % (decrease)	Change in fabric width, % (decrease)	Change in fabric area, % (decrease)	Fabric thickness inches x 10^{-3}
2	400	Greige	20.7	28.5	590	244	14.6	7.1 ϕ	12.8	68.5
		3R	22.4	20.2	632	237	19.6	0	19.7	65.3
		WR	26.9	26.8	721	241	35.4	8.3 ϕ	30.0	72.6
		DT	27.8	26.5	737	241	36.5	7.3 ϕ	32.0	76.6
3	600	Greige	22.4	26.9	602	241	10.4	4.2	14.2	72.5
		3R	22.9	27.1	620	235	13.5	8.3	20.8	69.5
		WR	27.5	25.7	707	233	26.0	6.3	32.2	76.7
		DT	28.0	26.0	728	230	29.2	8.3	35.0	81.2
4	800	Greige	23.4	24.4	571	240	7.3	10.4	16.9	76.9
		3R	24.0	25.0	600	233	9.4	13.5	22.0	73.8
		WR	26.0	25.0	650	237	16.7	10.4	25.2	78.0
		DT	27.3	24.8	677	232	20.8	13.5	39.1	83.7
5	1000	Greige	25.0	22.7	568	234	3.2	12.5	15.3	81.8
		3R	25.0	22.0	550	232	4.2	10.4	14.2	76.2
		WR	26.0	24.0	624	237	6.3	16.7	23.6	80.6
		DT	27.1	24.2	656	233	12.5	15.6	26.1	85.2

ϕ indicates an increase in fabric width.

TABLE 19.

(Using differing numbers of ends of 2/100/34 false twist crimped yarn (F_8), C.R. 30.8%)

- - - - -

No. of ends	Yarn Denier	Fabric State	c	w	S	1000 ℓ	Change in fabric length, % (decrease)	Change in fabric width, % (decrease)	Change in fabric area, % (Decrease)	Fabric thickness inches 10^{-3}
2	400	Greige	21.8	27.1	591	245	15.6	8.3	22.7	67.4
		BR	24.1	28.0	675	236	25.0	11.5	33.3	69.9
		WR	29.0	27.0	783	239	37.5	6.3	42.5	72.2
		DT	29.0	28.0	812	232	37.5	4.2	40.0	77.0
3	600	Greige	22.5	25.2	567	240	10.4	12.5	21.7	74.1
		BR	24.9	26.0	647	234	16.7	14.6	29.0	75.4
		WR	27.7	26.0	720	235	26.0	12.5	35.0	76.1
		DT	29.0	26.0	754	229	29.2	14.6	39.5	82.4
4	800	Greige	24.2	23.2	561	237	7.3	9.4	16.4	79.6
		BR	25.1	24.7	620	232	10.4	13.5	22.5	77.6
		WR	26.0	24.0	624	233	12.5	16.7	27.2	82.3
		DT	28.0	24.7	692	229	17.7	16.7	31.5	85.0
5	1000	Greige	25.0	20.7	518	236	3.2	8.3	11.1	82.8
		BR	26.0	22.0	572	234	6.3	12.5	17.8	79.4
		WR	26.6	23.4	622	230	8.3	18.8	25.5	80.3
		DT	27.6	24.0	662	228	28.2	18.8	41.5	86.7

TABLE 2[illegible].

(Stitch density constants and intercepts for 1 x 1 rib fabrics)

Code No.	Yarn Denier	k_{sb} Greige	k_{sb} SR	k_{sb} WR	k_{sb} DT	S_2 Greige	S_2 SR	S_2 WR	S_2 DT
FT1	2/70/34	37.5	37.5	37.5	37.5	-	50	100	100
FT2	2/205/34	29.4	29.4	30.0	33.1	25	25	100	100
TZ1	1/70/34	34.2	34.2	27.9	27.9	-	-	180	225
TZ2	1/205/34	29.5	29.5	27.9	28.0	75	75	180	140
		k_{wu}				S_1			
U1	70/34	29.5	29.5	29.5	29.5	51.7	51.7	51.7	51.7
U2	205/34	27.8	27.8	27.8	27.8	81.9	81.9	81.9	81.9

PART 2

ELASTIC RECOVERY PROPERTIES OF FABRICS PRODUCED FROM BULKED NYLON AND WOOL YARNS

INTRODUCTION AND SURVEY OF LITERATURE

C O N T E N T S

CHAPTER 4 | Page

4.1 Introduction

An important property of a knitted fabric is its ability to return to its original dimensions after extension. Thus, the amount of stretch and elastic recovery determines the suitability of knitted fabrics for specific end uses. For example, a fabric that stretches only a little is of little use for sweaters. On the other hand, one of minimum stretch requirement but possessing high recovery is desirable for gloves. Bulked yarns are incorporated in weft-knitted fabrics, for any one of, or a combination of, the following main reasons:

(a) Handle (texture), opacity, drape and lustre,

(b) Stretch and recovery, and

(c) Figure control (in conjunction with elastomeric yarns).

The property of stretch and recovery of bulked nylon is utilized in knitted articles like socks, stockings, slacks and swimwear. As stretch and recovery are of such great importance in knitted fabrics, the evaluation of these properties was thought highly desirable in the present work. The main object of this aspect of study was to determine the influence of the following factors on the elastic properties of ribbed fabrics.

(i) Effect of increase in the number of ends knitting at a single feeder.

(ii) Effect of change in denier per filament of yarn.

(iii) Effect of change in crimp rigidity of yarn.

(iv) Comparison of the elastic properties of 1x1 rib fabrics knitted from false twist crimped yarns with thos of stuffer box bulked yarn of comparable denier and crimp rigidity.

(v) Comparison of the elastic properties of 1x1 rib fabrics of stuffer box bulked yarns in the wale and coursewise direction.

(vi) Comparison of the elastic properties in the wale and coursewise direction of 1x1 rib fabrics with those of half cardigan structure both knitted from stuffer box bulked yarns.

(viii) Comparison of the elastic properties of 1x1 rib and half cardigan wool fabrics with those of bulked yarn fabrics in the wale and coursewise direction.

As all fabrics knitted from bulked yarns are subjected to a relaxation treatment the factors (i) to (vii) as previously stated were studied for fabrics in their four different states, namely, in, (i) the dry relaxed greige state, (ii) the steam relaxed state, (iii) the wet relaxed state and (iv) the dry tumbled state. The influence of these relaxation processes was studied in isolation, though it was realised that in practice, fabrics may have to undergo a combination of two or three of these processes in finishing.

With the above object in view a survey of literature was carried out but it revealed that very little data is available on the elastic performance of stretch fabrics although some work has been published on the elastic recovery of fabrics knitted from conventional yarns. Considerable work has been published on the recovery behaviour of textile fibres and yarns and though it was realised that this might not have a direct bearing on the present investigation, it was thought worthwhile to review the most important articles which have appeared in this field of work.

4.2 Survey of Literature

Meredith[101], Meillard et al.[102, 103] have furnished recovery data for a wide range of textile fibres using the repeated cycling technique. Meredith's studies were made on an autographic load-extension recorder described by Cliff[104] with a constant rate of loading. He determined the degree of elasticity or 'elastic recovery' (ratio of recoverable elongation to total elongation) of many single fibres for different loading steps along the stress-strain curve. Meillard and co-workers also used a constant rate of elongation method for a few single fibres and multifilaments.

Susich and Baker[105] stated that when fibres are stretched and then released, some of the elongation is recoverable immediately, some recovers after a period of time and some is permanent. The three components of the total elongation have been termed 'immediate elastic recovery', corresponding to perfect elasticity, 'delayed recovery' or 'primary creep' and 'permanent set' or 'secondary creep'. These components are known to contribute to some of the physical properties of fibres. For example, a high proportion of immediate elastic recovery is known to contribute to resilience [106], which according to Mark [107] and Dillon [108] is a combination of stiffness and fast recovery; to crease resistance and wrinkle recovery as shown by Gagliardi et al.[109,110]; to softness of fabrics, to fatigue and wear resistance and even to comfort.

Delayed recovery is also desirable, however to a lesser extent. Too high a value may be disadvantageous for special purposes. Delayed recovery frequently causes relaxation shrinkage in woollen fabrics creating problems in the tailoring of garments[111].

High permanent set is generally undesirable in textile fibres except perhaps in isolated instances. It is known that permanent set can be partially recovered by increasing temperature, humidity and by permutoid swelling, thus affecting dimensional stability[111].

When fibres have been extended and released, they are known to recover not only by different amount but also by different rates of speed. The recovery can therefore be characterised if differentiation is made between that which is immediate and that which is delayed. Thus the importance of relationship between recovery and time has been recognised even though no satisfactory method exists for measuring it. Leaderman[112] investigated the time factor in recovery and distinguished between 'instantaneous elastic deformation' and 'delayed deformation'. He also published some data on delayed deformation and delayed recovery for different fibres using long duration tests. Hoffman[113] discussed the influence of time and described different kinds of resilience, also indicating some possibilities for measuring the speed of recovery.

Hamburger[114,115] emphasised the necessity for determining immediate and delayed recovery separately and quantitatively. Taking advantage of the sonic-modulus technique, he used a pulse-propogation meter in connection with a Scot IP-2 constant rate of loading testing machine for measuring the deflection components. He thus determined the 'immediate elastic deflection', the 'primary creep' and the 'secondary creep' of viscose, acetate and nylon multifilament yarn on the first loading and unloading cycle and also repeated loading. Hamburger's investigation is a pioneer one in obtaining comparable data on all three elongation components as none of the earlier workers attempted this.

The reason for the differentiation between the three components of the total elongation, specially the separation of immediate and delayed recovery is mainly a practical one. It is significant to know not only to what extent, but also with what speed an imposed elongation recovers since some elongated fibres 'snap-back' whilst others 'creep-back' after the tension is released.

Susich and Baker[105] in their paper have attempted to explain the immediate elastic recovery, delayed recovery and permanent set in terms of the molecular structure of the fibres. Thus immediate elastic recovery is associated with the displacement of atoms or molecules from their positions of equilibrium and with their spontaneous or immediate return when the stretching force is removed. According to present theory, immediate elastic recovery of visco-elastic materials occurs mainly in the amorphous region. This recovery is predominant below the yield point, at low stresses or strains. Such recovery is possible when a sufficient number of strong cross-linkages are present to prevent the long chain-molecules from sliding over each other, thus facilitating the return of the deformed structure to its original arrangement. Immediate elastic recovery can also result from the folding of straightened flexible long molecular chains.

Delayed recovery is best described as a hindered elastic recovery since certain displaced molecules continue to return for some time after the release of tension. It can thus be considered as an interaction between the mechanism causing immediate elastic recovery and the process producing permanent set.

Permanent set is a result of the irreversible displacement of molecules and is associated in visco-elastic materials with one of the following processes: (1) slippage of long-chain molecules, or parts of them, along each other due to the break down of the secondary bonds; (2) alignment of linear chain molecules by tensile stress observable in X-ray diffraction patterns and also electron micrographs of high polymers; (3) stabilization of molecular rearrangement obtained during the stretching process by the formation of new cross-linkages between chain molecules, resulting in a permanent elongation which remains after releasing the force since the structural rearrangement attained represent new positions of equilibrium.

It will be noted that a certain amount of data has been published on the elastic recovery behaviour of textile fibres, both natural and synthetic, under various conditions. However, the investigation of elastic recovery of knitted fabrics of differing constructions provides a field where evaluation of these properties is of assistance in the future development of these fabrics.

Schiefer et al.[116] measured the elasticity of women's hose by determining the difference between the circumference of the stocking at a load of thirty pounds in the first cycle and the circumference at a load of ten pounds in the two-hundredth cycle of distension. Other investigators[117,118] using the same equipment expressed an estimate of the elastic properties of women's hose by the ratio of recovery load to stretch load.

For the above methods the fabric must be in the form of a stocking. Thus, when these methods are used, various construction factors pertaining to the shape of the stocking must be held constant to compare fabrics in which only one factor, such as fibre content, varies. Realising the disadvantage of this method, Hansen and Fletcher[119] devised a method for measuring elastic recovery of cotton knitted fabrics. They used a constant rate of loading incline plane serigraph type of machine designed to determine the breaking strength of yarns. A new set of wider and more substantial jaws were designed and constructed to hold the pieces of knitted material. The authors determined elastic recovery in the coursewise direction for eight knitted cotton fabrics from the cyclic stress-strain diagram. They found that the elastic recovery-strain data for these fabrics approximated straightlines. For any given stress all the knitted fabrics made of natural and mercerised carded and combed yarns exhibited a decrease in their elastic recovery with the number of loading cycles. In general, the elastic recovery was greater for fabrics knitted from mercerised cotton yarns than those knitted from unmercerised cotton yarns; also, those knitted from combed cotton yarn had greater elastic recovery than fabrics of carded cotton.

Fletcher and Gilmore[120] also used a constant rate of loading, incline plane, serigraph type of machine[119] with an automatic load-elongation recorder to study stress-strain properties of certain yarns and knitted fabrics made of rayon, nylon and natural fibres. Their study included thirteen commercial yarns and plain knit fabrics produced on a 42 gauge full-fashioned machine from these yarns and having 64 and 40 courses per inch respectively. The results showed that all yarns had considerable elastic recovery for small stresses and strains, but the majority showed rapid decreases in this characteristic with large stresses and strains applied to the yarns. Of the yarns from natural fibres, linen and cotton were the least elastic, and wool and silk the most elastic for large strains. Of the yarns from manufactured fibres, nylon was the most elastic and of all the yarns, nylon exhibited the greatest elastic recovery. From the molecular stand-point, this is understandable because nylon consists of a series of short hydrocarbon springs united by strong cross-linkages. These seem to be responsible for the high recovery and low permanent set since they prohibit significant slippage of the long chain molecules. Continuous filament acetate and spun acetate were comparable to silk and wool, whilst cuprammonium and viscose rayons were similar to linen and cotton yarns. There was only little difference in the elastic recovery of the linen and cotton yarns at small strains.

The elastic recovery of knitted fabrics, like that of yarns, decreased with an increase in the stress and strain and all fabrics stretched more in the fifth cycle than in the first cycle. Furthermore fabrics which had high recovery for large strains also had high recovery for large stresses, but this was not so for some of the yarns. Wool yarn which had much lower recovery than linen for large stresses had much greater recovery than linen for large strains. Elastic recovery-strain data for all the fabrics approximated straight lines as reported for cotton fabrics[119]. Of the fabrics from the natural fibres, linen was the least and wool was by far the most elastic. The results for cotton fabrics were generally in agreement with those of Hansen and Fletcher[119]. Both wool and silk maintained a high recovery over a wide range of strains but that for the linens and cottons decreased quite rapidly as the strain increased.

In the group of fabrics produced from the manufactured fibres, nylon, continuous filament cuprammonium rayon and spun acetate decreased the least in elastic recovery with increase in strain. In both groups, however, wool ranked the highest and linen the lowest.

Silk, wool and nylon fabrics of both 40 and 64 courses per inch decreased least in elastic recovery with an increase in strain. Combed cotton and continuous filament acetate exhibited similar elastic recovery properties whether knitted at 40 or 64 courses per inch. However, the elastic recovery of nylon, silk and continuous filament viscose was considerably less at 40 courses per inch than at 64.

In summing up the above results, it is evident that the elasticity of knitted fabric could not be predicted by measuring the elasticity of the yarns. Outstanding examples were the yarns and fabrics of silk, wool and nylon. The nylon yarn was the most elastic, but the knitted nylon fabrics were not nearly as elastic as the wool or silk.

The method employing a constant rate of load incline plane machine measured only the instantaneous or immediate elastic recovery, since in one complete stress-strain cycle there are only one or two seconds during which stress is not applied to the specimen. Also, it is not possible by this procedure to measure the stretch and elastic recovery in both wale and coursewise directions simultaneously. Since delayed recovery as well as instantaneous recovery in knit fabrics determines the suitability of these materials for specific uses, a method was developed by Fletcher et al.[121]. They designed an apparatus in which the loads were manually applied. The fabric was laid horizontally on pins set in moveable segments so that the measurements of elastic recovery could be made in either wale or coursewise direction, or in both directions simultaneously when loads were applied. Using this apparatus they evaluated the elastic recovery in the coursewise direction for four plain knit fabrics knitted with 32 courses per inch from mercerised cotton, continuous filament nylon, viscose rayon and wool yarns. These recovery measurements represented the combined immediate and delayed recovery, the results being then compared with those obtained by using an incline plane machine. The instantaneous recovery as measured by the incline plane machine was considerably less than the recovery measured with new apparatus revealing the influence of a time factor. For a strain of 70 per cent. the instantaneous recoveries for the cotton, nylon, rayon and wool fabrics studied were 26, 19, 26, and 48 per cent. respectively, whereas the combined instantaneous and delayed recoveries were 58, 59, 55, and 80 per cent respectively. For cotton and rayon fabrics the delayed recovery was approximately equal to the instantaneous recovery. However, the delayed recovery of nylon fabric was twice that of the instantaneous recovery, but for wool, the instantaneous recovery was one and one-half times that of the delayed recovery.

Fletcher and Graham[122] employed the manual apparatus[121] described to study the recovery properties of plain knit and 1x1 rib cotton fabrics in both wale and coursewise directions. They also studied the effect of finishing (before and after laundering) on the recovery behaviour of these fabrics. Elastic recovery values for 60 per cent. strain ranged from 73 to 80 per cent. for the plain and rib knit fabrics in the coursewise direction. In the wale direction the maximum strains attained for these rib and plain knit fabrics were 17 and 22 per cent. respectively and their elastic recoveries decreased quite rapidly with an increase of strain. The elastic recovery of the finished plain knit fabric was greater than that of the greige fabric, but the recovery of 1x1 rib greige fabric was greater than that of the finished fabric. Both plain and ribbed laundered fabrics had considerably less recovery than the greige or unlaundered finished materials.

Fletcher and Roberts[123] investigated stress-strain and recovery properties of yarns and two-bar tricot fabrics of filament acetate, viscose and cotton. They used a table model Instron tensile tester for these measurements. For yarns a 10 inch gauge length was used with a jaw speed of 2 in./min. Fabric breaking strength and elastic recovery determination were made on 12 x 4 in. specimens, a gauge length of 3 in. was used with a jaw speed of

5in./min. Elastic behaviour of these yarns and fabrics at various stress-strain levels was evaluated from the hysteresis curves obtained at constant loads, varying from a low load to 80 or 90% of the breaking load. Five cyclic curves were recorded, the total elongation and immediate elastic recovery on the fifth cycle being measured as described by Hansen and Fletcher[119]. Thirty minutes after the specimen was removed from the machine, permanent set was measured. Delayed recovery was then calculated as the difference between the total elongation at the fifth cycle and the sum of the immediate elastic recovery and the permanent set as described by Susich and Baker[105] for fibres. For acetate and viscose yarns, after cycling, the stress-strain curves at different twist levels (of yarns) varied only a little. The influence of the twist of yarns upon their recovery behaviour was also small. At lower strains, immediate elastic recovery was greater for acetate than for viscose yarns. Cotton yarns had less elongation and less immediate elastic recovery than either of the previous yarns. Like the yarns, the acetate fabrics had the most immediate elastic recovery and the smallest permanent set, the cotton fabrics had the smallest immediate elastic recovery and the largest permanent set. The influence of the course spacing was also studied and it was found that with an increase in course spacing, elongation in width increased for all fabrics, but elongation in length did not change. The percentage immediate elastic recovery changed little in either wale or coursewise direction with the change in course spacing.

Fletcher[124] realised the importance of standardising test methods for evaluating the elastic performance of knit fabrics, as several different methods[119, 121,123] have been used to measure elongation and recovery. An investigation was carried out to compare results obtained (i) with the Instron tensile tester set at predetermined loads, (ii) with the Instron tensile tester set as predetermined extension and (iii) with the simpler machine that could be operated manually. Three plain knit cotton and wool fabrics, 1x1 rib cotton and stretch nylon fabrics and three tricot acetate, cotton and viscose fabrics were selected to give variety of the fibre and fabric construction for the evaluation of elastic recovery by each of the above three methods.

In the two tests on the Instron tensile tester, measurements were made by the grab method on 4 x 7 in. specimens using a gauge length of 3 in. with a jaw speed of 5in./min. In the method using cyclic stress-strain curves at a predetermined extension, the specimen was extended to the predetermined length and held for 30 second while stress relaxation occurred, the moveable jaw being then returned to the initial gauge length. In the procedure using cyclic stress-strain curves with the Instron machine set at predetermined loads, the machine was run continuously until all cycles were completed, the first cycle being made with the machine set at the smallest load. In the method used for applying loads manually, two ends of each specimen were sewn with a plain seam to form a loop of fabric exactly 10 in. in circumference. The specimen loop was slipped over the horizontal bar of the apparatus with the seam at the top, then the bar with the indicator was put through the loop. After straightening the fabric by applying a nominal load (10 - 20 gm.), loads of 1,3,5, 10 and 25 pounds were applied successively to each specimen. Thirty second after each load was applied, the elongation was noted. The load was then removed, the nominal load reapplied, and the unrecoverable elongation noted. Elastic recovery was then calculated as the ratio of recoverable elongation to total elongation and expressed as a percentage.

The results indicated that the recovery determined by applying loads manually was higher than the recovery determined by cyclic stress-strain curves, the maximum load applied manually being 25 pounds as higher loads were not practical. The Instron machine set at a predetermined load gave the lowest recovery values, this being due to the fact that very little or no time was allowed for stress relaxation by this method. On this machine larger loads are easily applied and elastic recovery could be determined for greater elongations than by the manual method. It was concluded that the Instron machine set at a predetermined extension, and the manual method with certain limitations, were satisfactory, techniques for measuring the elastic recovery of knit fabrics.

The author could not find much work on the recovery behaviour of bulked yarns and fabrics knitted from them. However, there was one paper which dealt with recovery behaviour of false twist nylon yarns. In this work[125,126] an attempt was made to study the effect of such production variables as setting temperature, amount of twist and pretensioning on the recovery behaviour of yarns in the hank form. Tests were performed on the Instron tensile tester with a cross-head speed of 20 cm./min. By adjustment of the reversing cams controlling the cross-head, it was found possible to make the cross-head reverse at 1500 gm. load. As it was not possible to reverse the cross-head at zero load, it was reversed at the lowest possible load of 50 gm. equivalent to 0.00397 gm./denier. Each specimen was subjected to seven cycles of loading and unloading, three measures of work recovery being calculated as follows:

(i) All cycles expressed as percentage of the first cycle, excluding the portion of the curve which was below 50 gm. load.

(ii) Percentage work recovery for each consecutive cycle in the normal way for the portion of the curves down to the recovery load of 50 gm.

(iii) Full areas of the first loading and the last recovery curves were compared.

The pattern of the results indicated that work recovery differed from cycle to cycle and according to the method by which the yarn was processed and after several cycles the samples had not reached a stable condition. The amount of recovery appeared to increase with the increased temperature of processing, suggesting that a degree of heat setting plays an important part in determining the recovery of the yarns.

The relationship between work recovery and degree of pre-tensioning was not so well defined, but the trend appeared to be one of increased recovery with increased pretensioning. Presumably if the amount of pretensioning exceeded the elastic limit of the processed yarn to such an extent as to cause straining of that yarn, then the amount of recovery of the yarn would be reduced.

The relationship between work recovery and twist showed a tendency for increased recovery with increased twist, but excessive twisting distorted the yarn unduly which resulted in a reduced amount of recovery in the resultant textured yarn.

Munden and Fletcher[38] in their study of the properties of stretch fabrics, measured the recovery behaviour of stretch plain fabrics from Helanca, Fluflon, Banlon, Stretch and Crinkle yarns. They attempted to correlate recovery with stitch length of these fabrics and found that it decreased slightly for the slacker fabrics. It was also shown that the recovery of fabrics from Crinkle yarns was inferior to that of other stretch yarns.

EXPERIMENTAL METHODS

C O N T E N T S

EXPERIMENTAL

5.1 Materials

The yarns used for knitting various samples in this study are shown in table (21). Crimp rigidity of the yarns was determined by HATRA Crimp-rigidity tester[68]. In addition to the yarns shown in table (21), 64's quality, 2/24's wool (worsted spun) yarn was also used.

1x1 rib fabrics were produced from several deniers of multi-filament nylon yarns as shown in table (21) bulked by false twist and stuffer box methods. They varied in number of filaments, denier per filament, crimp rigidity etc. Some of these yarns were also used in knitting half cardigan fabrics. 1x1 rib and half cardigan fabrics were also knitted from 2/24's wool yarns. All the knitting was on a Universal Power Flat knitting machine, keeping stitch cam settings and other settings constant to minimise the influence of knitting variables. Details of the machine have already been given in Chapter 2. The resultant fabrics were finished by the following three processes:

(1) Relaxation in steam, using the lower bed of a Hoffman press. The fabrics were steamed for two minutes, lower bed (surface) temperature being 105°C.

(2) Wet relaxation at 45°C for 20 minutes with slow agitation. This was carried out in a paddle dyeing machine so that the necessary agitation could be obtained.

TABLE 21.

(Details of bulked nylon yarns used)

Yarn Code No.	Yarn Denier	Type	Grade	Crimp rigidity, %
F1	2/100/34	S&Z STAB	M 470/08046	12.0
F2	2/100/34	S&Z OPT	M470/08046	19.8
F3	2/100/34	S&Z OPT	M470/08046	30.8
F4	2/70/34	S&Z OPT	M53/1503	31.8
F5	2/70/20	S&Z OPT	M50/0456	27.6
T1	1/70/20	[illegible]	D	13.0
T2	1/2[illegible]5/34	O	D	16.0
T3	1/150/50	O	D	16.0

(3) Dry tumbling at 90°C for 15 minutes using a modified Burco-Tumblair. Because water was acting as a lubricant in wet relaxation, the temperature required was lower in that case than when the agitation was carried out in air as in dry tumbling.

Tables (22) and (23) show the list of fabrics used along with their physical analyses. As is seen from the tables each fabric was available in its four different states namely, greige, steam relaxed, wet relaxed, and dry tumbled for recovery determinations. Physical assessments of fabrics were made after conditioning the fabrics under standard atmosphere for 24 hours and each value for courses, wales and length of yarn per stitch represent an average of 10 readings.

5.2 Measurement of Elastic Recovery

As has been stated in the introduction and survey literature a number of methods have been employed for the measurement of elastic recovery of fibres, yarns and fabrics. Most of these methods relate to the measurement of recovery behaviour of conventional fibres and fabrics from them. William et al.[127] have described one apparatus made in the Cone Laboratory for measurement of elastic properties of stretch woven fabrics. The stretch tester is a portable table model which holds six samples. It is composed of a platform with two vertical supports for a transverse beam with six sample hangers. Six pulley-ratchet devices are mounted on the platform under the sample hangers for pulling and holding samples to specified extensions.

TABLE 22.

(Details of 1 x 1 rib fabric produced from false twist crimped nylon yarns)

Yarn Code No.	Yarn C.R.%	No. of ends knitted	Fabric state	c	w	1000 l
F1	12	2	Greige	19.9	29.4	251
"	12	2	SR	21.6	29.0	243
"	12	2	WR	25.0	27.0	245
"	12	2	DT	25.0	28.0	242
"	12	3	Greige	22.1	27.2	245
"	12	3	SR	23.0	26.6	239
"	12	3	WR	26.0	25.6	236
"	12	3	DT	25.4	26.6	240
"	12	4	Greige	23.4	24.7	241
"	12	4	SR	24.0	25.0	242
"	12	4	WR	25.6	25.8	238
"	12	4	DT	26.0	26.0	241
"	12	5	Greige	24.9	22.6	238
"	12	5	SR	25.0	23.0	238
"	12	5	WR	25.5	25.3	234
"	12	5	DT	26.3	25.0	237
F2	19.8	3	Greige	22.4	26.9	241
"	19.8	3	SR	22.9	27.1	235
"	19.8	3	WR	27.5	25.7	233
"	19.8	3	DT	28.0	26.0	230
F3	30.8	3	Greige	22.5	24.9	240
"	30.8	3	SR	24.9	26.0	234
"	30.8	3	WR	27.7	26.0	235
"	30.8	3	DT	29.0	26.0	229

TABLE 22 (cont'd).

Yarn Code No.	Yarn C.R.%	No. of ends knitted	Fabric state	c	w	1000 ℓ
4	31.8	3	Greige	23.5	25.5	235
	31.8	3	SR	25.5	27.0	228
	31.8	3	WR	28.9	27.6	223
	31.8	3	DT	30.0	27.0	224
	31.8	4	Greige	25.0	24.6	227
	31.8	4	SR	26.1	25.6	230
	31.8	4	WR	28.6	26.2	225
	31.8	4	DT	29.0	26.0	226
5	27.6	3	Greige	21.5	28.0	241
	27.6	3	SR	22.8	28.6	236
	27.6	3	WR	27.0	26.0	232
	27.6	3	DT	27.7	27.0	236
	27.6	4	Greige	21.6	26.7	244
	27.6	4	SR	22.1	27.4	239
	27.6	4	WR	26.9	26.2	234
	27.6	4	DT	27.0	26.0	239

TABLE 23.

(Details of fabrics produced from stuffer box bulked nylon (Textralized) and wool yarns).

Fabric structure	Yarn Code No.	C.R.%	No. of ends knitted	Fabric state	c	w	1000 ℓ
1 x 1 rib	T1	13	6	Greige	23.0	29.4	224
1 x 1 rib	T1	13	6	SR	24.0	30.0	224
1 x 1 rib	T1	13	6	WR	28.2	26.9	223
1 x 1 rib	T1	13	6	DT	28.1	28.1	221
1 x 1 rib	T1	13	8	Greige	-	-	-
1 x 1 rib	T1	13	8	SR	-	-	-
1 x 1 rib	T1	13	8	WR	-	-	-
1 x 1 rib	T1	13	8	DT	-	-	-
1 x 1 rib	T3	16	4	Greige	23.9	24.6	241
1 x 1 rib	T3	16	4	SR	23.6	25.4	241
1 x 1 rib	T3	16	4	WR	25.6	25.0	240
1 x 1 rib	T3	16	4	DT	27.0	26.0	239
1 x 1 rib	T2	16	3	Greige	21.0	26.0	249
1 x 1 rib	T2	16	3	SR	20.2	26.3	251
1 x 1 rib	T2	16	3	WR	24.0	25.2	250
1 x 1 rib	T2	16	3	DT	25.0	26.0	249
H.C.	T2	16	3	Greige	17.0	18.0	243
H.C.	T2	16	3	SR	17.0	17.6	243
H.C.	T2	16	3	WR	19.3	17.1	240
H.C.	T2	16	3	DT	20.0	18.0	238
1 x 1 rib	2/24's wool		2	Greige	17.2	22.0	277
1 x 1 rib	2/24's wool		2	SR	17.4	21.0	273
1 x 1 rib	2/24's wool		2	WR	18.9	21.3	275
1 x 1 rib	2/24's wool		2	DT	18.1	23.7	278

TABLE 25 (cont'd)

Fabric Structure	Yarn Code No.	No. of ends knitted	Fabric state	c	w	1000 l
H.C.	2/24's wool	2	Greige	15.0	16.0	276
H.C.	2/24's wool	2	SR	15.8	15.0	272
H.C.	2/24's wool	2	WR	15.6	15.1	276
H.C.	2/24's wool	2	DT	16.0	16.0	274

A test strip, 2.5 x 15 inches with two bench marks 10 inches apart, is mounted on a rod hanger at the top of the apparatus. A four pound weight is then clamped to a dowel pin slipped through the bottom seam of the specimen. The specimen is then exercised by cycling three times between zero and four pounds at approximately 5 seconds per cycle. The increase in specimen length at the bench mark is measured within 10 seconds after application of the fourth full load. The entire load is then removed slowly and the span length is again measured after 30 seconds. The increase in span length is converted to per cent. stretch and per cent. growth.

Keaton and Smith[128] have described three methods which can be employed for measuring the elastic properties of stretch fabrics. Apparatus for two of these three methods are commercially available and are marketed by John Heath-Coat and Co. Ltd. These three methods are described briefly as under:

(i) The sample of fabric taken is 7 inches long in the stretch direction and is 3 inches wide. Bench marks are drawn 5 inches apart and the sample is gripped in two clamps along the bench marks. The load is applied manually by turning the handle and as the handle is turned, the clamps separate and the applied load is recorded on the spring balance. The extension is read from the position of the moving clamps against the scale built into the side of the instrument, when the predetermined load is recorded. On release of the load, residual elongation can be determined and hence elastic recovery estimated.

(ii) The available stretch in woven leisure wear fabrics may be determined on the dynamometer. The sample with bench marks 10 inches apart in the stretch direction and 2.5 inches wide is secured between the two clamps. The load is applied by turning the handle and this allows the moveable jaw to travel along the guide rails. The extension of the fabric is measured on the attached scale when a predetermined load is applied, either immediately or after period of up to 24 hours. The non-recoverable extension may be measured when the sample has been released from the load. Thus the elastic recovery from extension under known load could be measured.

(iii) In this method use is made of the Scot IP 4 inclined plane tester in which a load is applied at constant rate, and as the load carriage moves along the tracks, the load extension hysteresis curve is recorded automatically. This method has also been described by Fletcher and Hansen[119].

5.3 Experimental Method

In the present work the tensile elastic recovery of fabrics was measured on an Instron tensile tester employing a constant rate of extension and retraction. Fletcher[124] has recommended this method as the most suitable for measuring elastic recovery properties of knit fabrics.

Figure (67) illustrates a typical trace. This method deals with the extension of a fabric by a selected amount OL which

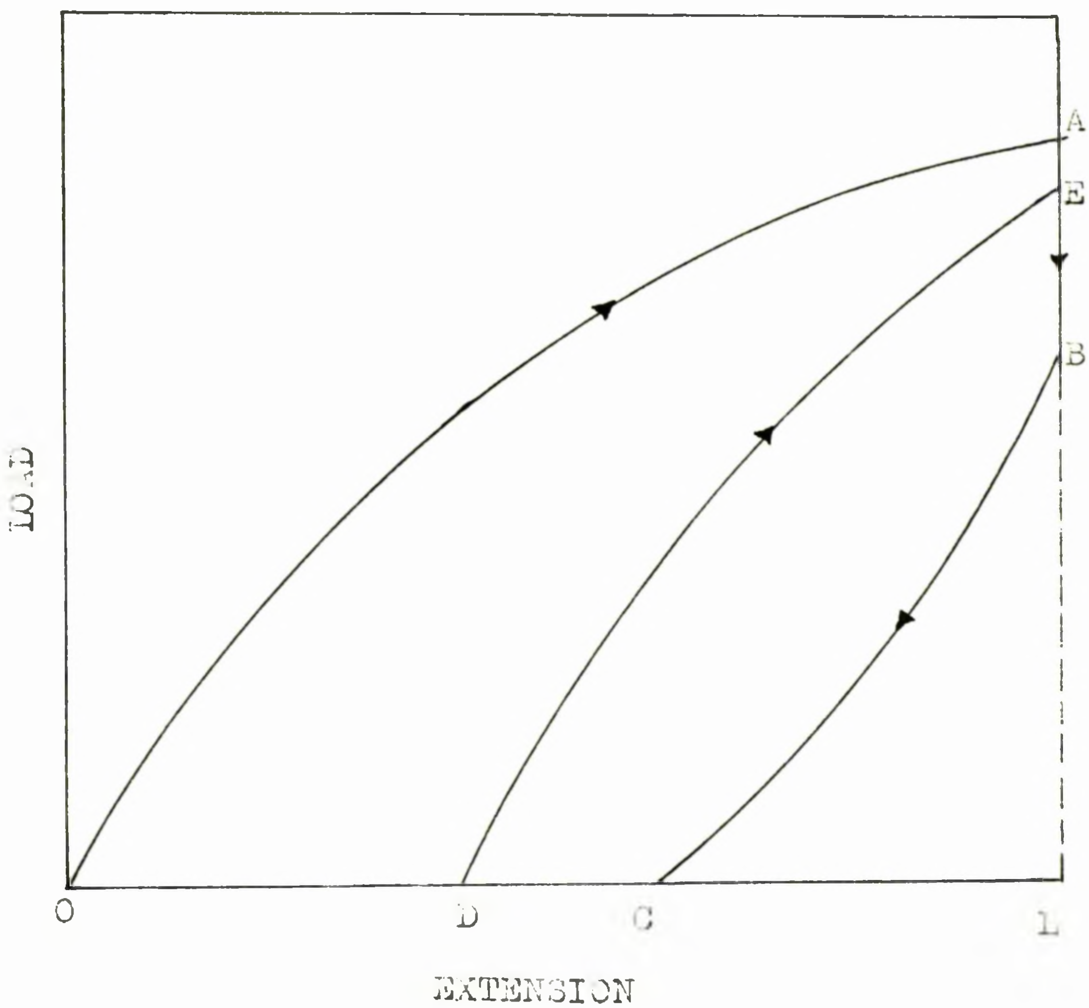


Fig. 67. Typical load-extension trace for elastic recovery measurements.

gives the load/extension curve OA. The fabric is held at this extension for a given time during which stress relaxation AB occurs. The moveable jaw of the Instron is then returned to its initial position and the fabric recovery BC is traced out. The strain value when zero stress is reached is referred to as the immediate recovery LC. The jaw is kept at zero for some time while further recovery CD takes place, where D is the beginning of the trace for the next load cycle.

Immediate elastic recovery is thus given by

$$\frac{LC}{LO} \times 100\ (\%)$$

and immediate plus delayed recovery is given by

$$\frac{LD}{LO} \times 100\ (\%)$$

where LD consists of an initial recovery LC and a delayed recovery CD.

The tensile elastic recovery of all the fabrics was measured from extension of 5% to 50% in steps of 5% in a standard atmosphere, i.e. 65% R.H. and 20°C. These extensions were chosen because various authors have shown that stretch fabrics during their normal wear life have to meet extension requirements of up to 50%. It has been noted that when the arms are lifted above the head, the skin on the human back stretches from 13-16%, whilst bending the elbows or knees causes the skin to stretch by as much as 40%[129]. Thus to provide the wearer of the garment with comfort and freedom and also to keep the initial shape of the garment, built in stretch must be from 35-40% for sports wear. Rest[130] in his paper has given levels of body (unclothed) extension as follows:

Body part	East/West direction Av. % elongation in use
Elbow	19
Knee	13
Seat	5
Back	15

Relating this data to fabrics and considering the normal garment fit, it is thought that the body will demand about 15-20% minimum extension in the East/West direction. In order to ensure high performance of a garment, safety factors must be built into the fabric. Experience has shown that fabric elongation potential should be in the range 30-35% to ensure fully that the fabric meets all the requirements in wear. In ski-wear the elongation likely to be encountered varied from 45% to 60%. Such extension requirements have also been quoted by Riley[131].

Test specimens of fabrics about 16 cm in length were clamped between the jaws of the Instron set at a gauge length of 10 cm. Certain workers designate the use of some weight in pretensioning the specimen prior to clamping in the jaws. There is also the practice of hand tensioning but this results in an elongation of a varying degree, depending upon the operator. Thus pretensioning was not employed in the present work because tension or pre-loading would cause distortion of the sample and a resultant loss in fabric elongation. The cross-head speed was maintained at 10 cm/min. The fabric specimen was extended to the predetermined extent, held at this extension for 30 sec. for stress relaxation to occur and then returned to the initial gauge length. The time allowed for recovery was one minute. These time conditions were established by carrying out an auxiliary experiment in which the times of stress relaxation and recovery were varied. Also, it is known[105,132] that so long as the conditions of the test are kept constant and are known, the relative values of recovery will be comparable. At the end of the recovery time the specimen was again extended to the same extent, and each fabric specimen was subjected to five loading and recovery cycles because textiles are seldom designed to withstand a single stress application of high magnitude. The fabrics in general are subjected to a long usage and during their life time experience a series of repeated stress applications and removals. Thus it is not sufficient to know how the material behaves after single stress application and it is therefore desirable to study the reproducibility of stress/strain properties exhibited by material following cyclical loading and unloading. A fresh specimen was used for each increase in extension. From the cyclic curves obtained, elastic recovery was calculated for the first and fourth cycles.

RESULTS AND DISCUSSION

CONTENTS

6.7 Comparison of the Elastic Recovery Properties of 1 x 1 Rib and Half Cardigan Wool Fabrics with those of Bulked-yarn Fabrics in the Wale and Course wise Directions

Presentation of Results:

Two forms of tensile elastic recovery were calculated for each set of fabrics from cyclic loading-unloading curves. Immediate elastic recovery was calculated as the ratio of recovered elastic extension taken at the instant at which zero stress value was reached, to total extension. Total elastic recovery was measured as described by Meredith[101] for fibres. This total elastic recovery may be considered as the sum of immediate elastic recovery and delayed recovery or primary creep.

Results are presented in a series of tables and graphs for immediate elastic recovery and total recovery plotted against per cent. strain. Some stress-strain curves for fabrics, computed from the cyclic loading-unloading curves are also included. The influence of various factors on elastic recovery of knitted ribbed fabrics as laid down in the introduction will now be discussed in the light of the results obtained.

6.1 Effect of Increase in the Number of Ends Knitting at a Single Feeder on the

6.11 Elastic Recovery of Fabrics

Four fabrics were knitted from false twist crimped nylon yarn (F1) using 2,3,4 and 5 ends, this amounting to fabrics from 400,600, 800 and 1000 denier yarns. The percentage strain applied to the fabrics versus immediate and total recovery behaviour from hysteresis curves, in the walewise direction, at various strain levels are shown in Figures 68(a) to 68(d) and tables 24(a) to 24(d) for fabrics in their greige, steam relaxed, wet relaxed and dry tumbled states. In the figures, results are presented for the first cycle whereas in the tables recovery values are also included for the fourth cycle.

It can be seen from Figure 68(a) for the greige fabric that as the number of ends increase, there is an increase in the immediate elastic recovery up to about 4 ends and a further increase in the number of ends either produces no effect (at low strain levels) or actually slightly decrease the recovery values (at high strain levels). This is explained by the fact that in the case of fabrics of lower denier, the extending forces are small and therefore the recovery forces are also small and may not completely overcome the friction within the fabric when it is released from strain. Further, in fabrics, yarns can only contract to the point where the crimp forces within the yarn are balanced by the opposing forces in the fabric due to pressure from the adjacent loops. The tighter the fabric quality, the less is the space available for yarn contraction. The tightness of the fabric depends on the yarn denier and loop length. Thus in the case of fabrics from five ends of 2/100/34 denier yarn (F1) (total denier 1000), the loop length is 0.238 in. as compared with 0.251 in., 0.245 in. and 0.241 in. for fabrics from 400, 600 and 800 denier respectively. When a tight fabric is released from extension, the distorted loops will have to exert considerable pressure against adjacent loops, or in other words compress the structure to recover

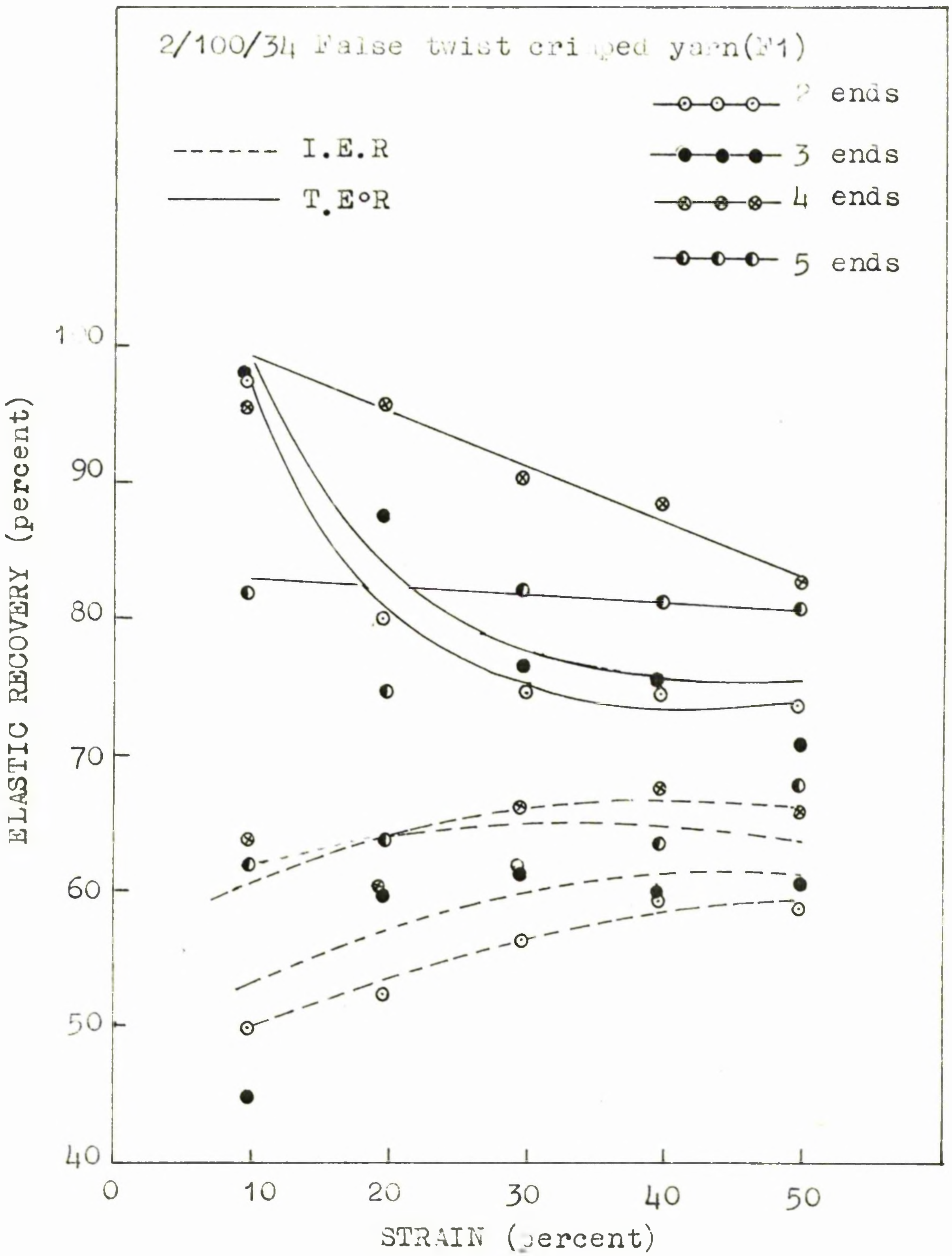


Fig.6?(a). Effect of increase in the number of ends knitting at a single feeder on the elastic recovery of fabrics (greige state).

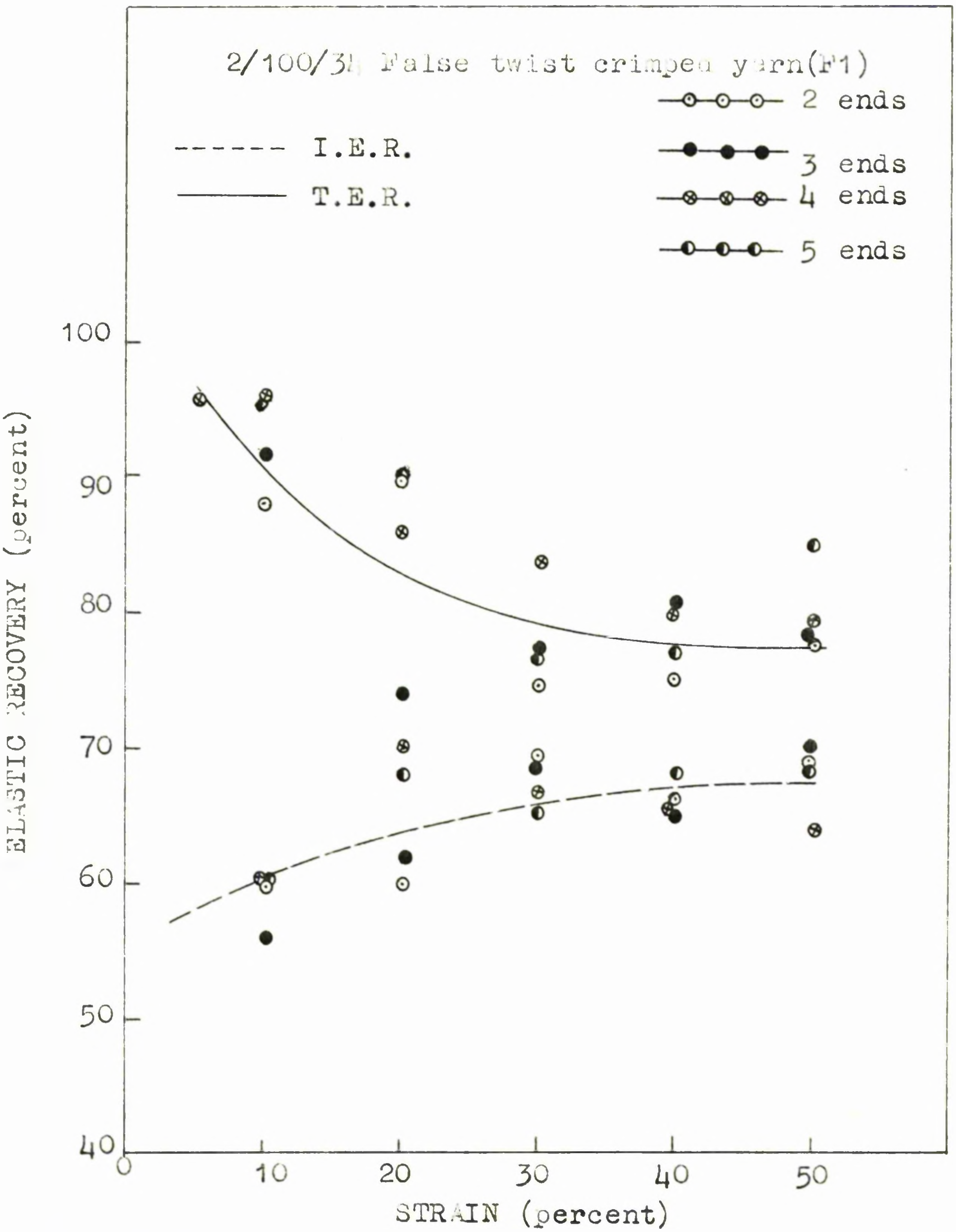


Fig.68(b). Effect of increase in the number of ends knitting at a single feeder on the elastic recovery of fabrics (steam relaxed).

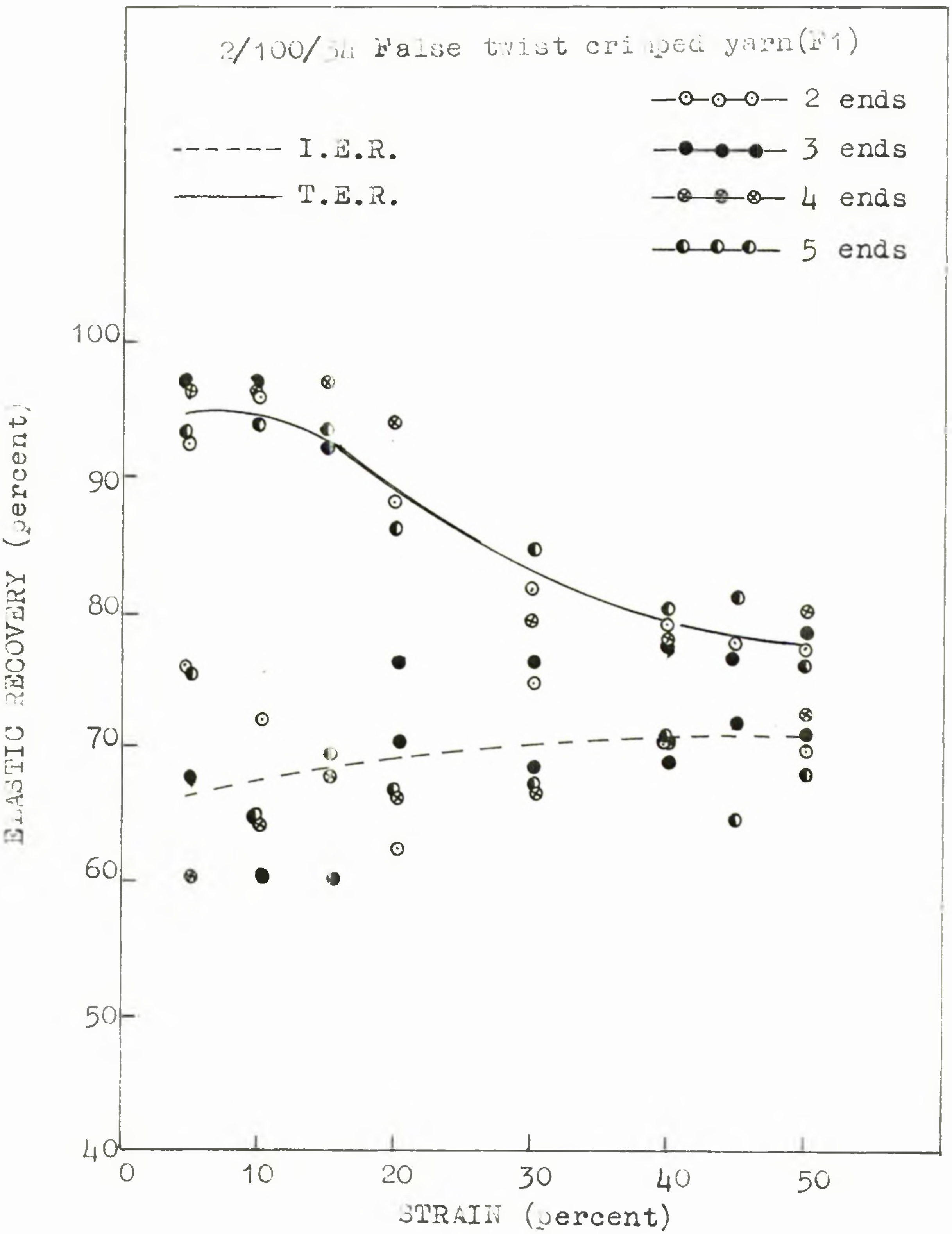


Fig.68(c). Effect of increase in the number of ends knitting at a single feeder on the elastic recovery of fabrics (wet relaxed).

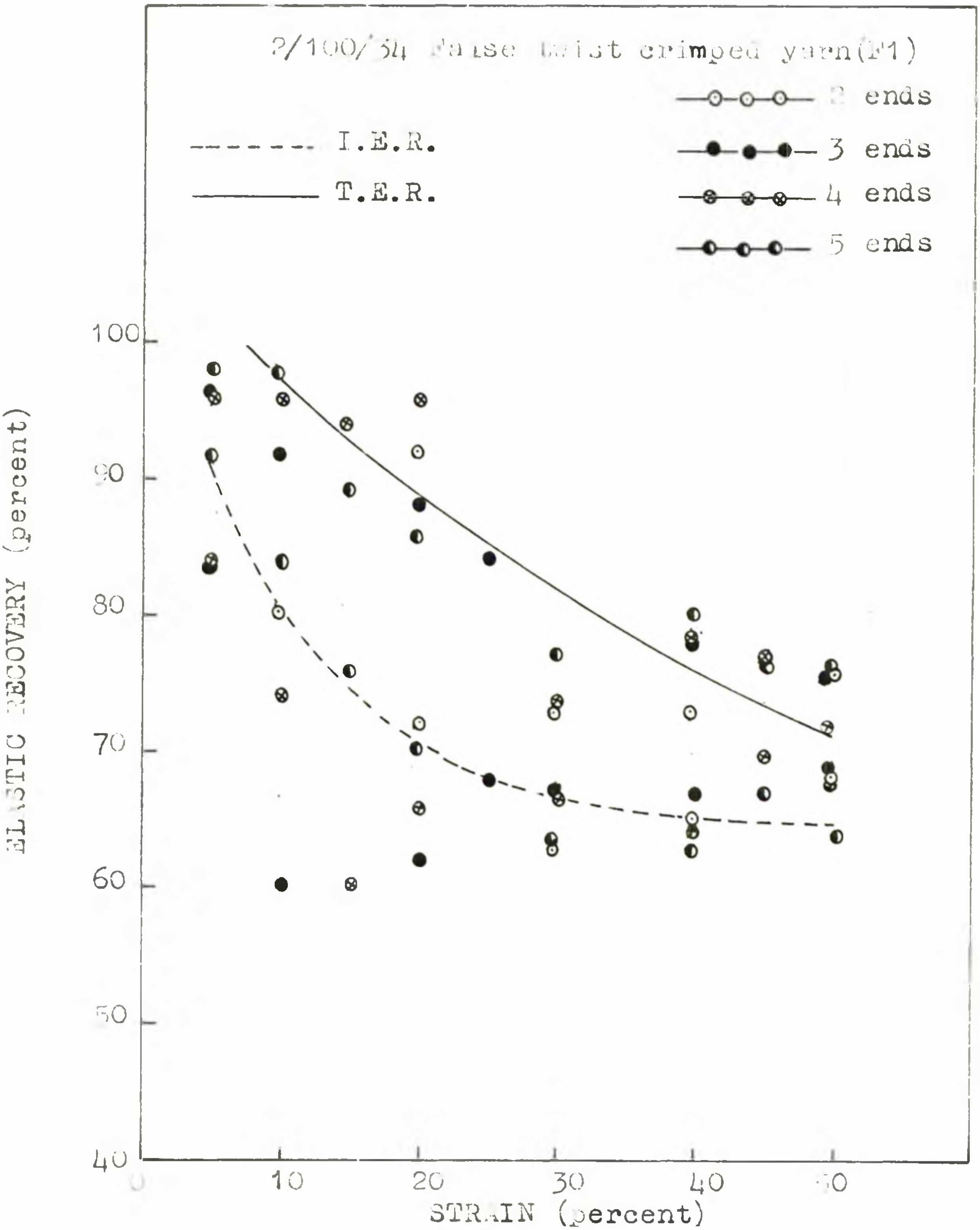


Fig.68(d). Effect of increase in the number of ends knitting at a single feeder on the elastic recovery of fabrics (dry tumbled).

their relaxed shape and dimension. The loop and crimp forces favouring recovery to the original fabric shape will be opposed by frictional forces within the yarn and adjacent loops and it is reasonable to assume that those frictional forces will be large in case of fabrics of higher denier.

There is an increase in the immediate elastic recovery with increase in per cent. strain (Fig. 68(a). Susich and Baker[105] also observed an increase in immediate elastic recovery at very low stress values for nylon, type 300, and some other fibres including polyethylene and vinyon. Since recovery tests were performed at a constant rate of extension and retraction, it is evident that for lower strain values less time was permitted for recovery and hence the lower resultant values. In the present work, recovery behaviour of fabrics was evaluated from extensions of up to 50 per cent. Up to this level no decrease in immediate elastic recovery is observed for any fabric tested. If the tests were performed for extensions beyond 50%, it is likely that a decrease would have been observed because in that case the deformation of the fabric would have been predominant as opposed to the time factor for lower strains.

Figure 68(a) also shows total elastic recovery plotted versus per cent. strain. For fabrics from 400,600 and 800 denier yarns, the elastic recovery at 10% extension is almost identical but the rate of decrease with increase in extension is much more in case of fabrics of 400 and 600 denier and the curves for these fabrics tend to flatten out beyond 30% extension and exhibit minimum total elastic recovery. Fabrics from 800 denier yarn (4 ends of 2/100/34) gives the maximum total elastic recovery as it also resulted in maximum immediate recovery. Recovery behaviour of fabric from 1000 denier yarn appears to be independent of increase in extension but at low strain values, its recovery is far less compared with fabrics from yarns up to 800 denier. Fletcher and Gilmore[120] in assessing the influence of the number of courses per inch on the fabric elastic recovery, found that plain fabrics knitted from continuous filament nylon yarn were more elastic when knitted with 64 courses per inch than with 40 courses per inch. For the same machine setting, when the denier of the yarn is changed it would result in the variation of the number of courses, a higher denier leading to an increased number of courses. In the present case, changing denier from 400 to 1000 gave variation in courses per inch from 19.9 to 24.9. Thus it can be said that in case of fabrics in which good recovery from extension is highly desirable, it is necessary that a proper selection of the yarn denier and loop length of the fabric be made with respect to the gauge of the machine.

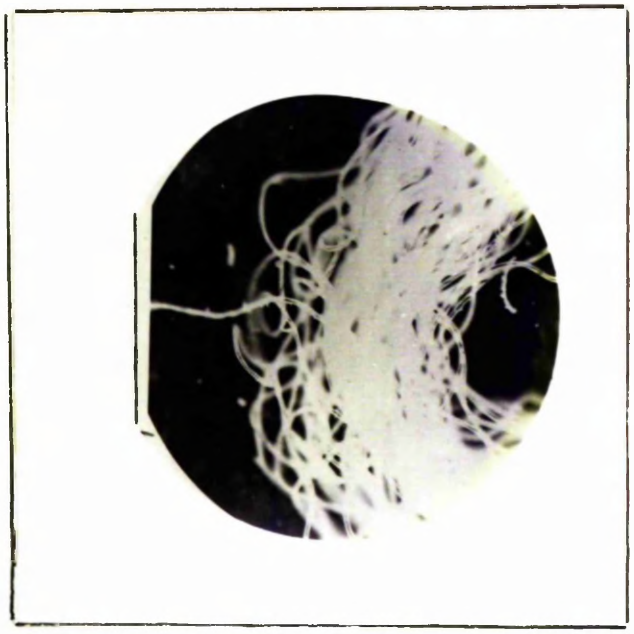
The influence of time factor on delayed recovery can be seen from Figure 69(a). For light fabrics at low strains, delayed recovery is as much as 50% of the total recovery. With the increase in strain the delayed recovery becomes smaller as would be expected because of the fact that the immediate elastic recovery is slightly higher for these strains as a greater time is given, due to the traverse of the head to return to zero strain. Thus during the one minute which is allowed after complete removal of the load, only small additional increases in recovery occur for higher extensions.

The effect of the relaxation processes on the elastic recovery of fabrics from 2,3,4 and 5 ends of false twist nylon yarn (F1) can be seen from Figures 68(c) to 68(d). The influence of the number of ends as observed for fabrics in greige state disappears after these processes. This is perhaps due to the consolidation of the fabric structure as a considerable amount of loop collapse takes place after finishing these fabrics. Further evidence to this effect is provided by the lighter fabrics (from 400 and 600 denier yarns) since considerable improvement in elastic recovery, particularly immediate elastic recovery, is observed for these fabrics after finishing.

Comparison of the finishing processes would reveal that whereas steam and wet relaxed fabrics show an increase in immediate elastic recovery with increase in per cent. strain, the same is not the case with dry tumbled fabrics in which case there is a marked decrease in immediate elastic recovery with increase in per cent. strain. Further, at low strains dry tumbled fabric is much superior in its recovery behaviour than steam and wet relaxed fabrics and that the delayed recoveries are higher for the latter two states of fabric. But when total elastic recovery is considered, it is seen that for steam and wet relaxed fabrics there is a gradual fall with increase in per cent. strain and beyond 30% extension the curves level out. On the other hand, dry tumbled fabric shows almost a linear decrease in its elastic recovery with increase in strain. When a fabric is dry tumbled, it collapses more than when it is steam or wet relaxed and as a result it developes more bulk. It has been reported[133] that as the bulk increases, fabric recovery becomes poor. On dry (Plate 2d) tumbling fabric, a greater amount of yarn and filament entanglement results which would lead to greater frictional forces hindering recovery. In the case of steam and wet relaxed fabrics the (Plate 2b & c) frictional forces will be much less because of a lower amount of entanglement and also during these processes and particularly during steam relaxation, adhesion of the individual filaments take place and the yarn appears as if it were continuous monofilament yarn and because of this factor, the fabric bulk is lower. Comparing figures 68(a) to 68(d) would indicate that finishing does improve fabric recovery but between the three processes used it is rather difficult to establish differences though their behaviour in the low and high strain region is somewhat different.

The influence of repeated cycling on elastic recovery behaviour can be seen from values in tables 24(a) to 24(d). Thus even after five successive cyclic loadings and unloadings a considerable amount of recovery is present, though there is a significant difference in recovery after the first cycle when compared with values for the fourth

(a) Greige



(b) Steam relaxed

(c) Wet relaxed

(d) Dry tumbled

Plate 2. Photomicrographs of yarns extracted from the fabrics knitted from 2/70/34 false twist crimped yarn.

cycle. In general, there is a drop of about 10% in elastic recovery after the fourth cycle.

However, from a practical stand-point it is not sufficient that the fabric recovery only should be good. Other factors such as bulk, handle, drape and ease of extensibility will also have to be taken into consideration and compromise made when finishing these fabrics from bulked nylon. It is pertinent at this stage to study the load-strain behaviour of the fabrics so far discussed.

6.12 Load-Strain Characteristics

The mechanism by which the extension of 1 x 1 rib fabrics takes place has been explained by Doyle[59] and more recently by Smirfitt[134]. Doyle states that in the initial stages of extension (say up to 50%) the load is taken up principally by bending and twisting couples in the yarn and frictional constraints at the point of intersection of the loops. When the maximum adjustment of the shape of the loop has been made, side-ways compression of the yarn in adjacent loops and bending into high curvature cause the load to rise more rapidly. Finally the load is transferred more directly as tension to the yarn along its axis.

According to Smirfitt[134] extension of 1x1 rib fabric proceeds by several different mechanisms: the rotation of the cross-links, the opening of the loops, the straightening of the cross-links, the withdrawal of the yarn from the face loops into the links, compression at yarn intersections to reduce curvature and finally yarn extension.

Thus, in actual use, these different mechanisms sometimes operate together but always there is gradual transition from one mode of extension to the next. At very high and very low extensions, it may be possible to establish the means by which extension takes place and relate it in terms of the properties of the yarn and the geometry of the fabric.

In practice, however, fabrics are seldom extended beyond 50% and the characteristics below this point are therefore of interest. Simple load-strain curves for 1x1 rib fabrics in the greige, steam, wet and dry tumbled states from 2/100/34 STAB false twist nylon yarn (F1) are reproduced in Figures 69(a) to 69(d). These fabrics differ in knitting stiffness (i.e. length of yarn per loop) as a result of a change in the number of ends used in knitting, this being a change in yarn denier. The range is covered from a fairly tight to a loose construction and they were subjected to the same values of strain. Extension of these structures involves a combination of bending, twisting, compressing and sliding of the yarns. In the looser structure there is more space available for movement and hence they are more easily deformed. For tight fabrics, the difference in the load required to stretch to any given extent, particularly at high strains, is very high. Because these tight fabrics are made from higher denier yarns, their flexural and torsional rigidities will be high, since these factors depend on the diameter of the yarn. It is

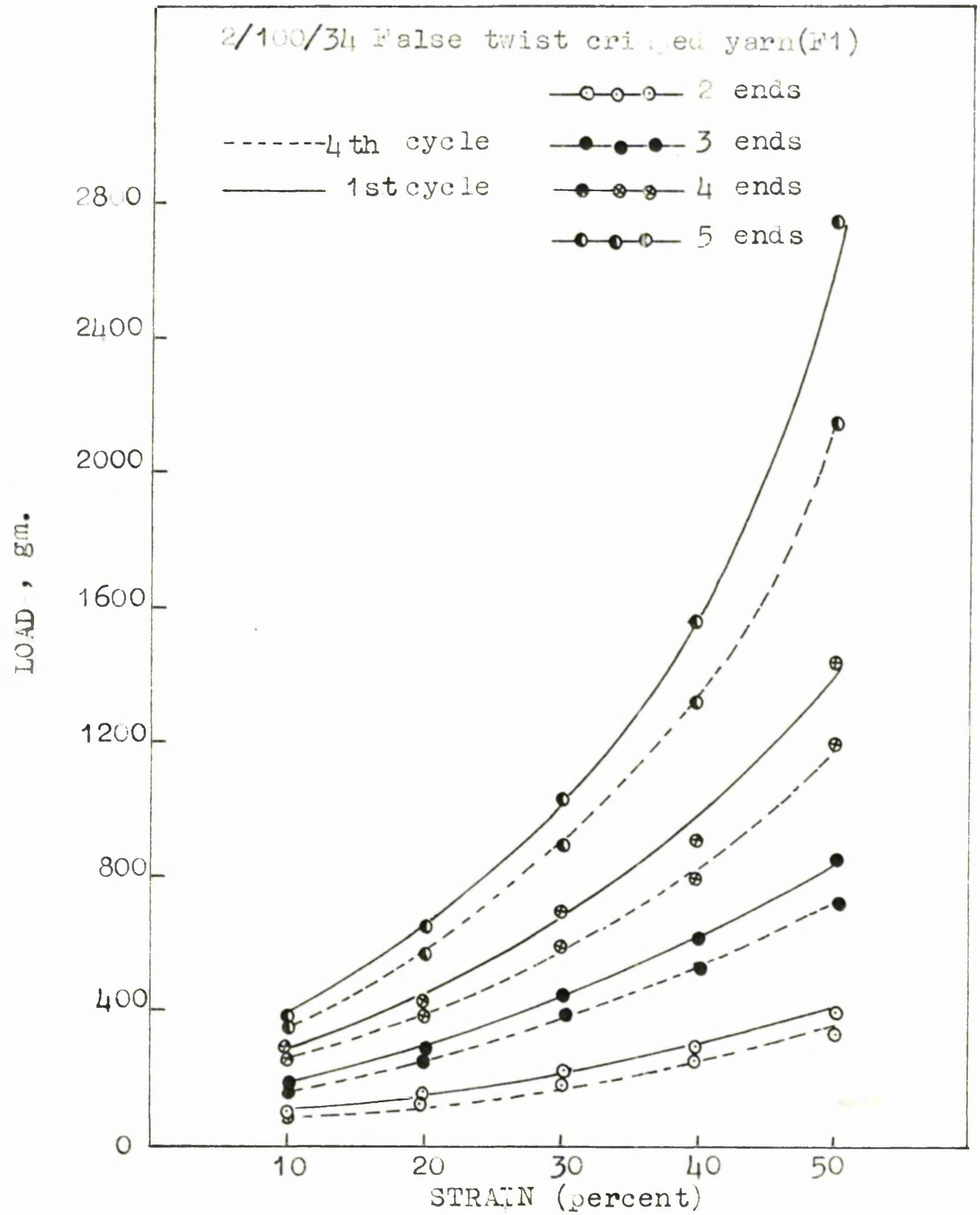


Fig.69(a). Load-strain characterstics of fabrics (greige state) knitted from varying number of ends of yarn.

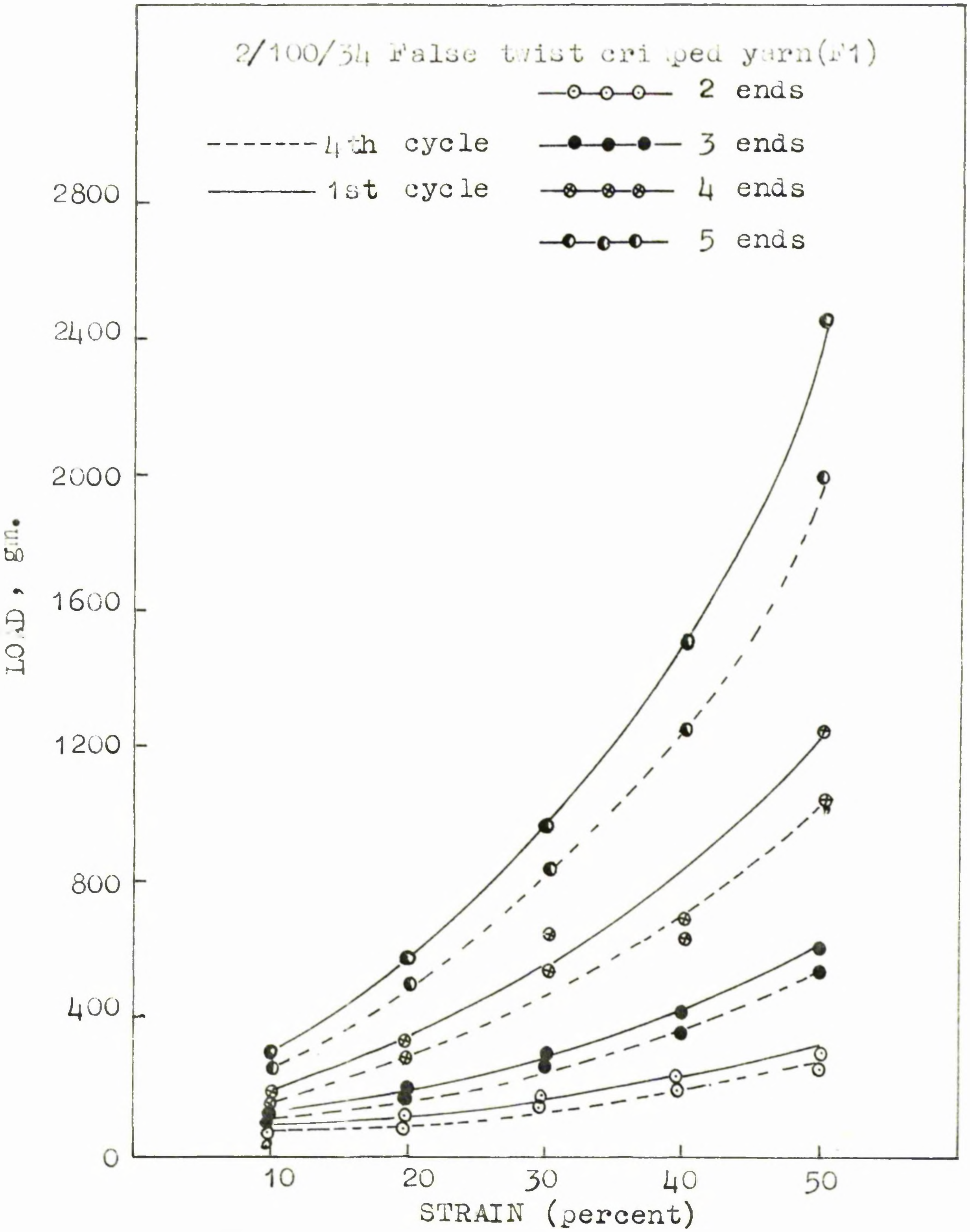


Fig.69(b). Load-strain characterstics of fabrics (steam relaxed) knitted from varying number of ends of yarn.

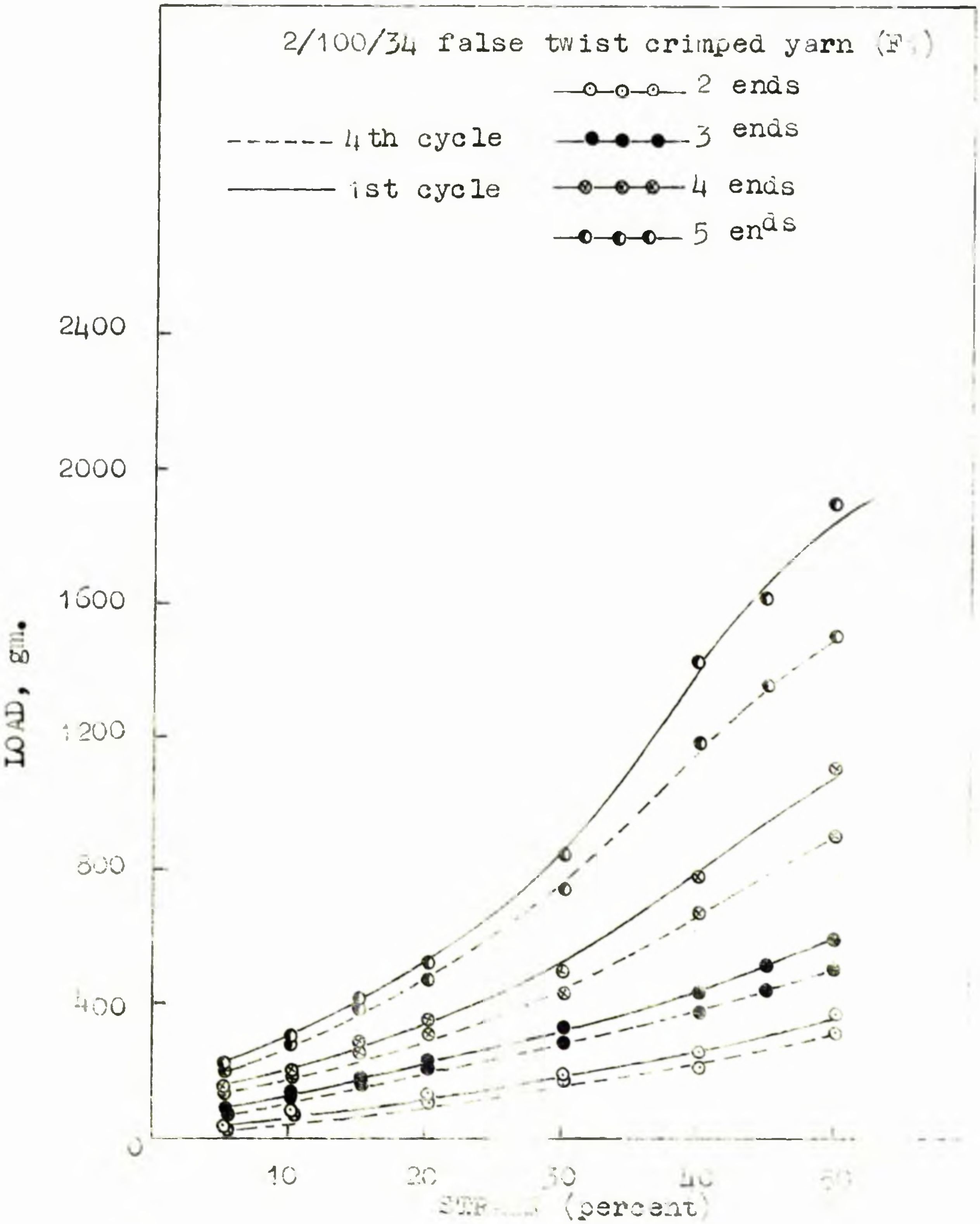


Fig. 69(c). Load-strain characteristics of [illegible] (wet relaxed) knitted from varying number of [illegible] of yarn.

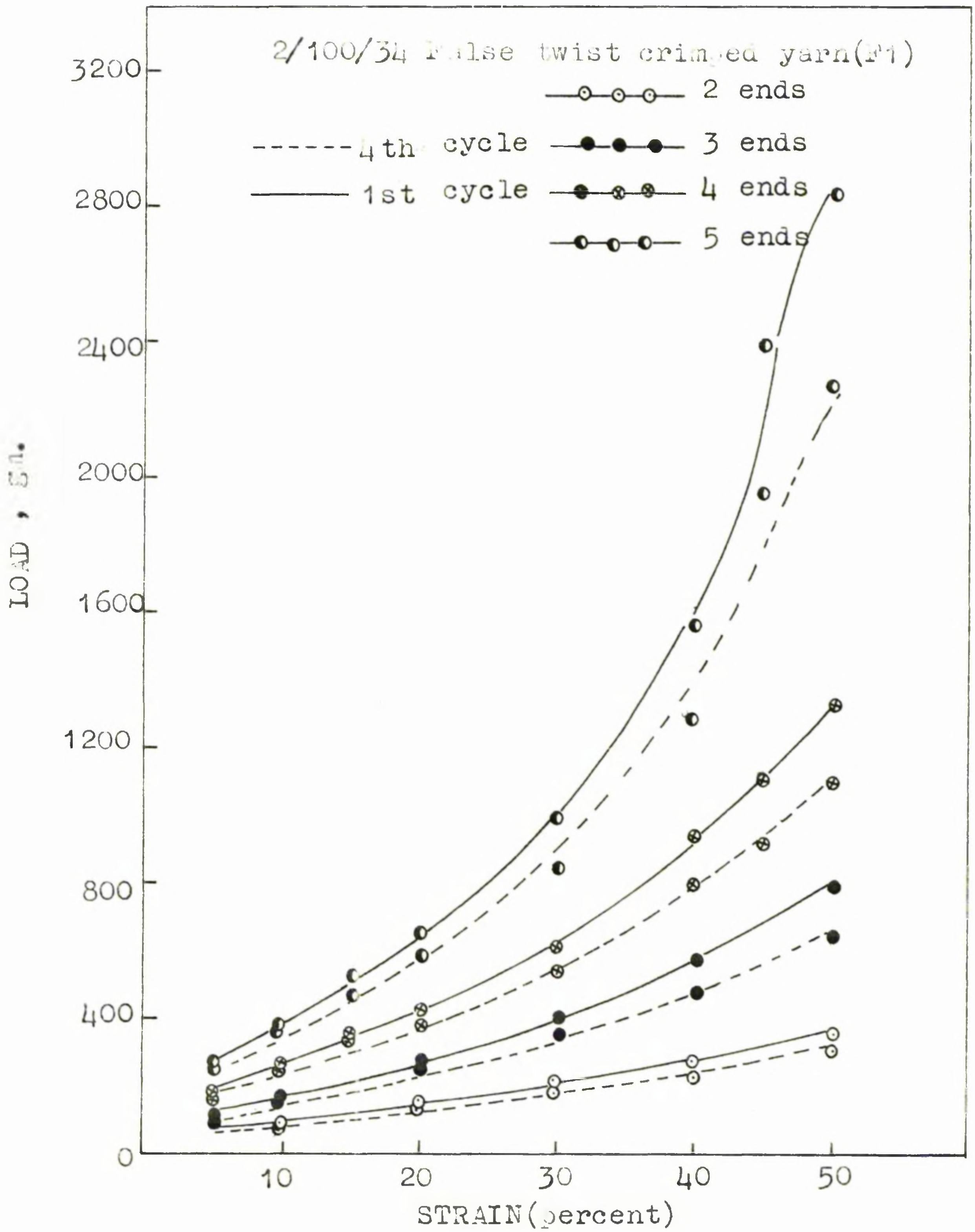


Fig.69(d). Load-strain characterstics of fabrics (dry tumbled) knitted from varying number of ends of yarn.

known[59] that doubling the diameter alone effectively increase the strength in extension by four times. Further, with an increase in the number of ends a greater frictional force will need to be overcome in extension. These facts will account for the divergence of the load-strain curves at higher strain values. It is also shown in Figures 69(a) to 69(d) that a smaller load is required to stretch a fabric in the fourth cycle than in the first cycle.

The effect of finishing processes on the load-strain behaviour of fabrics is more clearly seen from Figure (70) in which the load required to extend 1x1 rib fabrics knitted from 3 ends of false twist nylon yarn (F1) is plotted against per cent. strain. These curves are shown for the first cycle of extension. It will be seen that the load required to stretch steam and wet relaxed fabrics for any given extension is less than that for the fabric in the greige state, whereas there appears little difference between greige and dry tumbled fabrics. Though Figure (70) is for fabrics made from 3 ends of yarn (F1), study of the Figures 69(a) to 69(d) showing the effect of an increase in the number of ends knitted would indicate that the trend shown in Figure (70) could also be expected to happen to fabrics made form 2, 4 and 5 ends.

Tsuruta and Koshino[135] studied the effect of steam and dry heat setting of nylon 6 fibre. It was observed that when compared with dry heat setting, steam setting decreased the Young's modulus

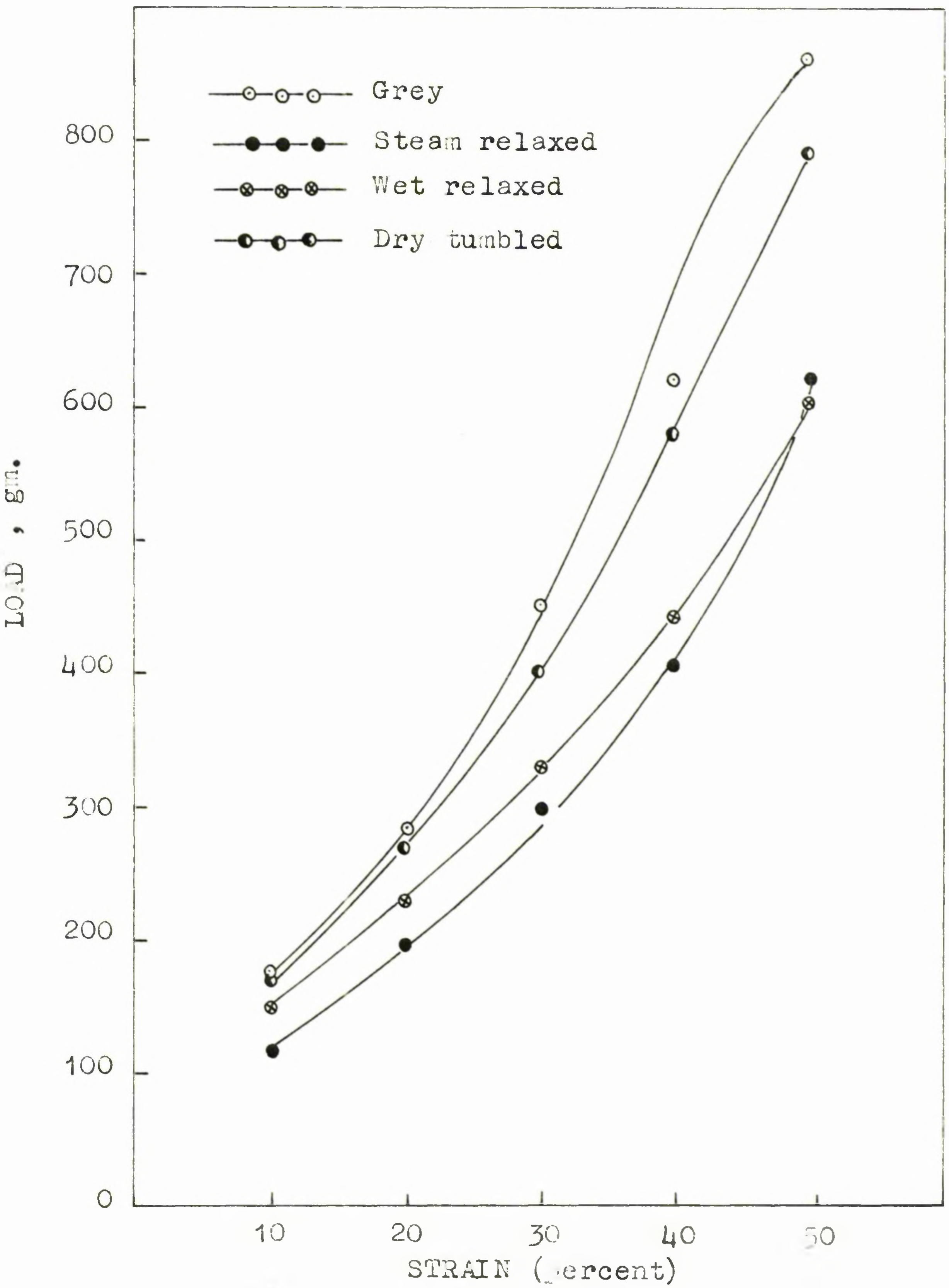


Fig. 70. Effect of finishing treatments on load-strain characterstics of fabrics knitted from 2/100/34 false twist yarns.

and tensile strength of the fibre. This phenomenon is attributed to the following changes in the fibre structure:
(a) a decrease in the crystalline orientation, and (b) hydrolysis of the polymer molecules or the decrease in hydrogen bonding in the amorphous region. Since the authors observed an increase in density and crystallinity under conditions sufficiently severe to cause hydrolysis, the phenomenon is attributed to the decrease in hydrogen bonding.

The hydrogen bonds among polymer molecules are affected due to the existence of water molecules at high temperature and as the inter-molecular spaces increase, there is permeation of water molecules among the polymer molecules. When nylon 6 is cooled again, the amorphous part shows a state of loose packing because rebonding is inhibited by the existence of water molecules. Consequently, as the amorphous parts between crystalline sections are soft, even if the degree of crystallinity increases, it may be expected that the increase of Young's modulus and tensile strength would not be so large as that of crystallinity.

Further evidence to this effect is also provided by study of the effect of steam and dry heat setting of nylon 6 on dyeability of the fibre. Increased dyeability was observed for nylon 6 steam set fibre[136]. This was attributed not to the disorientation of crystallites but to the loose packing of nylon molecules in the amorphous region. The decreased dyeability resulting from dry heat setting is attributed ti a decrease in extent of the amorphous region accompanied by an increase of crystallinity and close packing. It is assumed that the bonding of nylon molecules after dry heat setting is facilitated by the absence of water molecules.

This is further substantiated by the results of the present study. In Figure (70) the loads required to stretch dry tumbled fabrics are very similar to those for the greige fabrics but a considerable drop is shown in the load values for steam and wet relaxed fabrics. An inspection of the results for the steam relaxed state show that for any strain up to 50%, there is a 30% strength loss when compared with the fabrics in their greige state. This is due partly to the relaxation of the fabric structure which causes an increase in the courses per inch but the more likely reason appears to lie in the fact that the fibre strength is reduced. The results of the study of stress-strain properties of single filaments extracted from fabrics finished by different treatments confirmed this. It was found that steam and wet relaxation treatments decreased the tensile strength of the single filaments whereas dry tumbling resulted in a slight increase in tensile strength when compared with the strength of the greige sample, thus indicating some relationship between basic fibre properties, fabrics made from them and the finishing processes applied to those fabrics.

6.2 Effect of Denier per Filament of Yarn on the Elastic Recovery of Fabrics

It is generally believed that the recovery of a fabric is greatly affected by the filament denier of the yarn used, a higher filament denier giving a better recovery[133,137]. As no experimental evidence was available to support this view, it was decided to study the effect of filament denier on recovery behaviour of rib fabrics. Three yarns 2/70/20 OFT/(F5), 2/100/34 OFT/(F3) and 2/70/34 OFT/(F4) of nearly the same crimp rigidities were selected and 1x1 rib fabrics knitted from them under the conditions described earlier.

Elastic recovery of these fabrics in the walewise direction is plotted against per cent. strain and is shown in Figures 71(a) to 71(d) for greige, steam relaxed, wet relaxed and dry tumbled states. It is noted from these figures that other things being similar, denier per filament does play a part in the elastic properties of fabrics. There are certain anomalies e.g. the greige state fabrics made from lower denier per filament yarn give better total elastic recovery, this behaviour suggesting that the lower denier filament is more suspect to time-recovery effects. The differences are marked at low elongation valued but at high elongations they become very small. Again for fabrics in the dry tumbled state there is no clear indication as to the role played by denier per filament of yarn. Since dry tumbling may be considered the most effective relaxation treatment for fabrics from bulked nylon, this would suggest that once the fabric has been thoroughly relaxed, their elastic recoveries would almost be the same irrespective of differences in filament denier. Tables 25(a) to 25(d) contain the data for the elastic recovery of

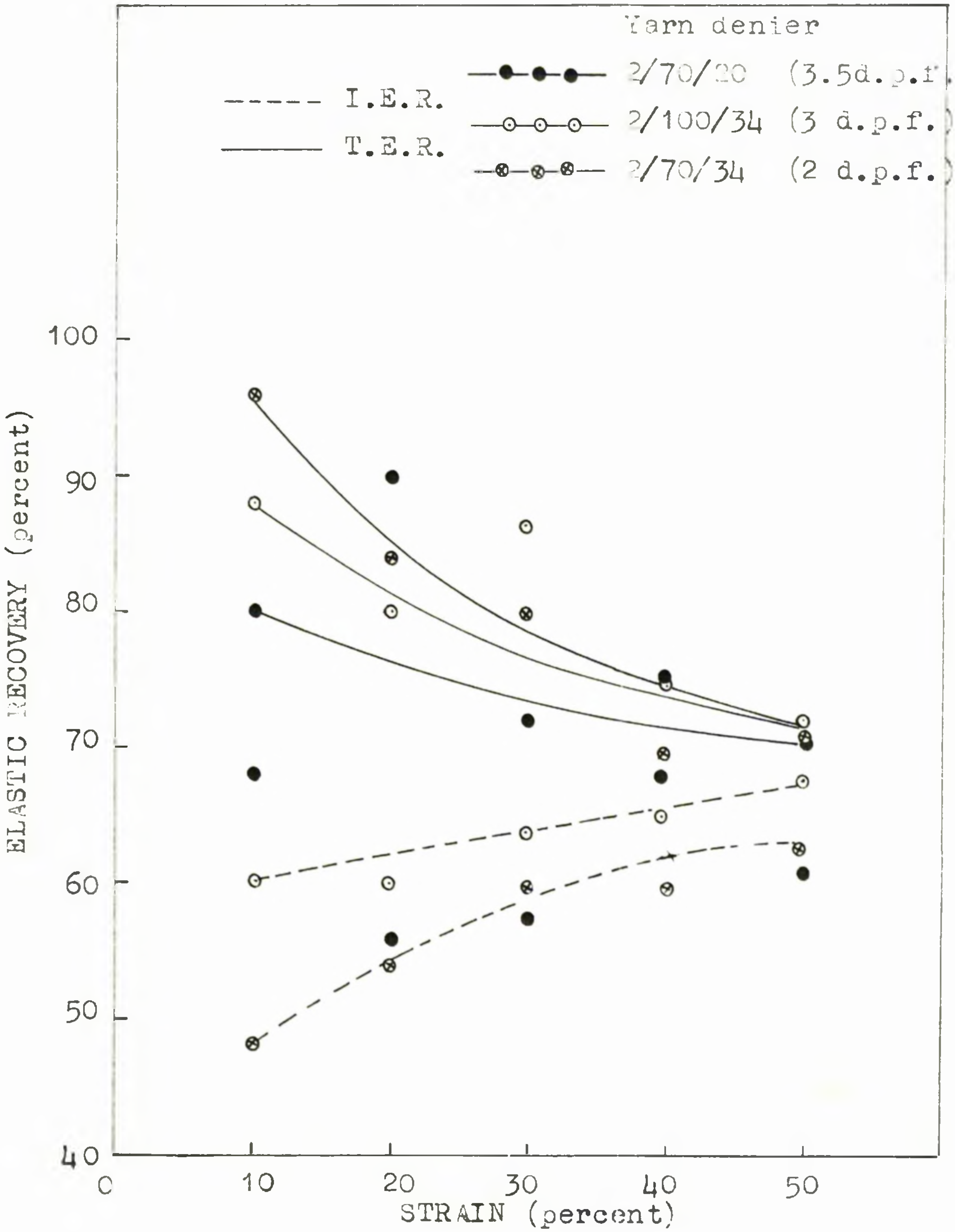


Fig.71(a). Effect of denier per filament of yarn on the elastic recovery of fabrics (greige state).

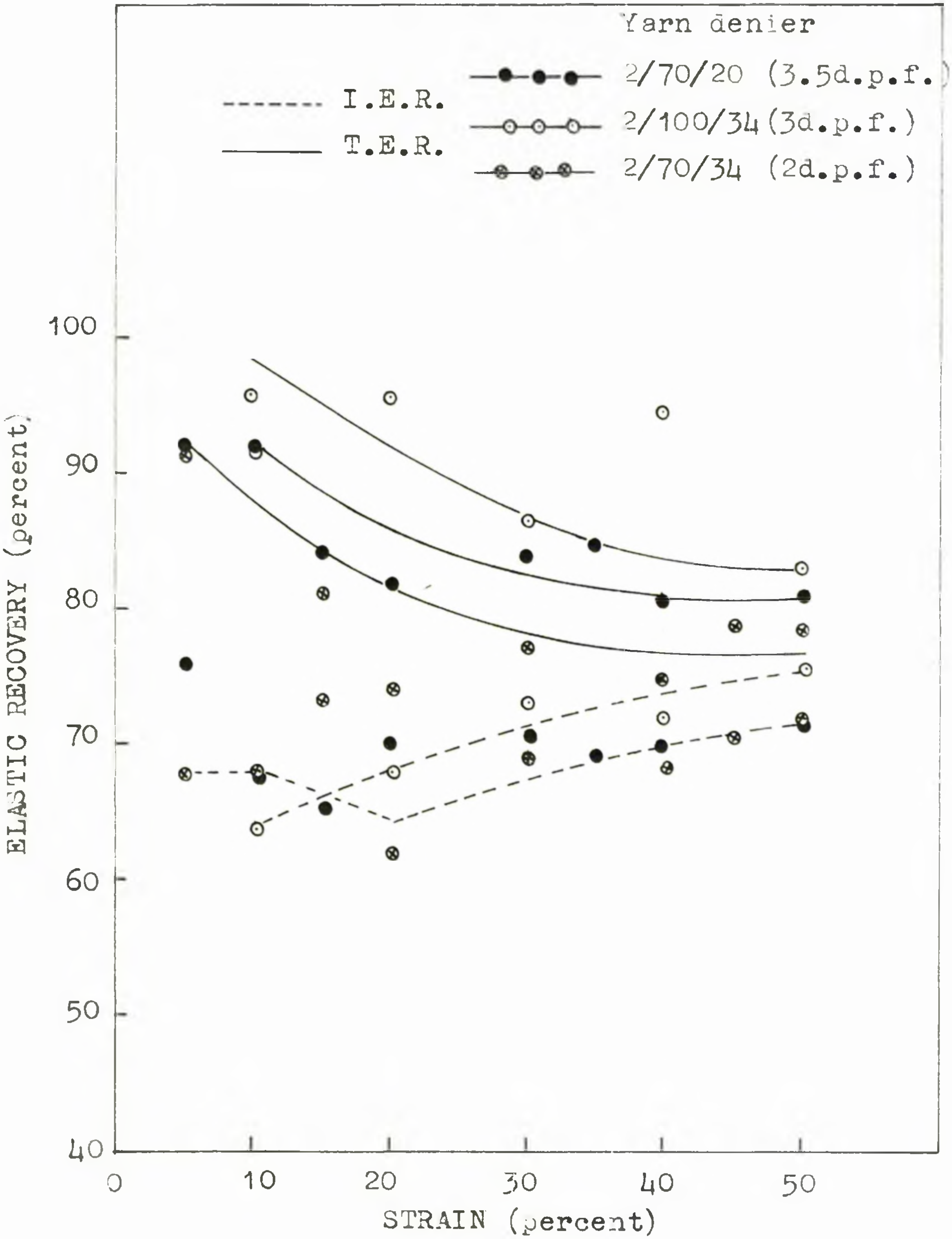


Fig.71 (b). Effect of denier per filament of yarn on the elastic recovery of fabrics (steam relaxed).

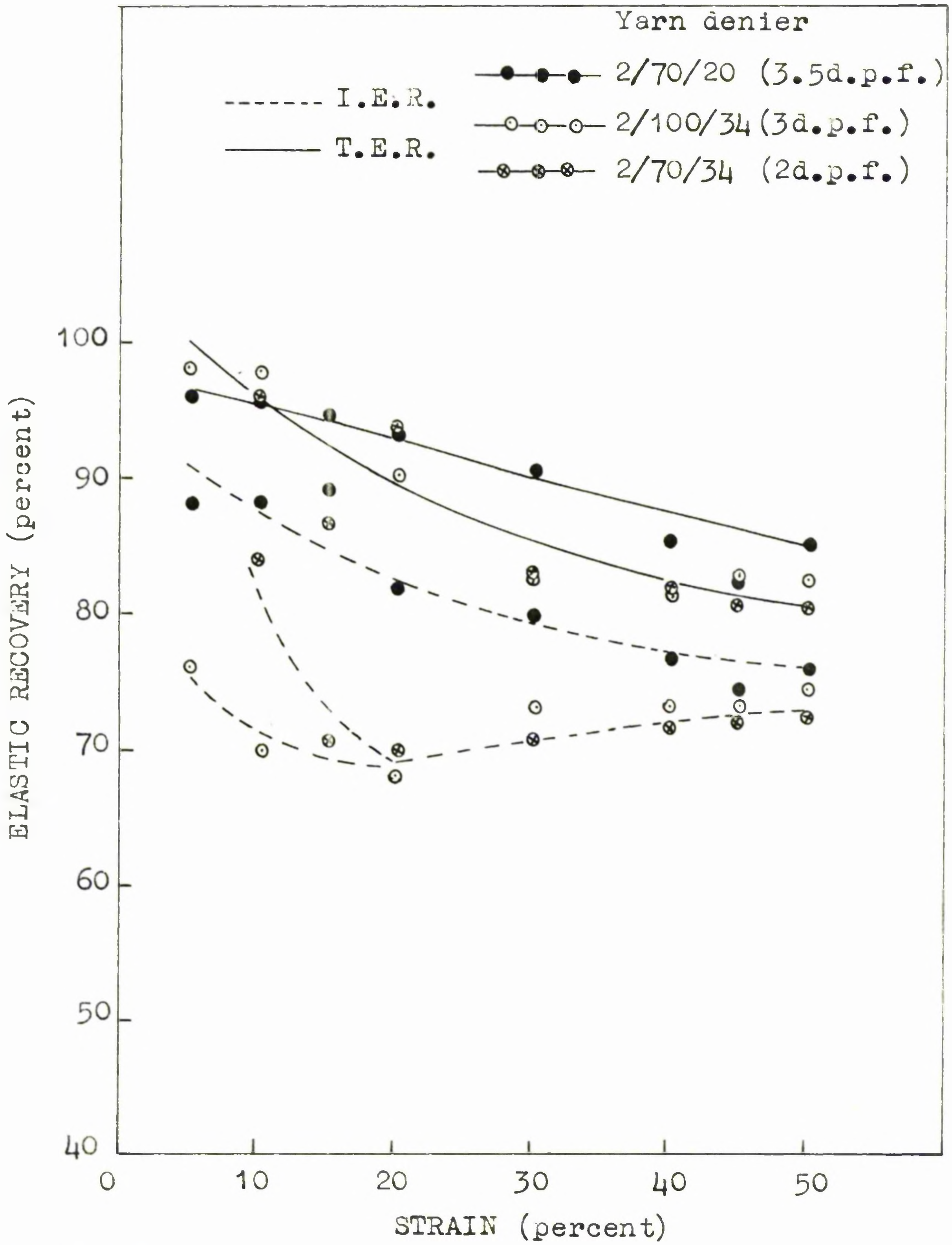


Fig.7 (c). Effect of denier per filament of yarn on the elastic recovery of fabrics (wet relaxed).

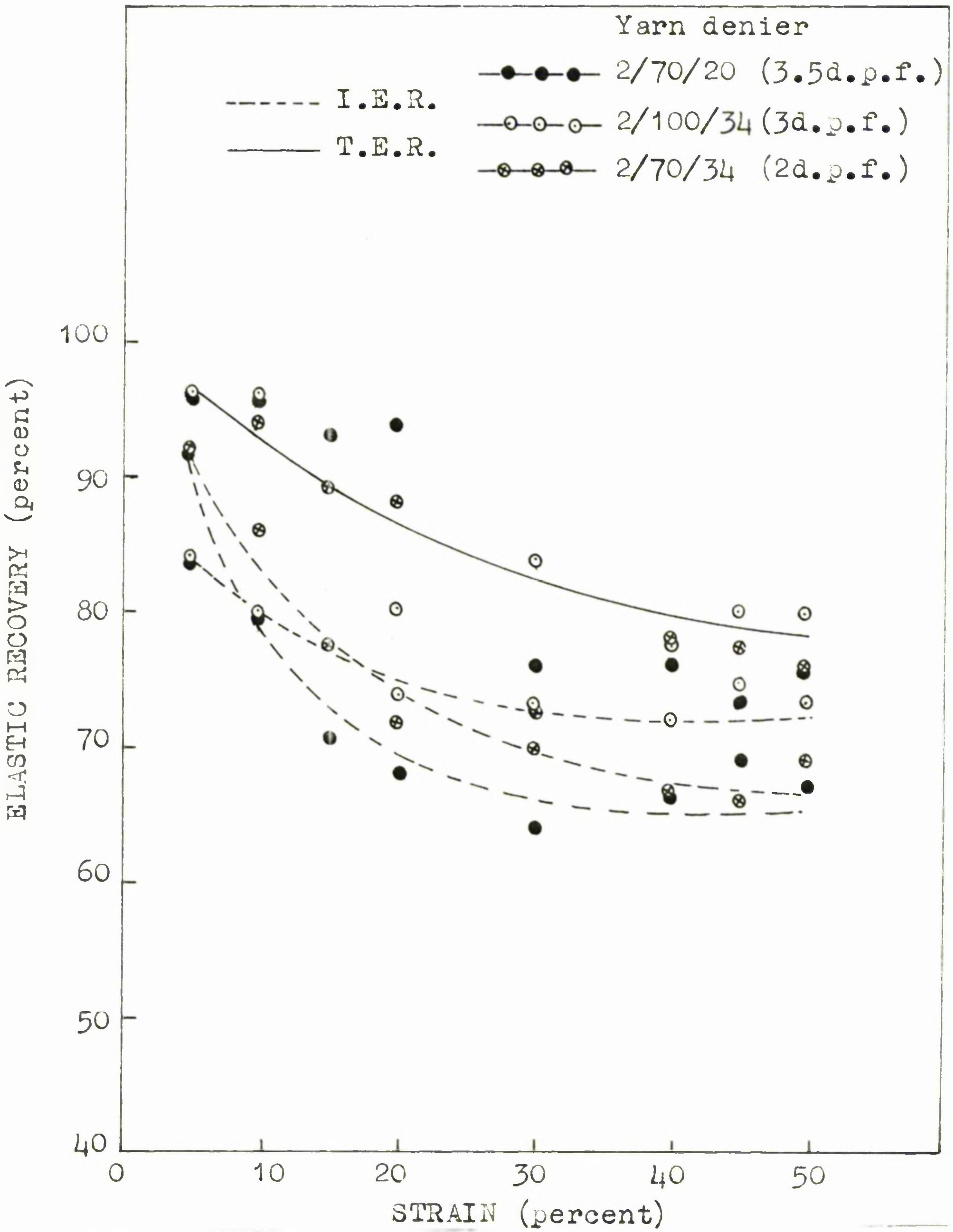


Fig.71(d). Effect of denier per filament of yarn on the elastic recovery of fabrics (dry tumbled).

these fabrics for the first and the fourth cycle along with loads required to stretch them up to 50% extension.

The above fabrics were made by knitting 3 ends of each of 2/70/20 (d.p.f. 3.5), 2/100/34 (d.p.f. 3) and 2/70/34(d.p.f. 2) yarns. Whereas the comparison of the fabrics from 2/70/20 and 2/70/34 yarns is justified, the same is not true for fabrics from 2/100/34 denier yarns since in this case the total denier amounted to 600 as opposed to 420 of the other two yarns. It was therefore, decided to knit fabrics using 4 ends of 2/70/20 and 2/70/34 denier yarns so that the total denier of these fabrics would be comparable. The elastic recovery data of these fabrics are included in tables 26(a) to 26(d). The general trend as observed in the earlier cases (Figs. 71(a) to 71(d)) still remain the same suggesting that slight changes in total denier do not significantly affect the elastic behaviour of fabrics.

The fabrics so discussed were made from yarns which varied in their filament denier from 2 denier to 3.5 denier. It was thought desirable to study fabrics from yarns in which the variation of filament denier was larger. In order to do this, Textralised yarns, 1/205/34 (T2) and 1/150/50 (T3) were selected and 1x1 rib fabrics knitted using 3 ends of T2 and 4 ends of T3 so that the yarn deniers were comparable. Tables 27(a) to 27(d) show the effect of filament denier on the elastic recovery. Despite the scatter in these results, it will be noted that there is no indication that the higher the filament denier, the better is the fabric recovery. This appears to be true for fabrics in their greige, steam relaxed, wet relaxed and dry tumbled states. Thus, for the range of filament denier studied, the initial as well as the total elastic recovery does not seem to be related to denier per filament of yarn. Whilst fabrics produced from yarns bulked by the two differing methods show some difference in behaviour, there is little evidence to suggest that filament denier has a marked effect upon the initial and total elastic recovery.

6.3 Effect of Crimp Rigidity of Yarn on the

6.31 Elastic Recovery of Fabrics

One of the important variables in bulked yarns is the amount of crimp introduced and is usually measured in terms of crimp rigidity. In order to assess how this factor affects the elastic recovery of knitted fabrics, 2/100/34 (F1, F2 and F3) denier false twist nylon yarns having crimp rigidities of 12%, 19.8% and 30.8%, were employed. 1x1 rib fabrics were knitted from these yarns and their elastic recovery in the walewise direction was determined for the greige, steam relaxed, wet relaxed and dry tumbled states of the fabric.

The results are presented in Figures 72(a) to 72(d) and tables 28(a) to 28(d). In general, it is seen from these figures that as the crimp rigidity of the yarn is increased, there is an increase

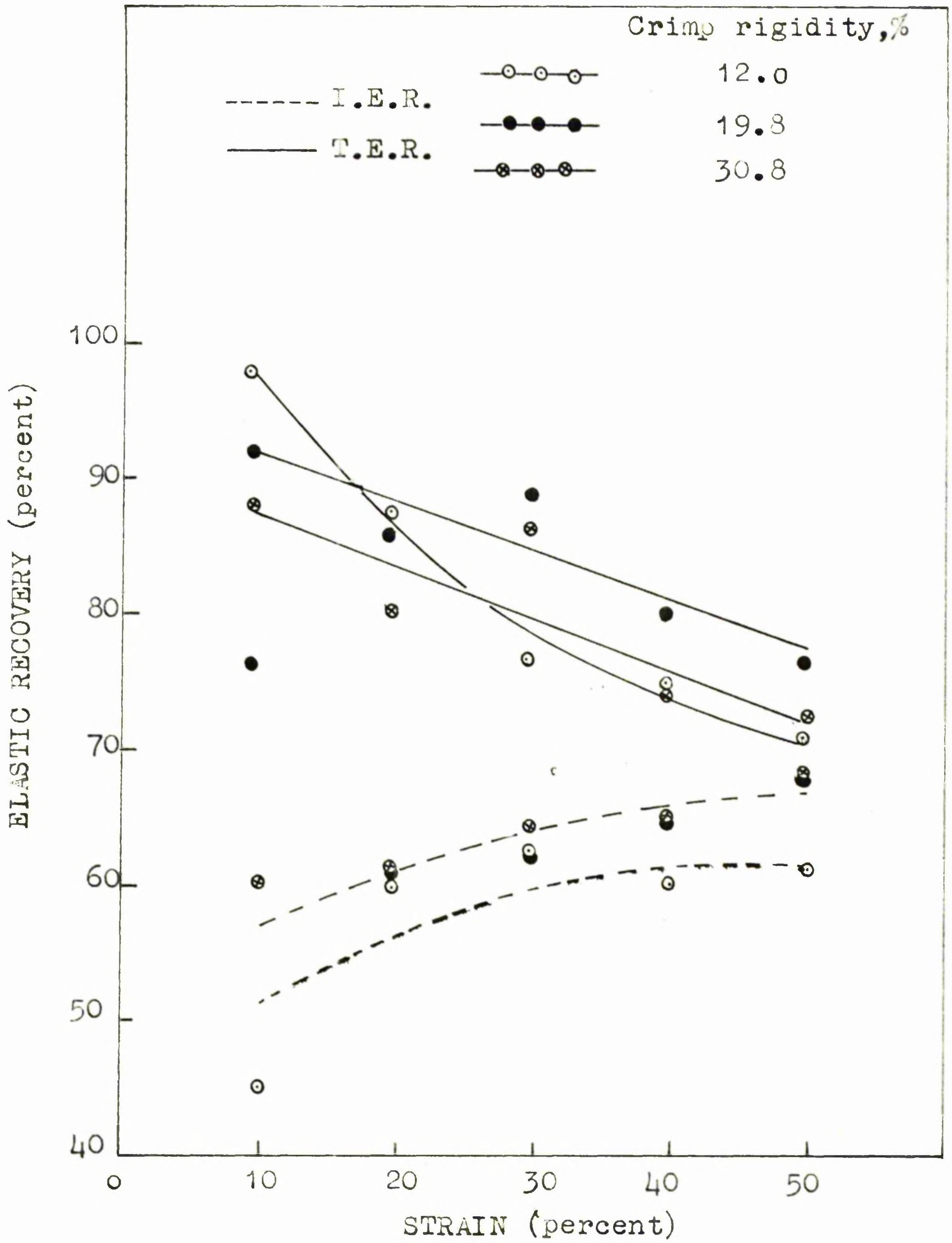


Fig.72(a). Effect of crimp rigidity of the yarn on the elastic recovery of fabrics (greige state).

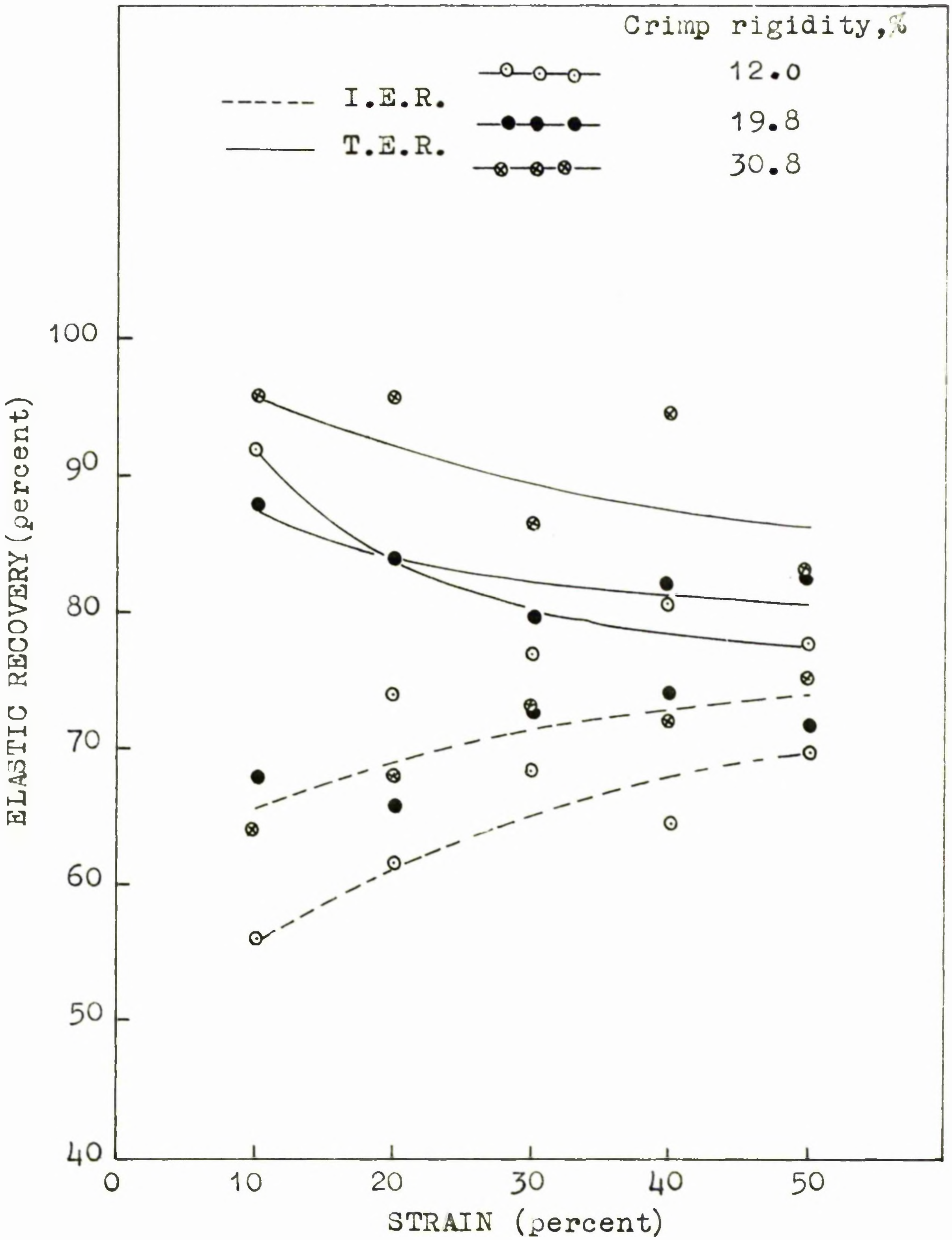


Fig.72(b). Effect of crimp rigidity of yarn on the elastic recovery of fabrics (steam relaxed).

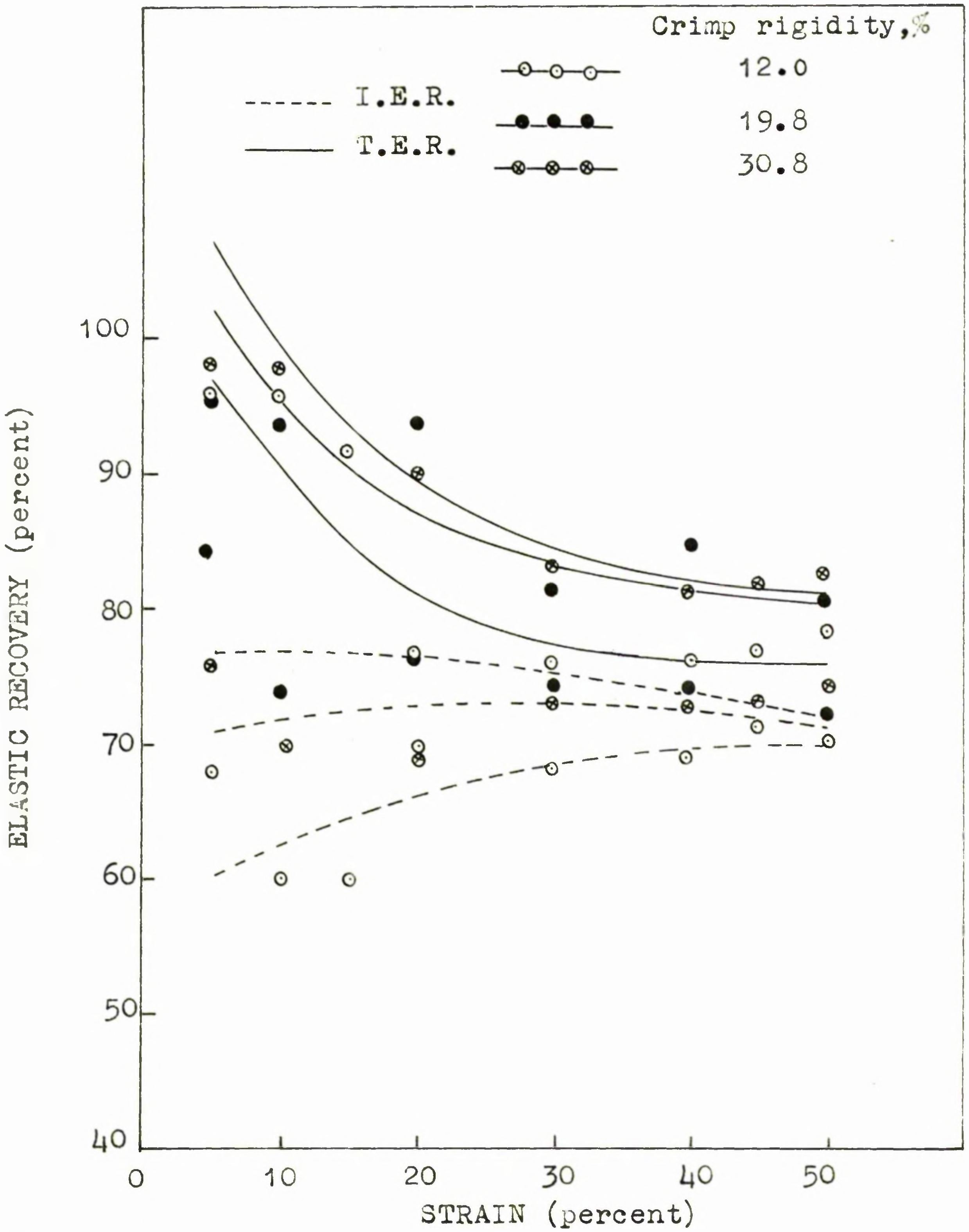


Fig. 72(c). Effect of crimp rigidity of yarn on the elastic recovery of fabrics (wet relaxed).

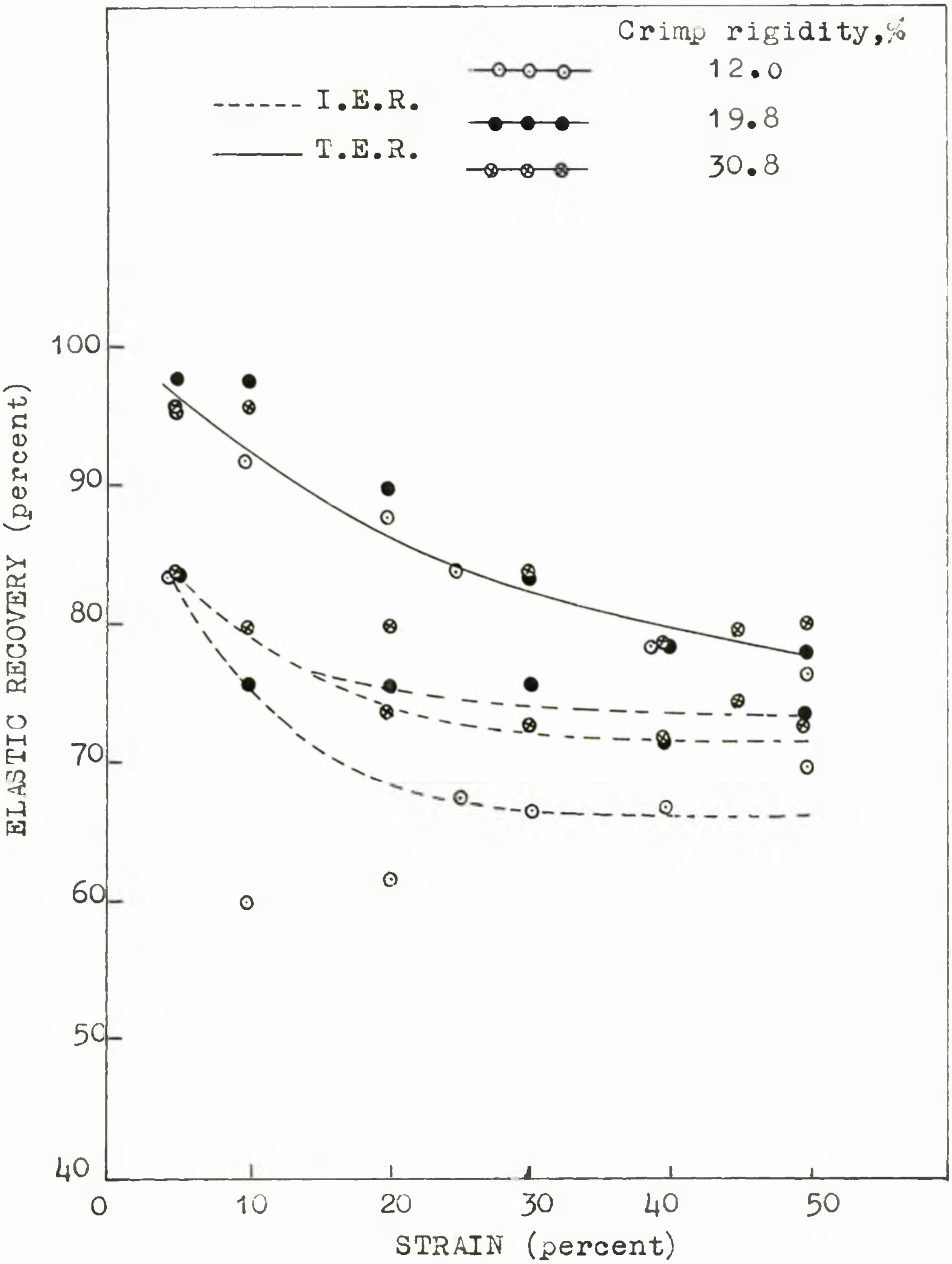


Fig.72(d). Effect of crimp rigidity of yarn on the elastic recovery of fabrics (dry tumbled).

in the initial elastic recovery of the fabric, but fabrics from yarns with 19.0% and 30.8% crimp rigidity values, give somewhat similar elastic recovery behaviour in all finished and greige states whilst the one with 12.0% crimp rigidity value shows slightly less recovery. When total elastic recovery is considered, it will be noted that the more severe finishing operations involving physical agitation (wet relaxation and dry tumbling) minimise the effect of differing yarn crimp rigidities.

It has been suggested that the greater the amount of crimp in a yarn, the more powerful the recovery and the more full the handle. The present results would indicate that this suggestion is not correct, these results being in agreement with the view expressed by Fox[138]. It is believed that an excessively high crimp rigidity value hinders recovery due to high inter-loop friction which restricts the return of the loops to their normal stable configuration after fabric extension.

The above observations suggest that it is inadvisable to use a high crimp rigidity yarn for fabrics in which high elastic recovery is desirable. It may perhaps be possible to achieve adequate recovery by very tight knitting but this would result in unnecessarily heavy fabrics. The use of a medium crimp rigidity yarn therefore offers more latitude in this respect.

The influence of finishing processes can be seen in tables 28(a) to 28(d). Thus, though an improvement in elastic recovery of fabrics is obtained by these finishing processes at low levels of strain, these differences are less marked at levels above 30 per cent. It is reasonable, therefore, to assume that once the fabric structure has been allowed to relax or consolidate to its greatest extent, no matter what method, it would exhibit similar elastic properties. It may be noted from table 28(d) that initial elastic recovery values for dry tumbled fabrics at low strain levels (approximately up to 10%) are fairly high.

6.32 Load-strain Characteristics

The influence of crimp rigidity of the yarn on the load-strain characteristics of fabrics is shown in Figures 73(a) to 73(d). These curves have been computed (as described earlier) from the data obtained from hysteresis loops recorded for the study of elastic recovery behaviour of fabrics up to 50% walewise extension. Figure 73(a) represents the load-strain behaviour of 1x1 rib fabric in its greige state. It is noted that a greater load is required to stretch a fabric to any given amount knitted from the yarn of 12% crimp rigidity as compared with fabrics from 19.8% and 30.8% crimp rigidity yarns. Also the fabrics from the last two yarns do not differ greatly in load-strain characteristics, though a slightly greater load is required to stretch a fabric produced from 30.8% crimp rigidity yarn.

It has been suggested in the previous section that a greater amount of inter-loop friction would exist as a result of inter-filament and inter-yarn entanglement in fabrics made from yarns of

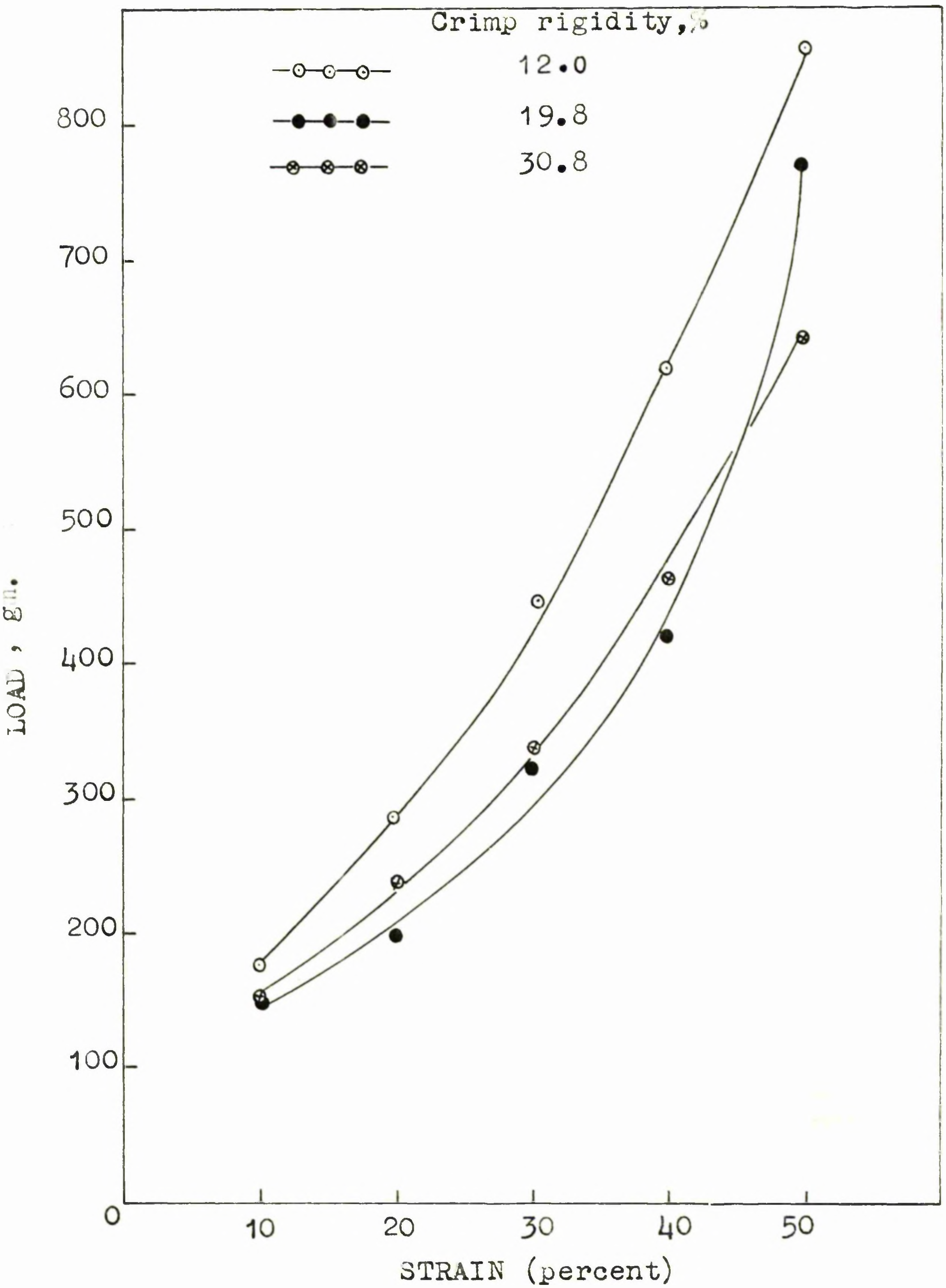


Fig.73(a). Load-strain characterstics of fabrics (greige state) knitted from yarns of varying crimp rigidities.

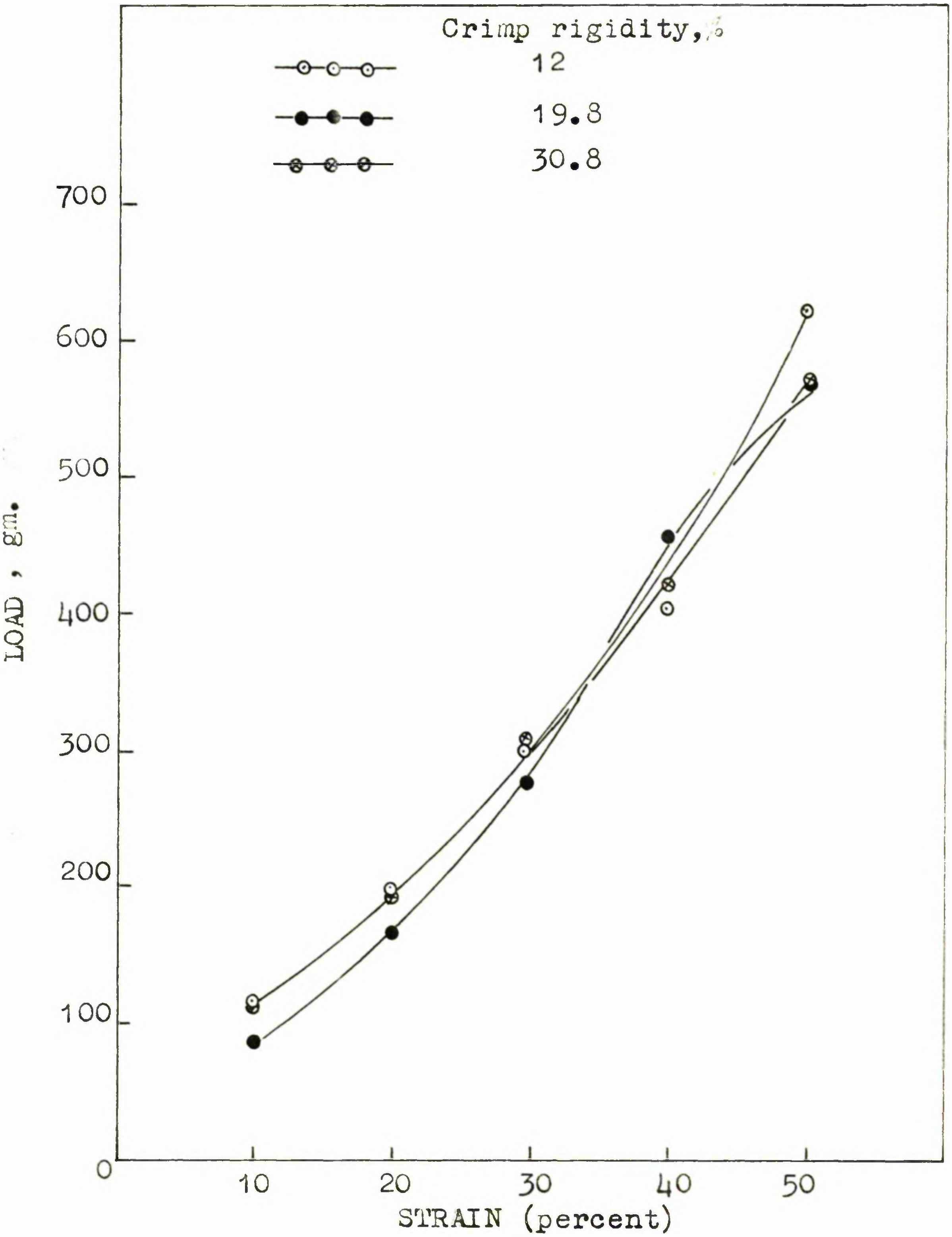


Fig.73(b). Load-strain characterstics of fabrics (steam relaxed) knitted from yarn of varying crimp rigidities.

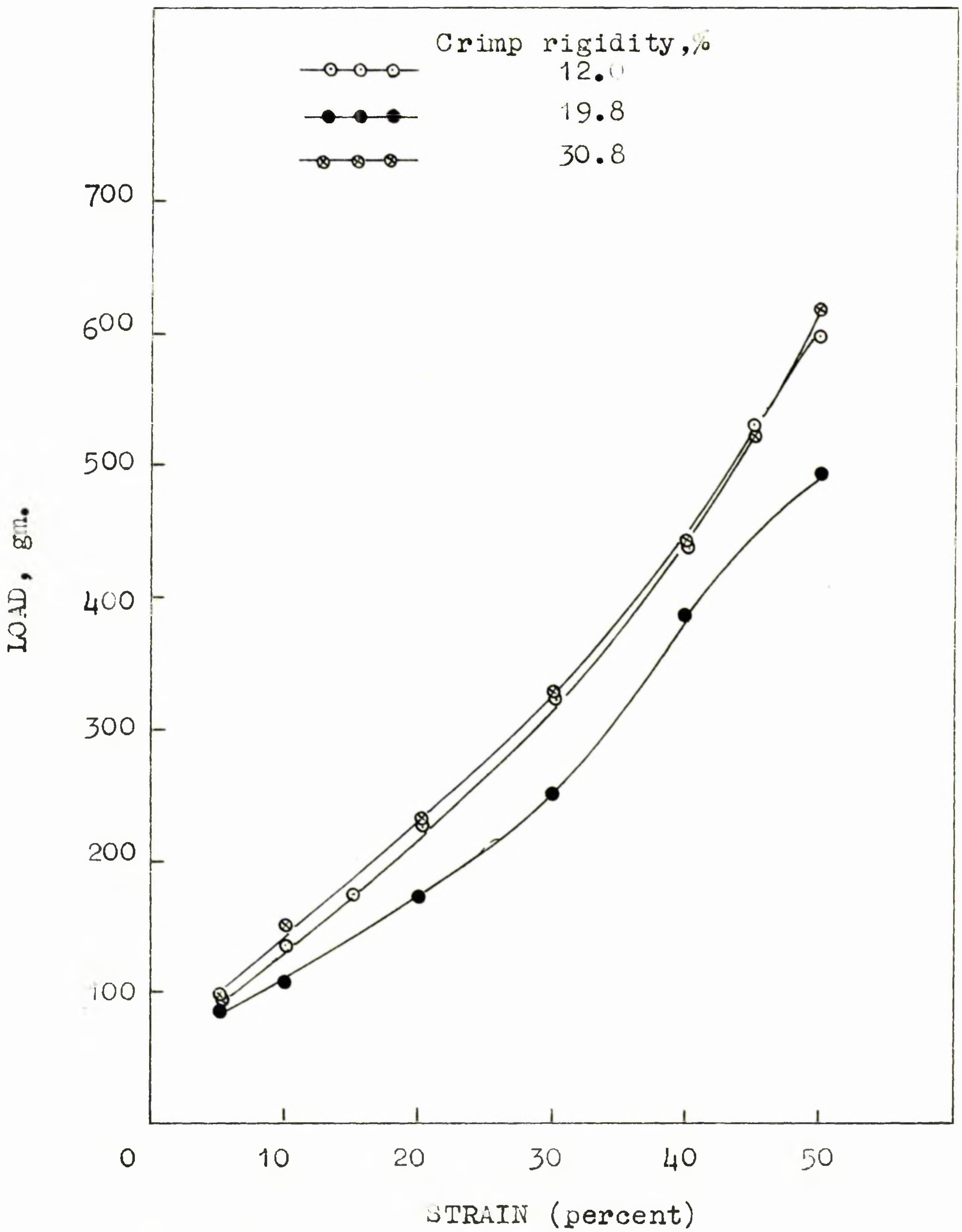


Fig. 73(c). Load-strain characteristics of fabrics (wet relaxed) knitted from yarn of varying crimp rigidities.

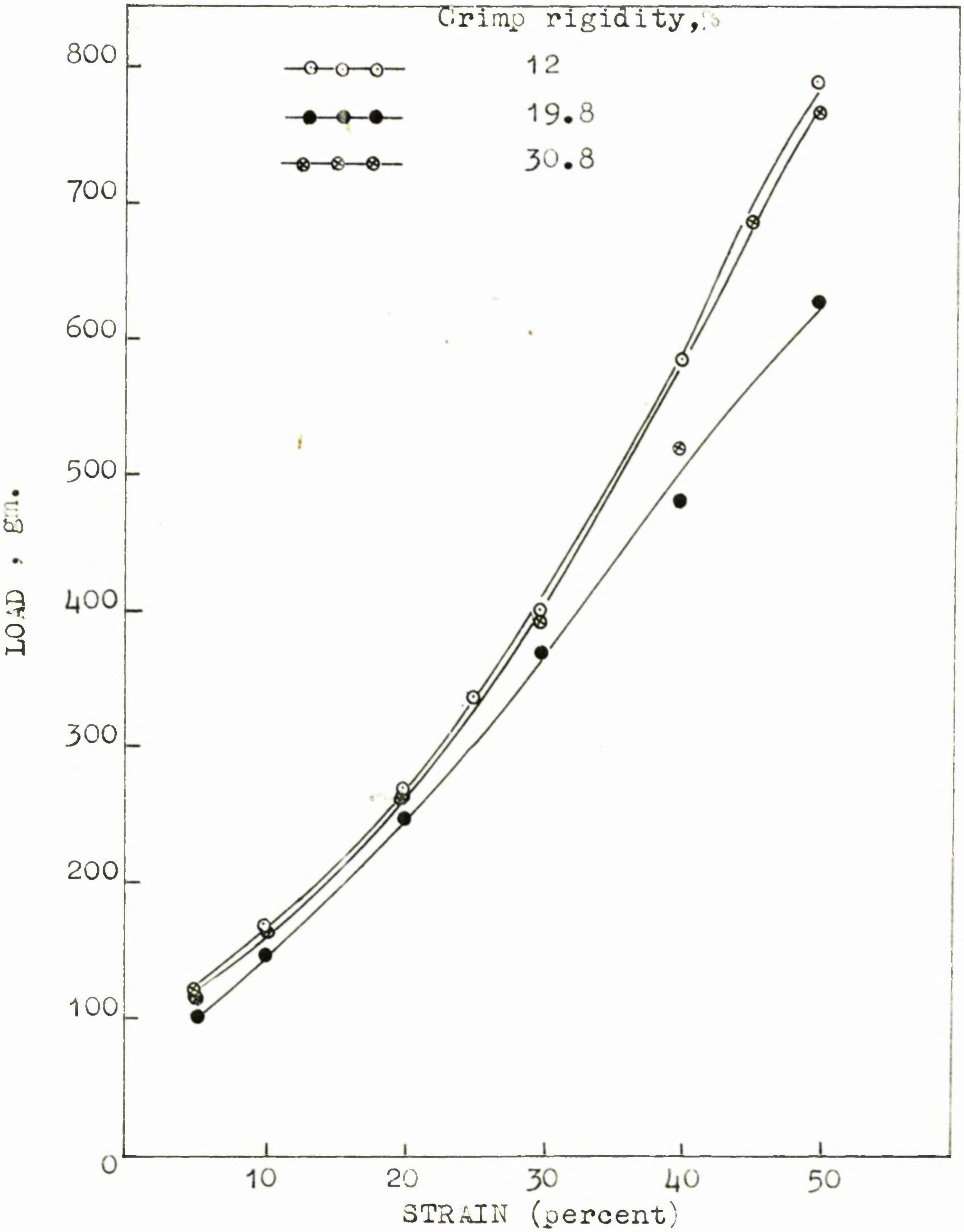


Fig.73(d). Load-strain characterstics of fabrics (dry tumbled) knitted from yarn of varying crimp rigidities.

high crimp rigidity. It would, therefore, follow that such fabrics would offer more resistance to tensile deformation and so need a greater load to extend to any given amount. In addition to this, it will be noted from table (22) in chapter (5) that the courses per inch to wales per inch ratio is higher for fabrics from yarns of high crimp rigidity indicating that the configuration of the loop is such that it is larger in length than in width. It is reasonable to expect that when such a fabric is stretched in the direction of the larger dimension of the loop, it will require a greater load. While these points explain the load-strain behaviour of fabrics from yarns of 19.8% and 30.8% crimp rigidities, the behaviour of the fabric from yarn of 12.8% crimp rigidity does not fit into this context. This is probably due to the fact that this yarn has the highest coefficient of friction (table 3(c) chapter 2) of these three yarns.

When these fabrics are relaxed in steam, the differences observed in the case of greige fabric, disappear (Fig.73(b). When yarns are extracted from the steam relaxed fabric, it is noticed that an adhesion of the individual filaments takes place and it may be assumed that the frictional forces (inter-filament and inter-yarn) will be reduced in steam relaxed fabrics. Also the collapse of the fabrics under examination is similar as will be seen from an inspection of courses per inch and wales per inch (table 22). Because of these considerations, it is, therefore, not surprising that the load-strain behaviour is more or less similar for these fabrics. Further, a comparison of Figures 73(a) and 73(b) would reveal that the modulus of steam relaxed fabric is lower than that of the greige state fabric. Reasons for this have already been explained under Section 6.12.

The effect of crimp rigidity on the load-strain behaviour of wet relaxed and dry tumbled fabrics is shown in Figures 73(c) and 73(d). These two relaxation processes lead to an almost identical behaviour in that the fabric from 12% and 30.8% crimp rigidity yarns do not show any significant differences between these processes whereas the fabric from the 19.8% crimp rigidity yarn requires a smaller load for the same amount of strain, the differences becoming larger particularly for extensions above thirty per cent. These observations are very similar to those obtained from the greige state fabric, except that the shift of the curve for fabric from 30.8% crimp rigidity yarn is towards that of the fabric from 12% crimp rigidity yarn.

6.4 Comparison of 1x1 Rib Fabrics Knitted from False Twist Crimped and Stuffer Box Bulked Yarns with respect to

6.41 Elastic Recovery of Fabrics

2/70/20 denier false twist (F5) and 1/70/20 Textralised (T1 stuffer box bulked) yarns were selected to study the effect of bulking process on the elastic recovery behaviour of 1x1 rib fabrics knitted from them. The fabrics were finished as described earlier, by steam relaxation, wet relaxation and dry tumbling. The recovery properties being determined for their differing states.

The results are presented graphically in Figures 74(a) to 74(d) and it will be seen that the initial as well as the total elastic recovery of fabrics from Textralized yarns are generally lower than those made from false twist yarns despite the slightly greater number of wales per inch in the fabrics from the Textralized yarns. After finishing these fabrics by steam and wet relaxation, the differences are more pronounced whereas dry tumbling seems to reduce these differences. This would, therefore, suggest that once the fabrics are dry tumbled, their elastic properties are almost the same, irrespective of the method of bulking the yarns. It is also noticed from these Figures 74(a) to 74(d) and tables 29(a) to 29(d) that all three relaxation treatments bring about an improvement in the recovery properties of fabrics under investigation and, after steam relaxation, the fabric appears to be stabilized in the sense that the total elastic recovery/extension curves tend to flatten out beyond approximately 30% extension whereas this flattening does not occur for wet relaxed and dry tumbled fabrics. This is perhaps reasonable to expect because when fabrics from bulked yarns are released from extension, the strained loops tend to recover their relaxed shape and length. The forces favouring recovery to the original fabric dimension or shape are generally opposed by frictional forces within the yarn and between adjacent loops, and when strain is removed, the individual filaments of each knitted loop

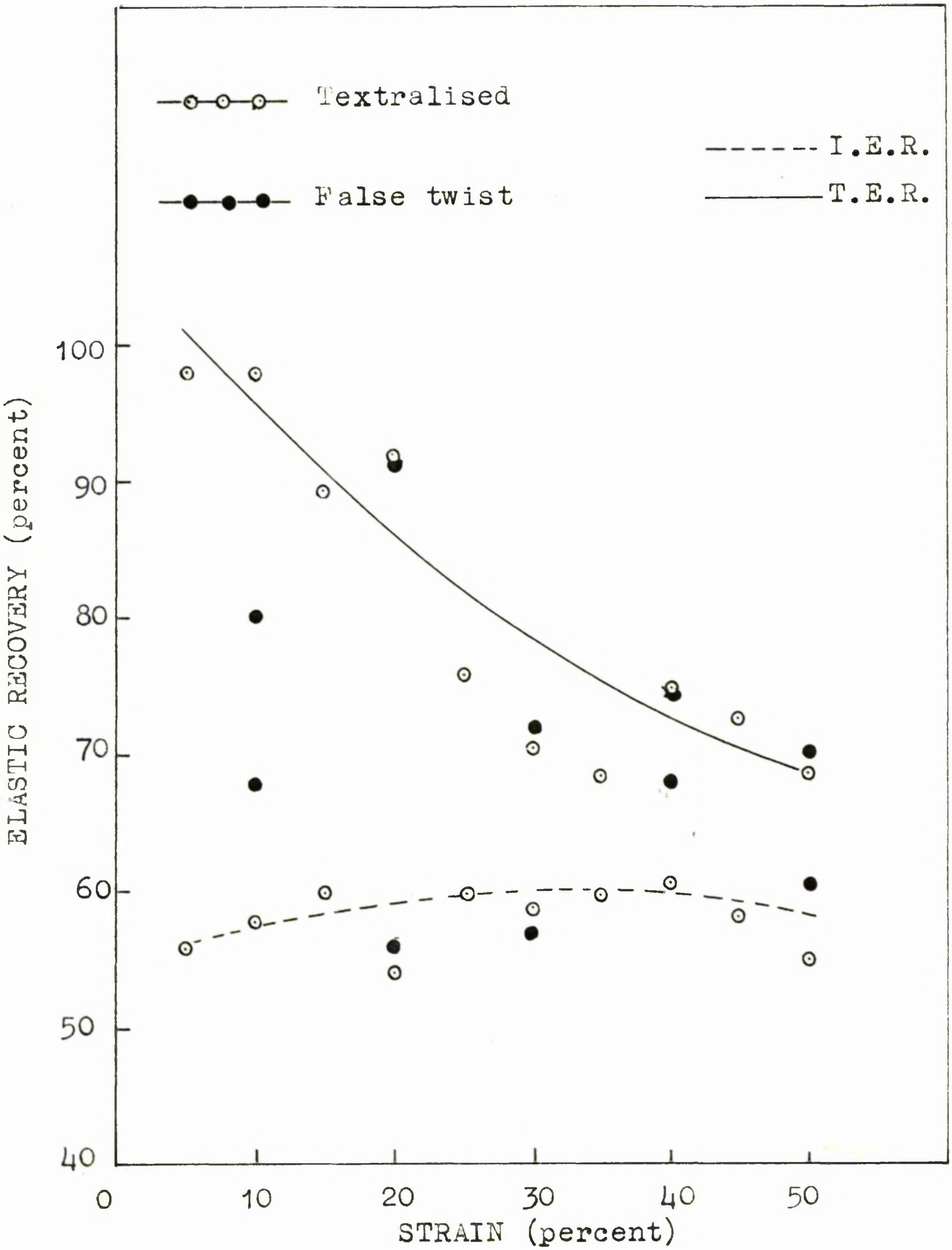


Fig.74(a). Comparison of elastic recovery of fabrics (greige state) knitted from Textralized (stuffer box bulked) and false twist crimped yarns.

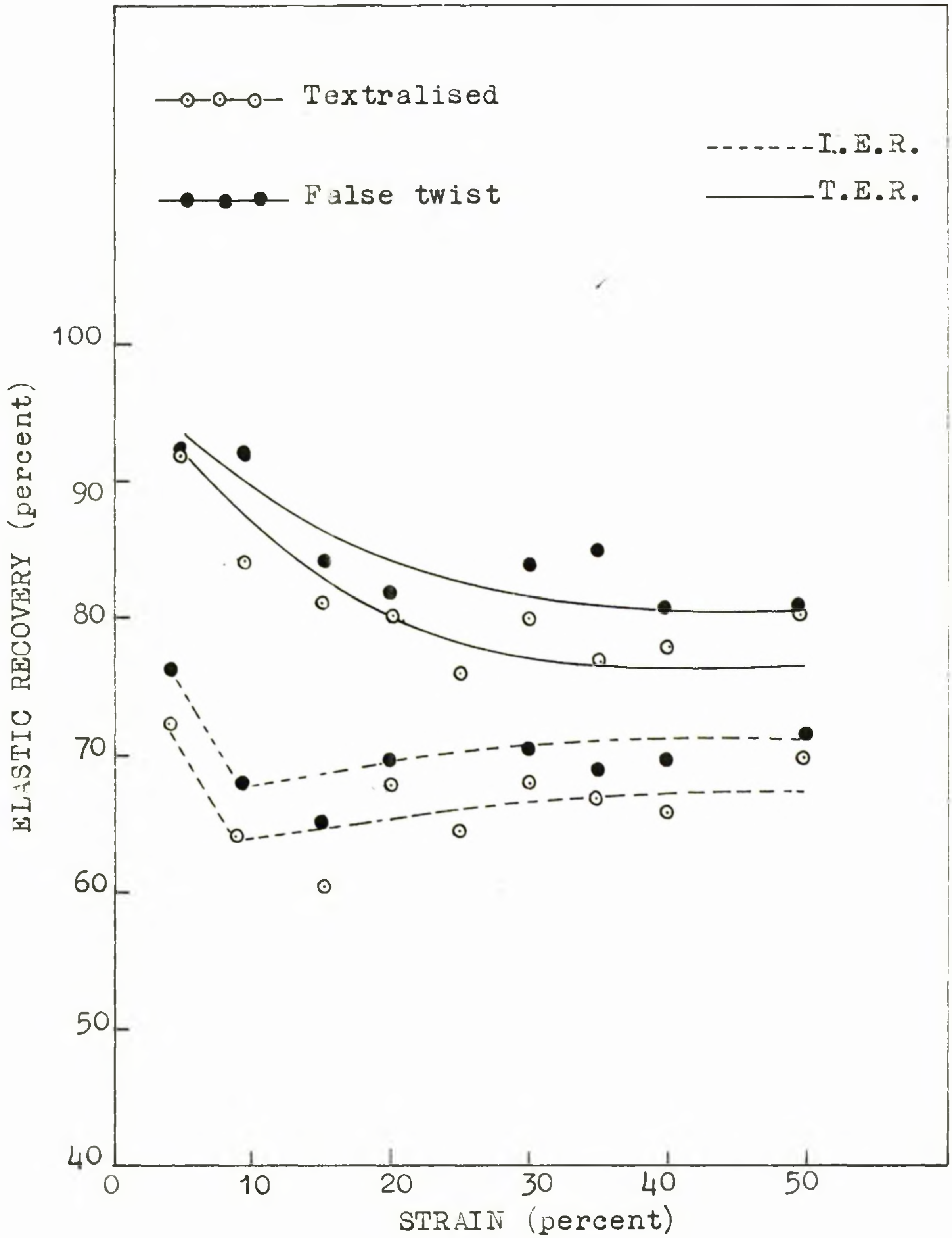


Fig.74(b). Comparison of elastic recovery of fabrics (steam relaxed) knitted from Textralized (stuffer box bulked) and false twist crimped yarns.

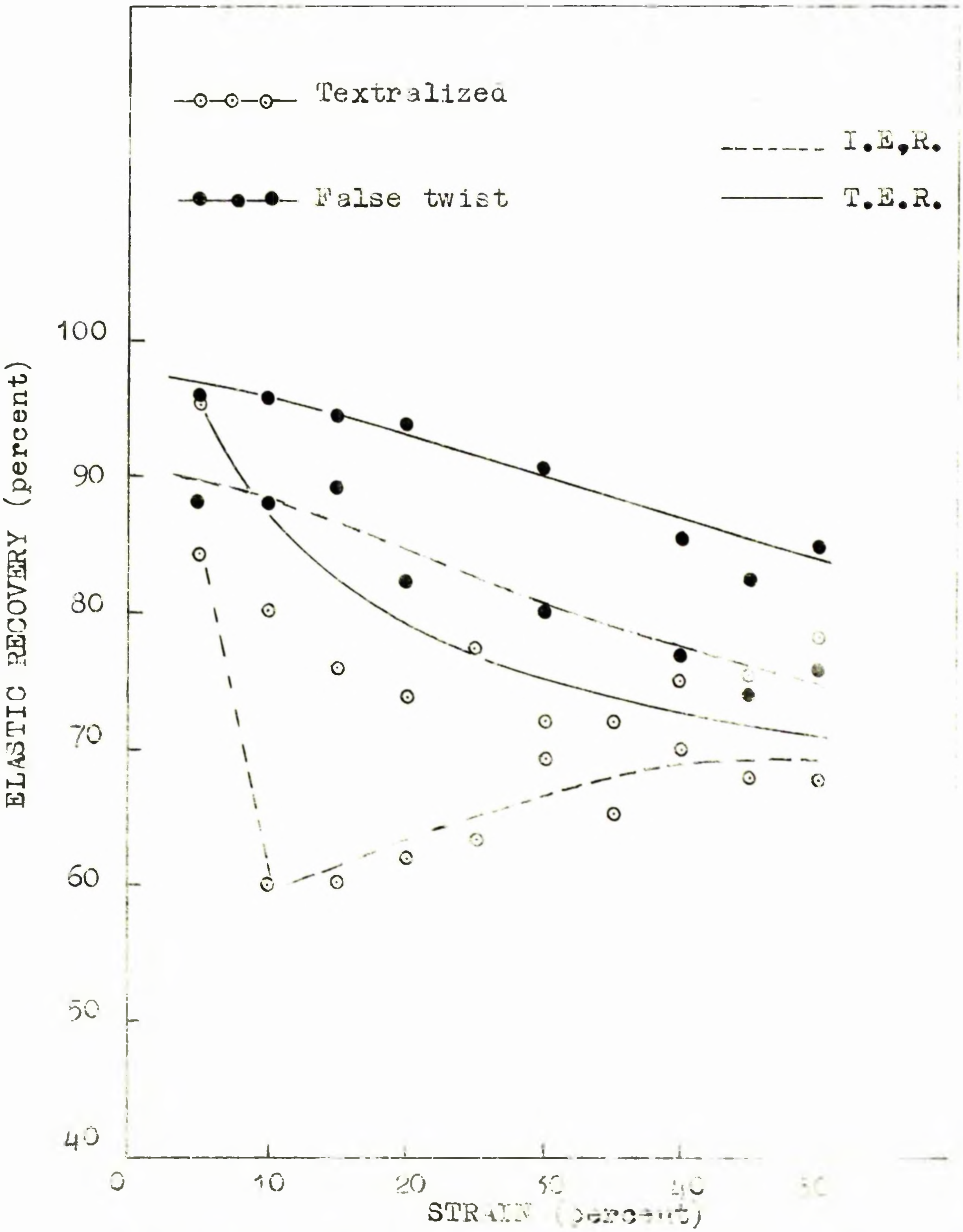


Fig. 74(c). Comparison of the elastic recov[illegible] fabrics (wet relaxed) knitted from [illegible] (stuffer box [illegible]) and false twist [illegible]

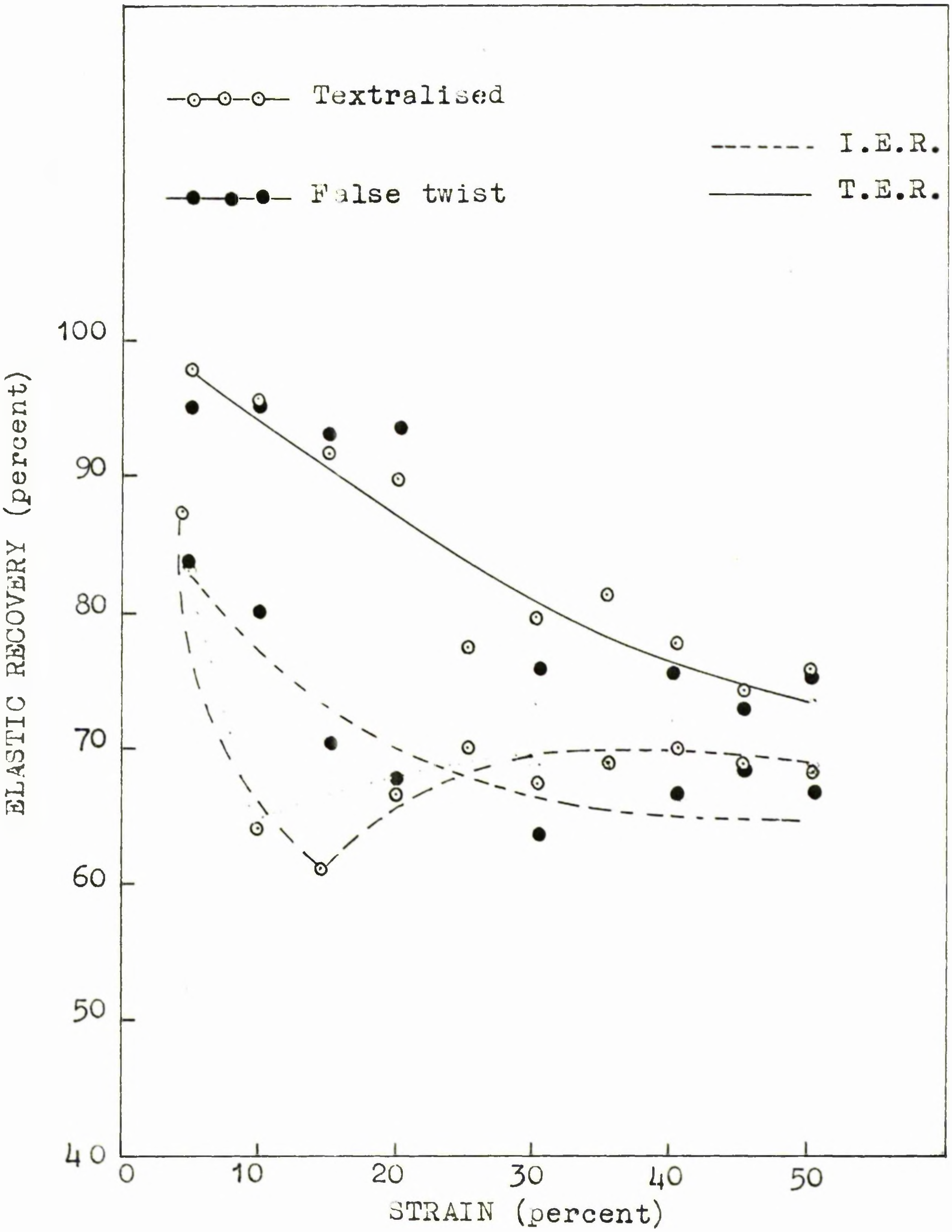


Fig.74(d). Comparison of elastic recovery of fabrics (dry tumbled) knitted from Textralized (stuffer box bulked) and false twist crimped yarns.

spring apart and therefore become entangled with each other, possibly assuming a new configuration. In the case of fabrics relaxed in steam, some of the individual filaments remain locked (filament adhesion) with each other and when these fabrics are extended and released, the chances of the individual filaments springing apart are much less as compared with fabrics finished by wet relaxation and dry tumbling (these two processes involving considerable agitation).

It has been stated that the recovery of fabrics knitted from stuffer box bulked yarns is lower than that of fabrics made from false twist yarns. It is appreciated that the type of the crimping process affects the nature of the yarn crimp and consequently its recovery power, friction etc. However, tables (22) and (23) would indicate that fabrics made from 1/70/20 Textralized yarn (T1) (6 ends) are tighter than those made from 2/70/20 false twist yarn (3 ends) because of their increasedstitch densities and decreased stitch lengths. Because of these differences one would expect a better recovery behaviour for fabrics from 1/70/20 Textralised yarn. Since this is not observed, the lower recovery can only be attributed to the nature of the crimp. In fabrics from Textralized yarns, it is not difficult to remove or deform the crimp when the fabrics are extended but when they are released from that extension, possibly there are not sufficient forces present to recover the original crimp and consequently the fabric shape within the time limit imposed by the method of testing.

The two yarns 2/70/20 false twist and 1/70/20 Textralised so far considered were similar in all respects other than the crimp rigidity of the two yarns which was different. Whereas the false twist yarn was of 27.6% crimp rigidity, Textralised yarn was of only 13% crimp rigidity. In order to clarify the doubt which might arise out of this variation, two other yarns, 2/100/34 false twist (F2) of 19.8% crimp rigidity and 1/150/50 Textralised (T3), of 16% crimp rigidity, were selected. These were two yarns available and were identical other than for the method of bulking. 1x1 rib fabrics were knitted using 3 ends of yarn (F2) and 4 ends of yarn (T3) so as to obtain the same total denier. The elastic recovery of these fabrics in the greige and finished states is presented in Figures 75(a) to 75(d). It will be seen from these figures that the results are similar to those obtained with fabrics from 2/70/20 false twist and 1/70/20 Textralised yarns. The performance of fabrics produced from the two previously mentioned yarns would indicate that those fabrics made from stuffer box bulked yarns are inferior in their recovery property but if the performance of other fabrics in this work is surveyed and consignance be taken of yarn variables such as crimp, filament count and yarn count, then the greige state stuffer box fabrics would appear to have a performance just a little above that exhibited by the greige state false twist fabrics. However, finishing by dry tumbling would appear to nearly eliminate the differences created by the differing

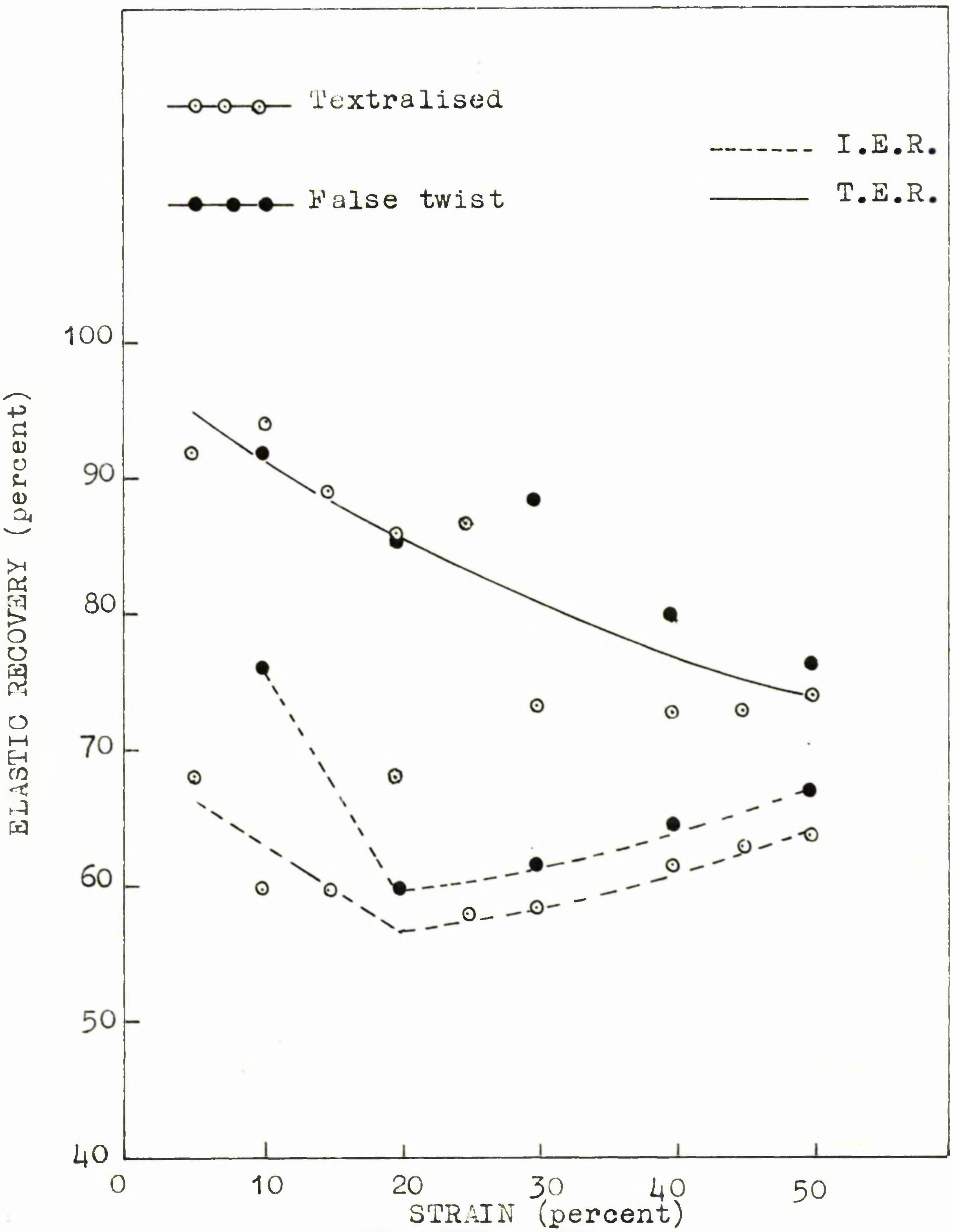


Fig.75(a). Comparison of elastic recovery of fabrics (greige state) knitted from Textralized (stuffer box bulked) and false twist crimped yarns.

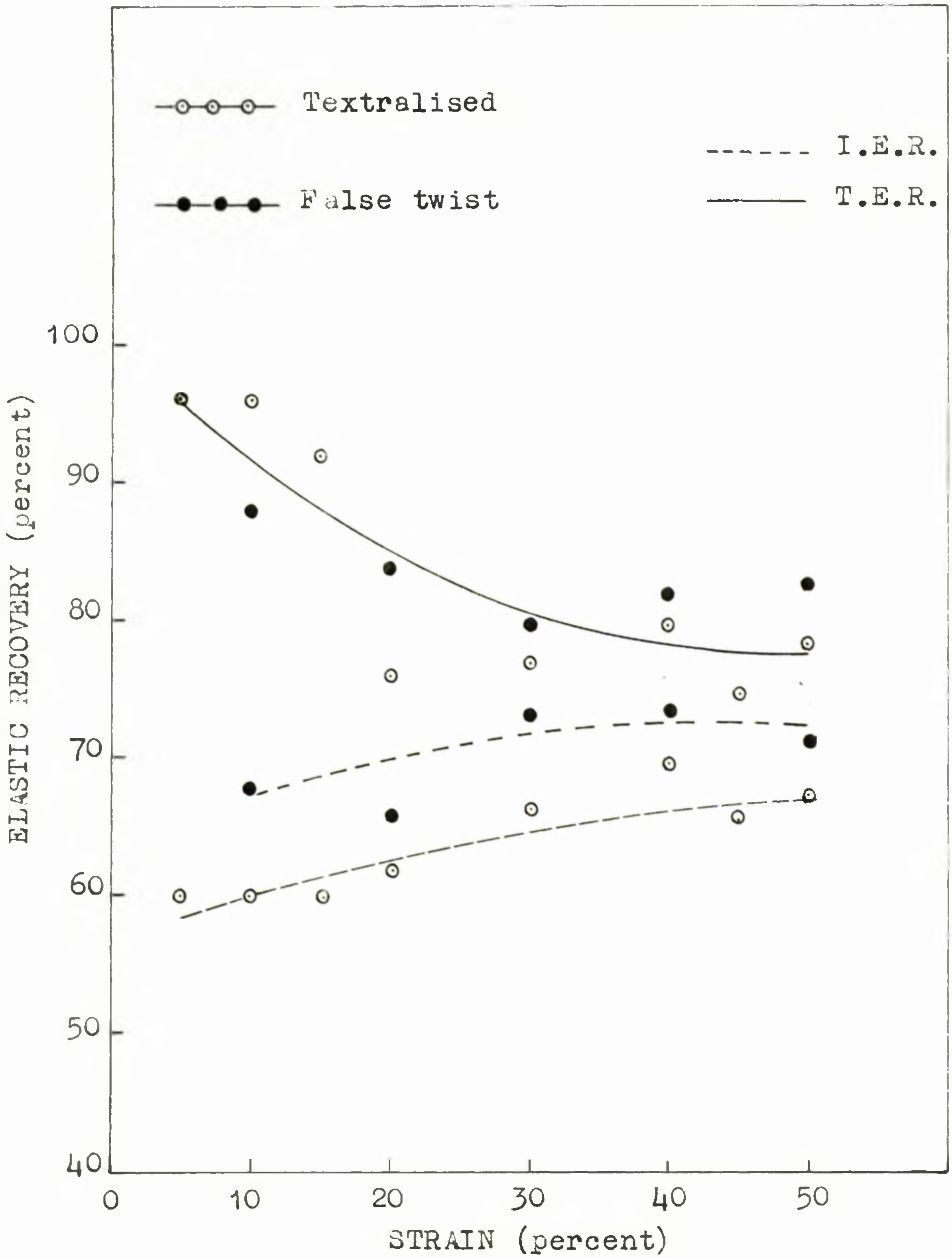


Fig.75(b). Comparison of elastic recovery of fabrics (steam relaxed) knitted from Textralized (stuffer box) bulked) and false twist crimped yarns.

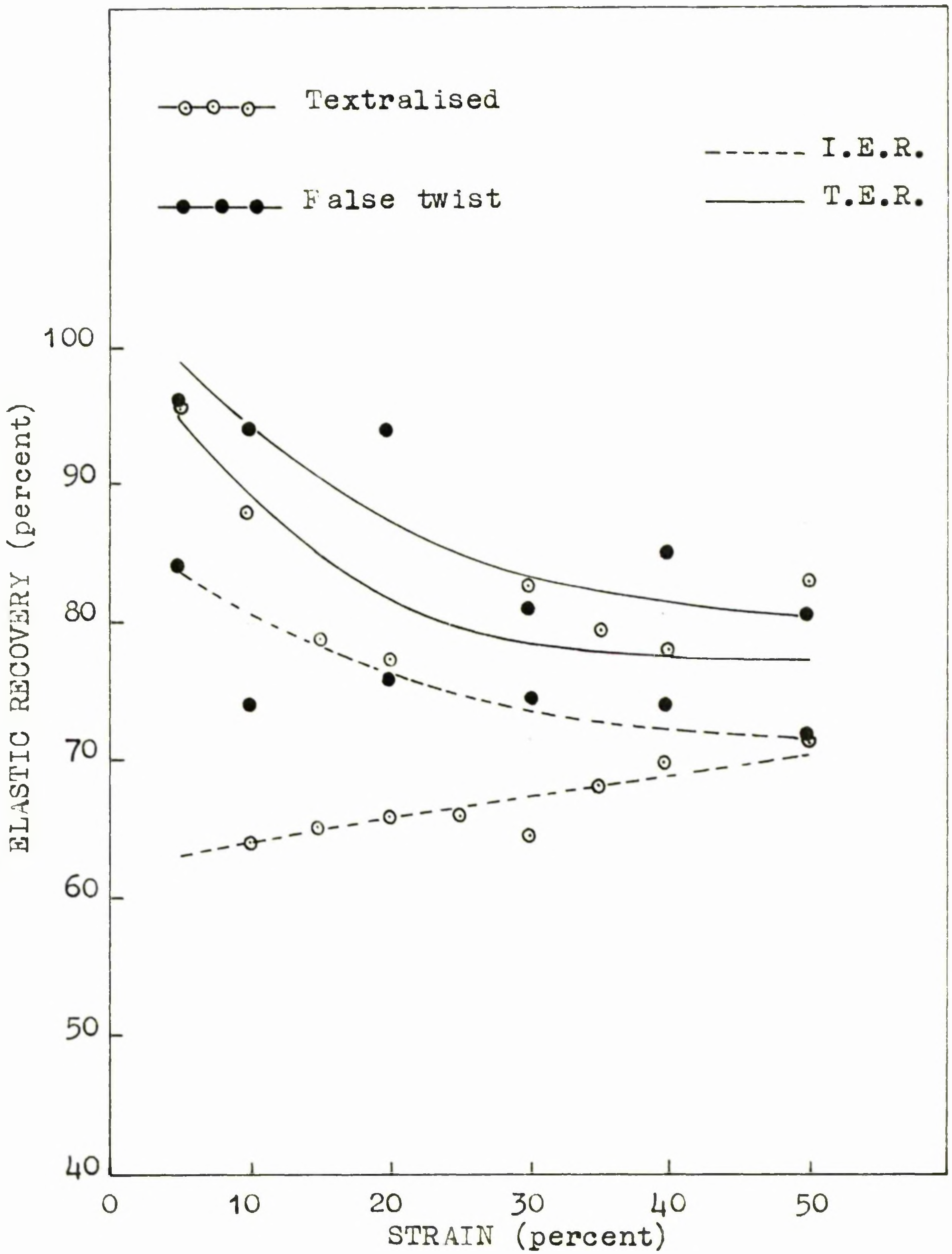


Fig.75(c). Comparison of elastic recovery of fabrics (wet relaxed) knitted from Textralized (stuffer box bulked) and false twist crimped yarns.

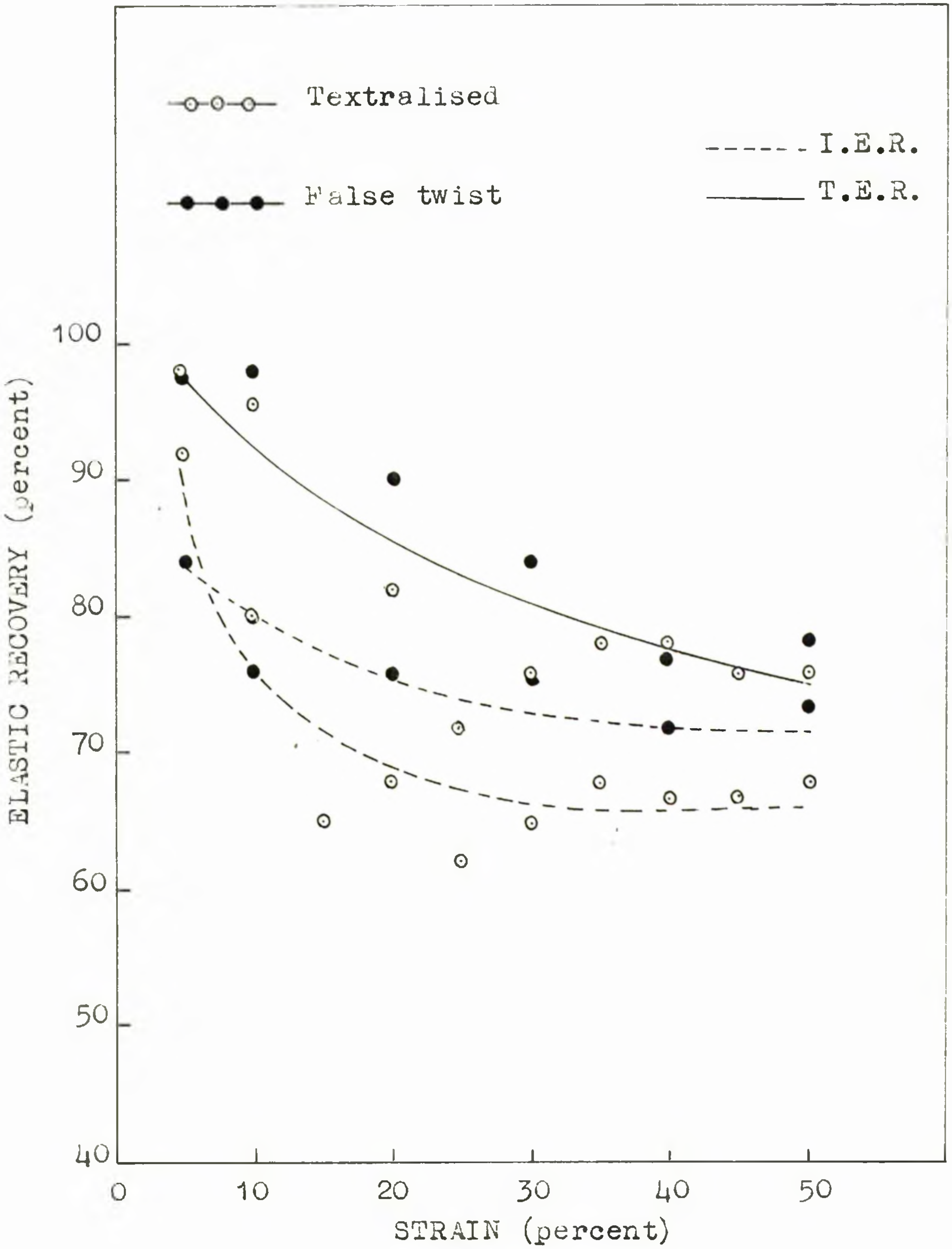


Fig.75(d). Comparison of elastic recovery of fabrics (dry tumbled) knitted from Textralized (stuffer box bulked) and false twist crimped yarns.

methods of yarn bulking.

6.42 Load-strain Characteristics

The load-strain data for fabrics made from 2/100/34 false twist (F2 and 1/150/30 Textralised (T3) yarns is shown in Figures 76(a) to 76(d). Generally, false twist yarns have a very high extension, of the order of 400-500 per cent. whereas stuffer box bulked yarns show a lower capacity for extension[139]. It is noted from these figures that the load-strain curves for fabrics knitted from Textralised yarns lie above those for fabrics produced from false twist crimped yarns. Arthur[37] compared the stress-strain properties of various types of bulked yarns and his results for Banlon and false twist crimped nylon yarn bear resemblance to the results obtained for fabrics in this work. However, Arthur did not provide and explanation for the differences encountered which could be probably attributed to the configuration of the Banlon yarn in which there would be more load bearing elements for a given extension than in the case of false twist crimped yarn. This suggestion accounts for the differences observed in the load-strain behaviour of fabrics made from Textralised and false twist crimped yarns.

Furthermore, it will be noted from Figures 76(a) to 76(d) that the influence of finishing treatments on the load-strain characteristics of fabrics from Textralised yarns is similar to that discussed already (Section 6.12) for fabrics knitted from false twist crimped yarns.

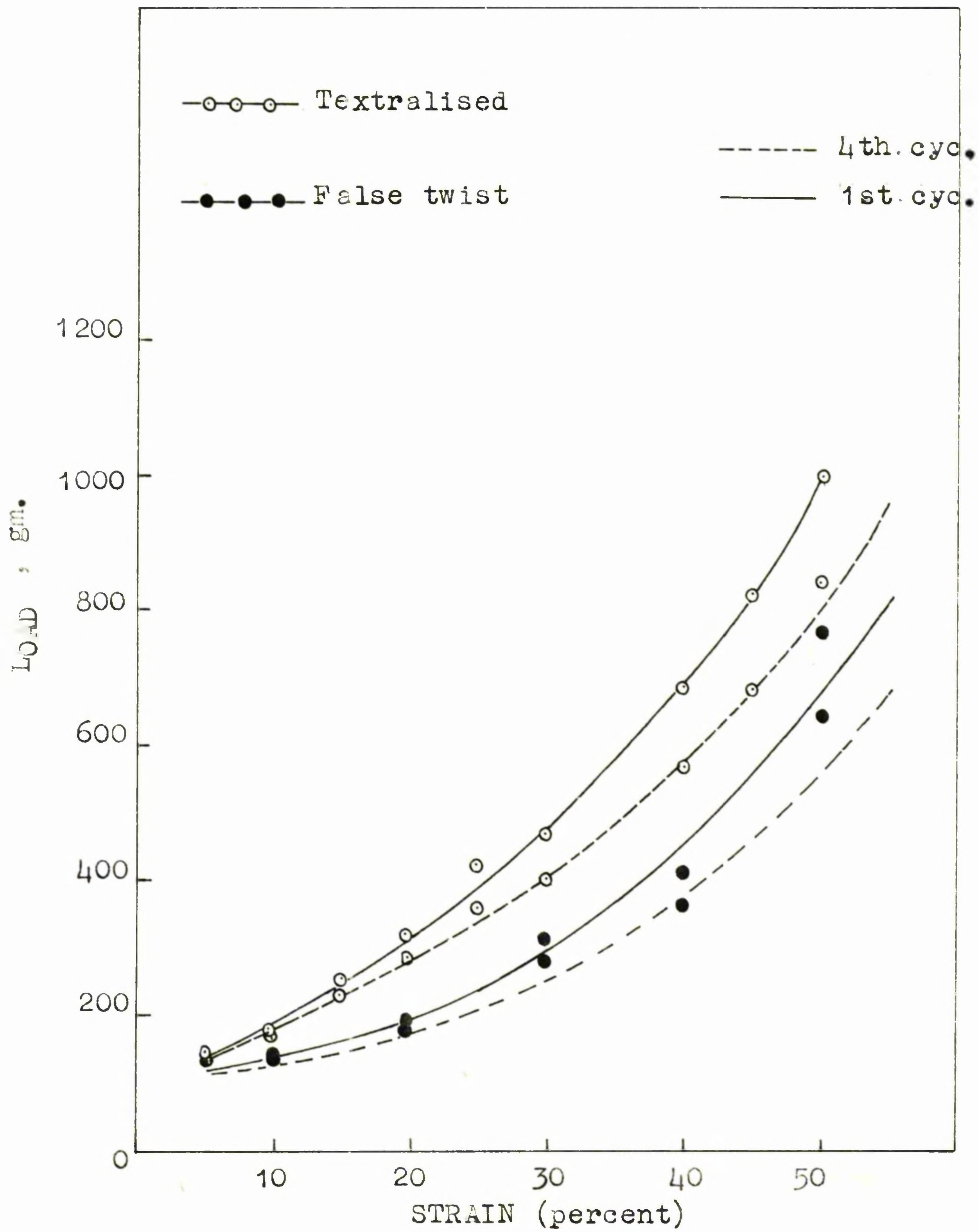


Fig. 76(a). Load-strain characterstics of fabrics (greige state) knitted from Textralized (stuffer box bulked) and false twist crimped yarns.

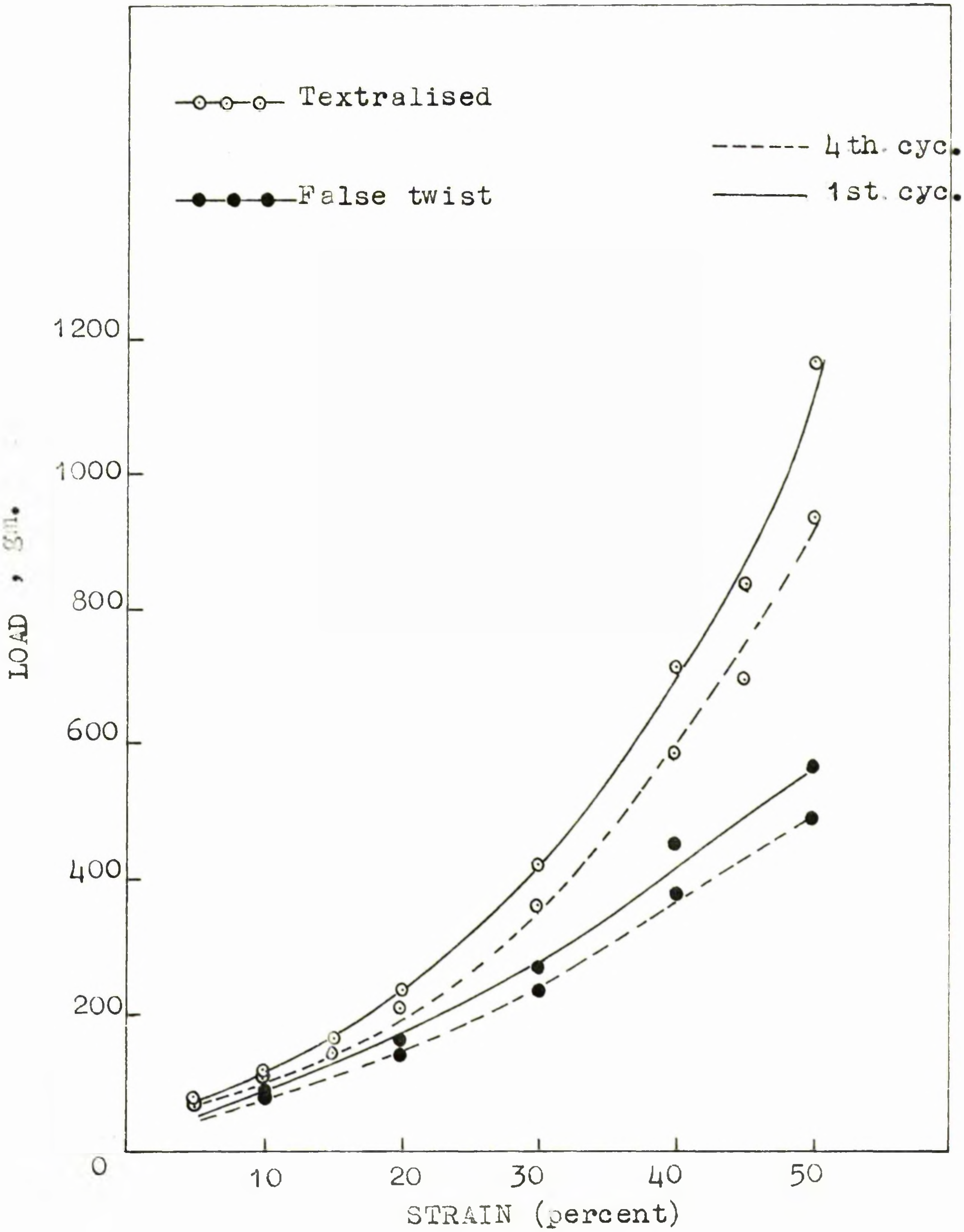


Fig.76(b). Load-strain characterstics of fabrics (steam relaxed) knitted from Textralized (stuffer box bulked) and false twist crimped yarns.

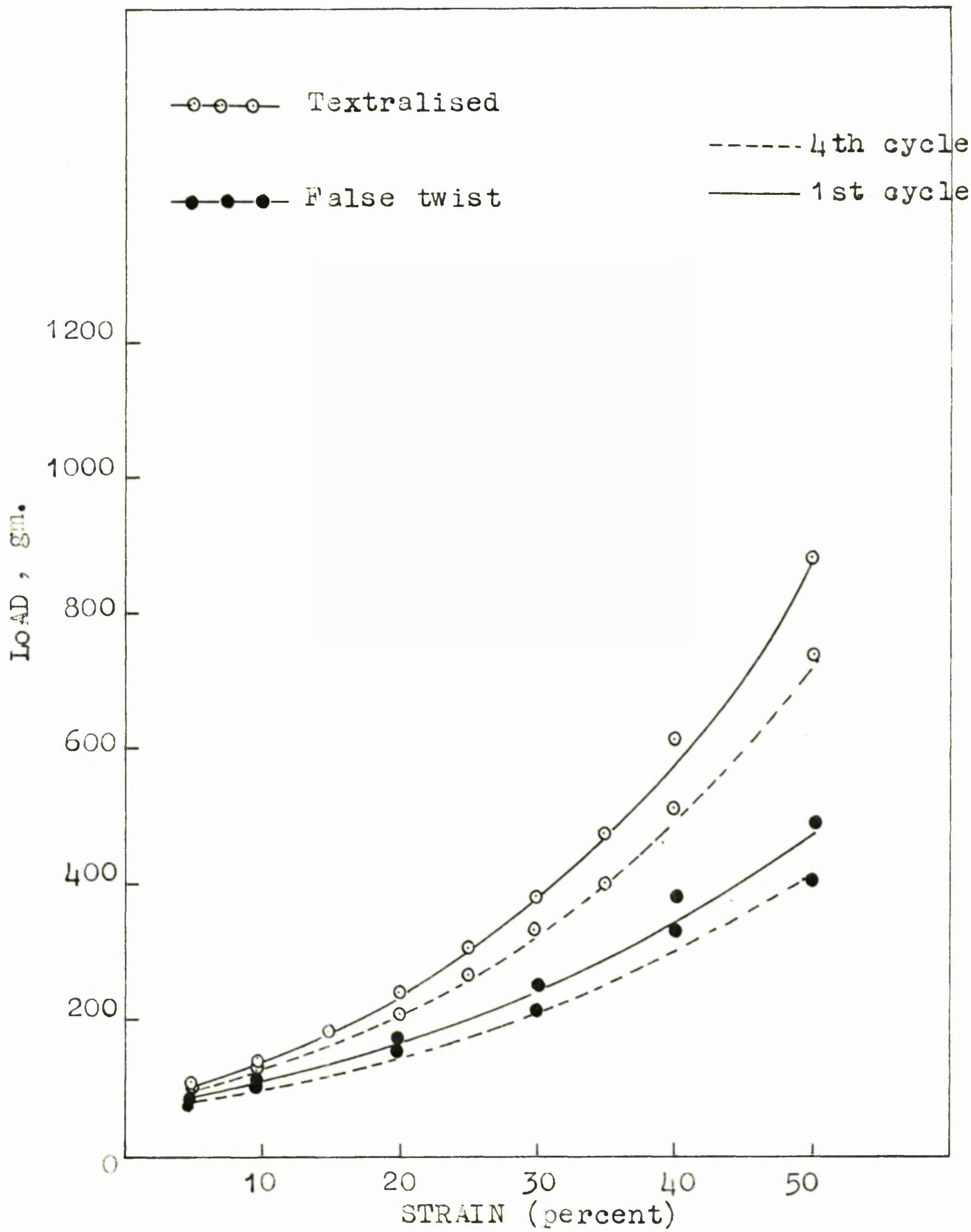


Fig.76(c). Load-strain characterstics of fabrics (wet relaxed) knitted from Textralized (stuffer box bulked) and false twist crimped yarns.

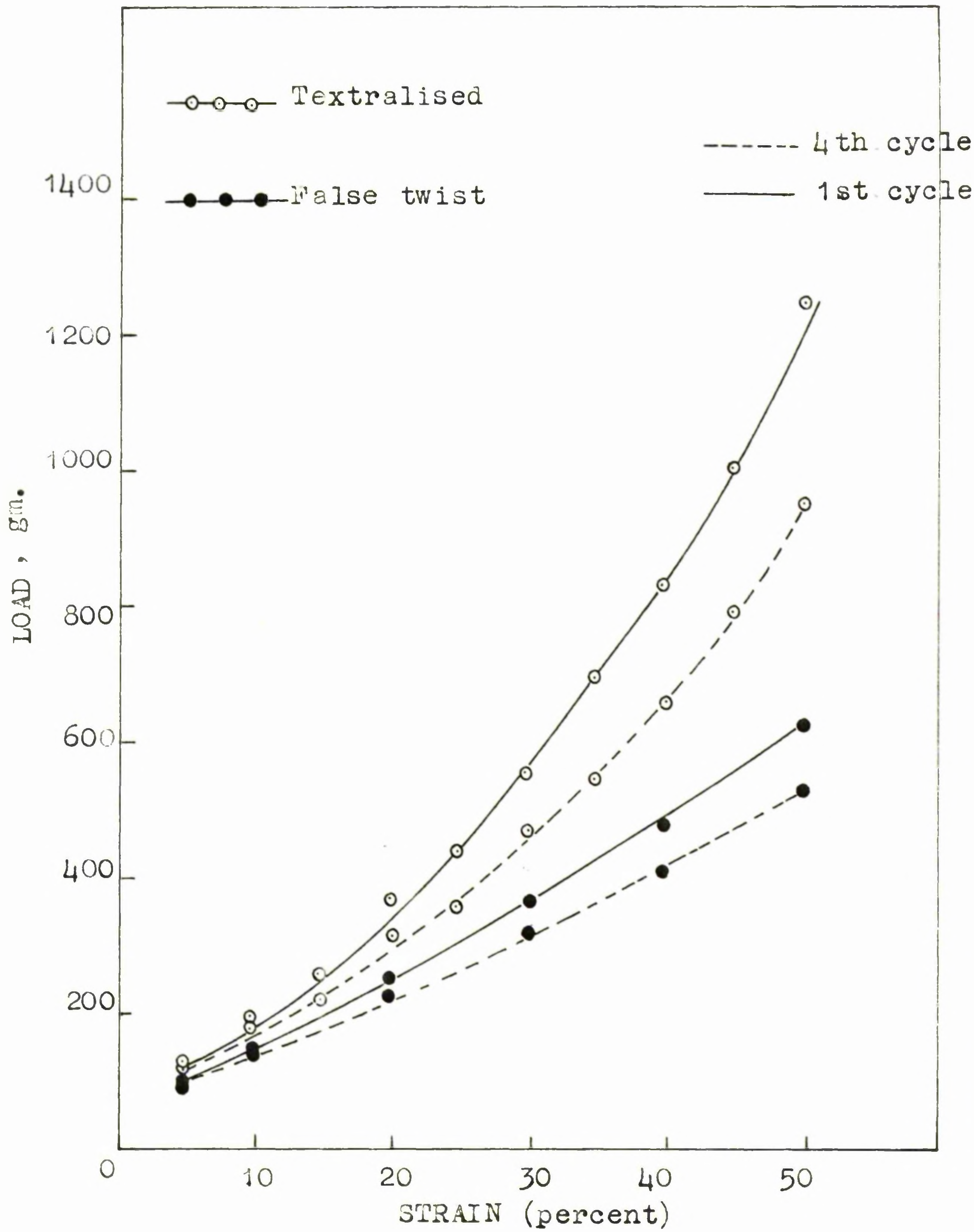


Fig.76(d). Load-strain characterstics of fabrics (dry tumbled) knitted from Textralized (stuffer box bulked) and false twist crimped yarns.

6.5 Comparison of 1x1 Rib Fabrics Knitted from Stuffer Box Bulked Yarns in the Length (wale) and Crosswise (course) Directions with respect to

6.51 Elastic Recovery of Fabrics

The extension requirements of a fabric in any particular direction is dependent on its ultimate use. For example, in footwear, the extension in wear is primarily along the wales but some knitwear and outer wear undergoes predominantly crosswise extension during wear. Consequently, the direction in which good recovery from extension is needed depends on the end-use of the garment. As the present work is concerned with the characteristics of the knitted fabrics for use in garments, it is of interest to compare their elastic recovery in the wale and coursewise directions.

Two Textralised yarns 1/205/34 (T2) and 1/150/50 (T3) of the same crimp rigidity were selected and 1x1 rib fabrics knitted from them using an appropriate number of ends so as to obtain nearly same total yarn denier. Elastic recovery of these fabrics was then determined for the wale and coursewise directions.

The results obtained are shown in Figures 77(a) to 77(d) and tables 30(a) to 30(d). For the sake of simplicity and clarity in presentation of the results in graphical form the data for fabrics from 1/205/34 (T2) Textralised yarn only is presented, where as the results obtained with fabrics from both Textralised yarns are given

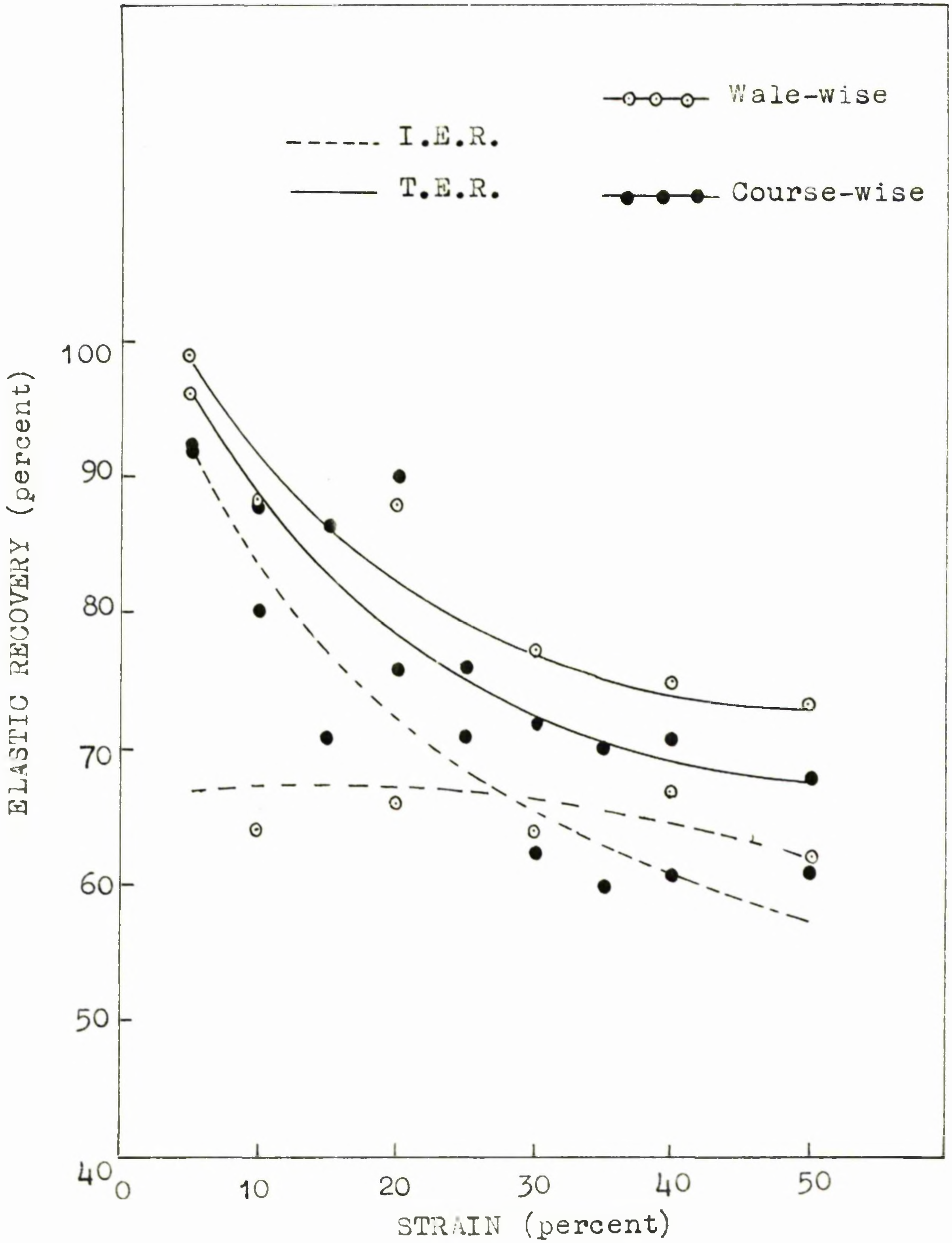


Fig.77(a). Comparison of the elastic recovery of the fabric (greige state) knitted from Textralized yarn(T2) in the wale and course-wise directions.

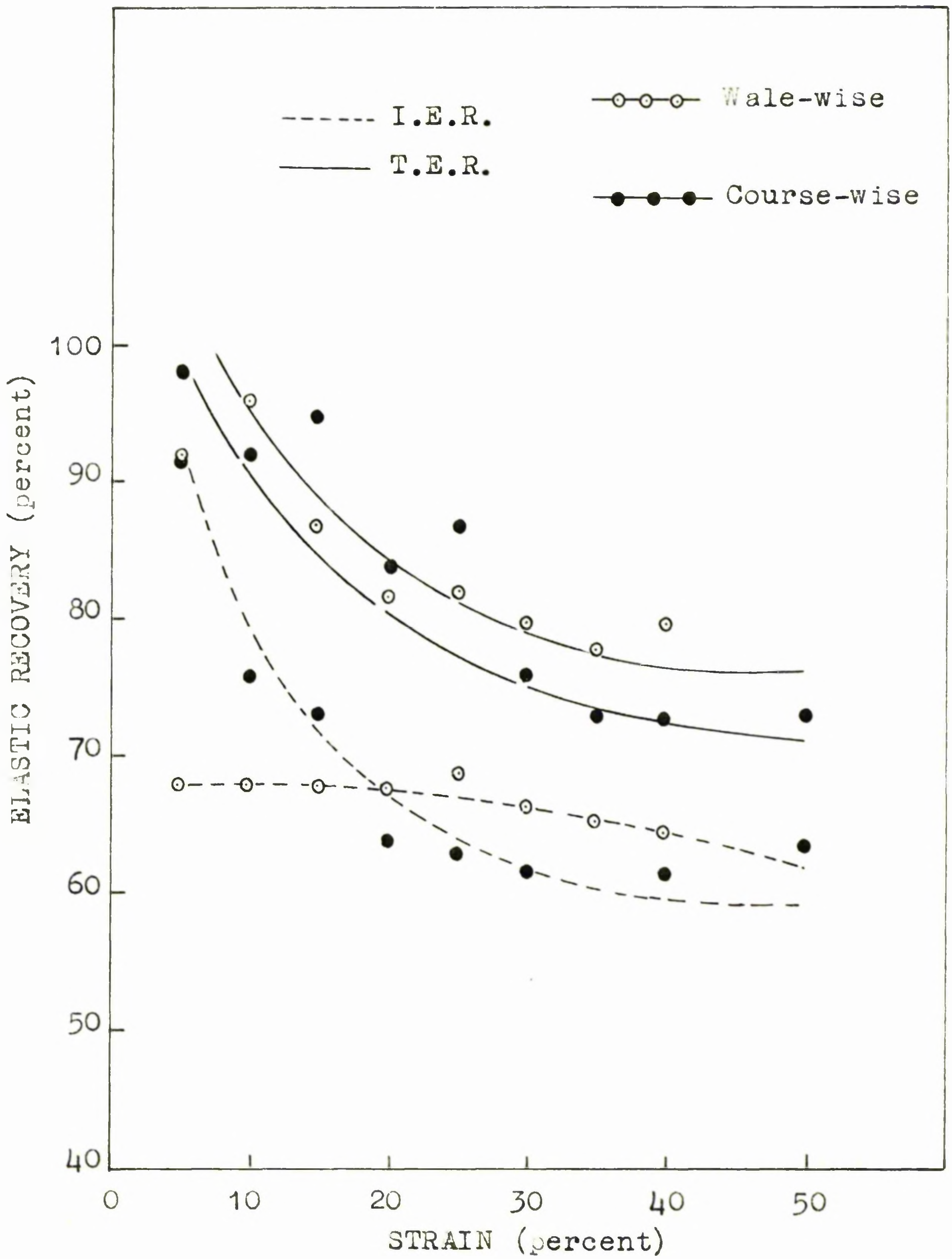


Fig.77(b). Comparison of the elastic recovery of the fabric (steam relaxed) knitted from Textralized yarn(T2) in the wale and course-wise directions.

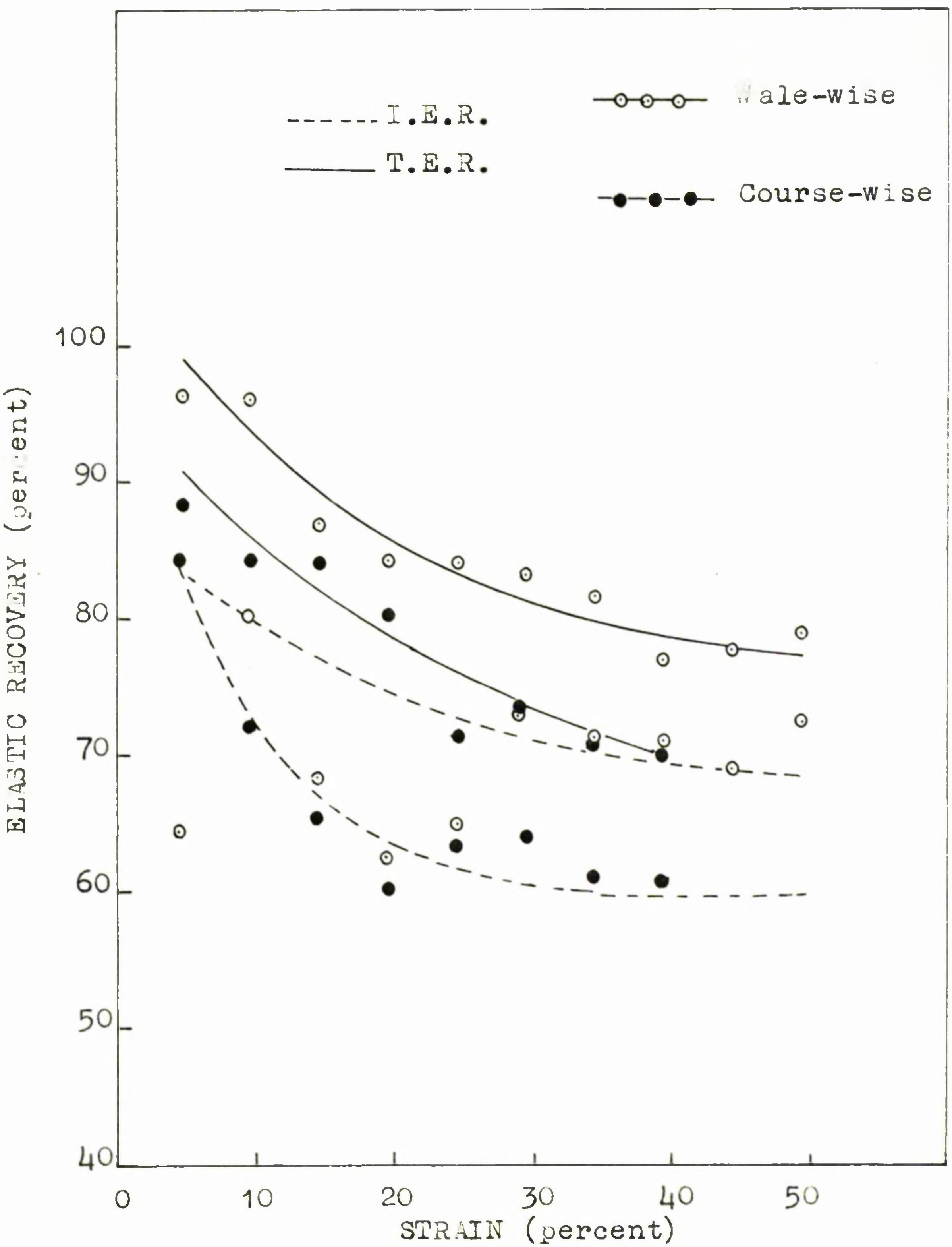


Fig.77(c). Comparison of the elastic recovery of the fabric(wet relaxed) knitted from Textralized yarn(T2) in the wale and course-wise directions.

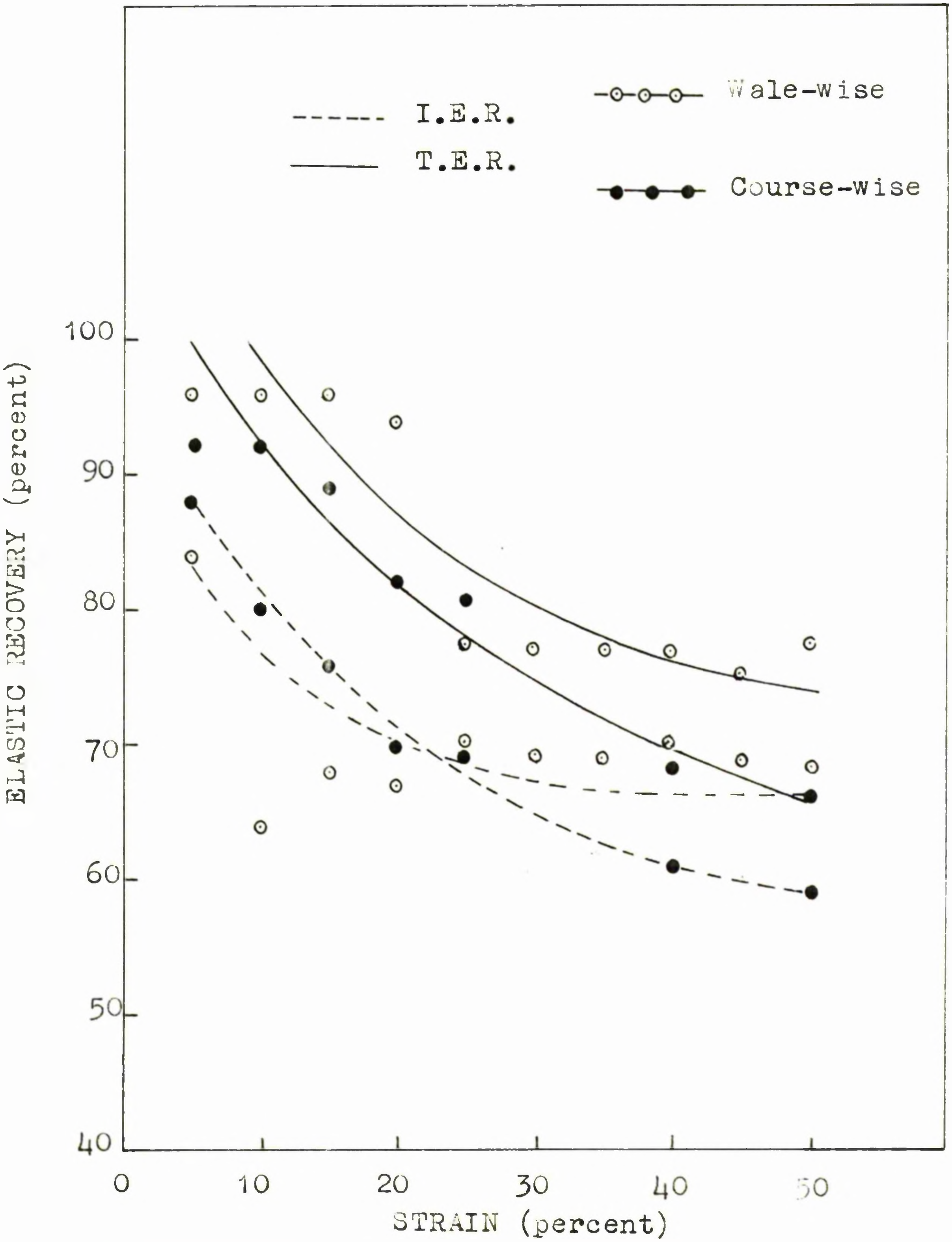


Fig.77(a). Comparison of the elastic recovery of the fabric (dry tumbled) knitted from Textralized yarn(T2) in the wale and course-wise directions.

in tables 30(a) to 30(d). The general trend of the results with both of these yarns is almost the same. Because of the nature of the loop in simple weft knitted fabrics, it is accepted that it is possible to obtain good recovery from extension from the walewise rather than from the coursewise extension. This fact is confirmed in Figures 77(a) to 77(d). In general, immediate as well as total elastic recovery in the walewise direction is greater than in the coursewise direction. This observation holds good for fabrics in their greige state and also after relaxation treatments. The difference in the elastic recovery values in the two directions appear to increase with an increase in extension. Thus for fabrics in which good recovery from extension in the coursewise direction is desirable, it is essential that these fabrics should be so designed as to have only as much extensibility as is actually required from comfort point of view.

When the knitted fabric undergoes extension in the coursewise direction, the knitted loops become wider and at the loop cross over points, the yarns form sharp angles around each other, and as the strain is increased yarn is moved from the vertical component of the loop to the horizontal component. Increased strain levels accentuate this yarn movement and it is the slow recovery of this movement, at these levels, which appears to account for the low elastic recovery difference between the greige and dry tumbled states. The low recovery of this movement may be due to a combination of factors, these being the transference of yarn from one portion of the loop to another portion of the same loop and an increase in the angle and area of yarn contact between loops, this latter causing a certain amount of yarn entanglement particularly when that yarn has an irregular surface, the amount of entanglement possibly varying proportionally with the degree of surface irregularity and an increase in angular arrangement of yarn.

Conversely, there would be little yarn movement from one portion of the loop to another portion when the walewise strain is encountered, the strain being carried by the vertical 'V' component for some time before affecting the displacement of the yarn in the loops. This allows the characteristics of the yarn to become more evident in the walewise behaviour of the fabric.

At low levels of strain, the initial extension is given by the rotation of the sinker loops which join the plain and rib wales. This rotation of the sinker loop requires only a low load and may be capable of almost complete reversal at low strains, but as the strain is increased, yarn movement and loop deformation, of only a partially reversible nature affect the recovery characteristics of the fabric.

6.52 Load-strain Characteristics

Figures 78(a) to 78(d) show the load-strain curves up to 50% elongation for fabrics from 1/203/34 (T2) Textralized yarn in the greige, steam relaxed, wet relaxed and dry tumbled states, the stretch having been applied along two principal directions, i.e. wale and course wise. It will be seen that the load required to stretch

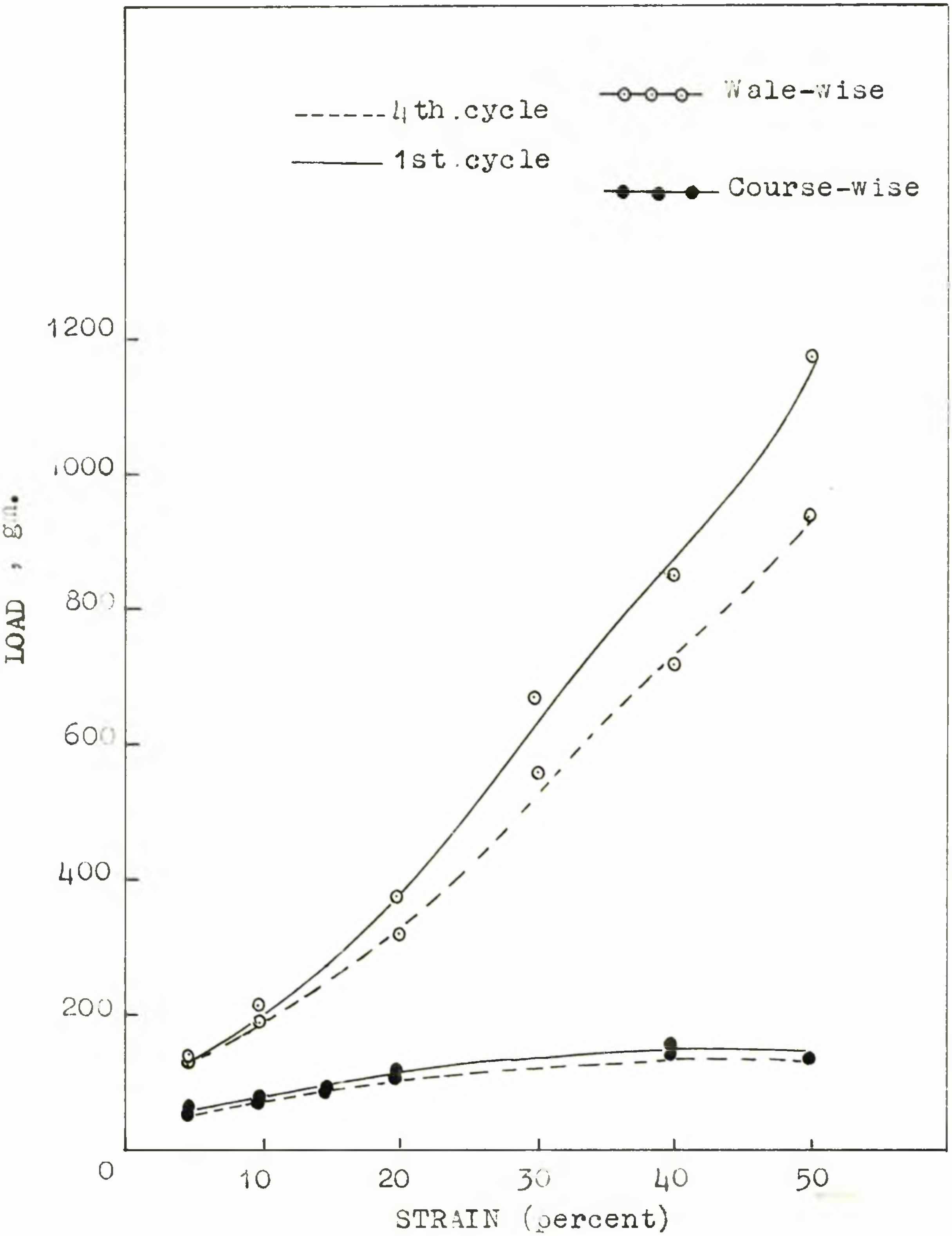


Fig.78(a). Load-strain characterstics of the fabric (greige state) knitted from Textralized yarn(T2) in the wale and course-wise directions.

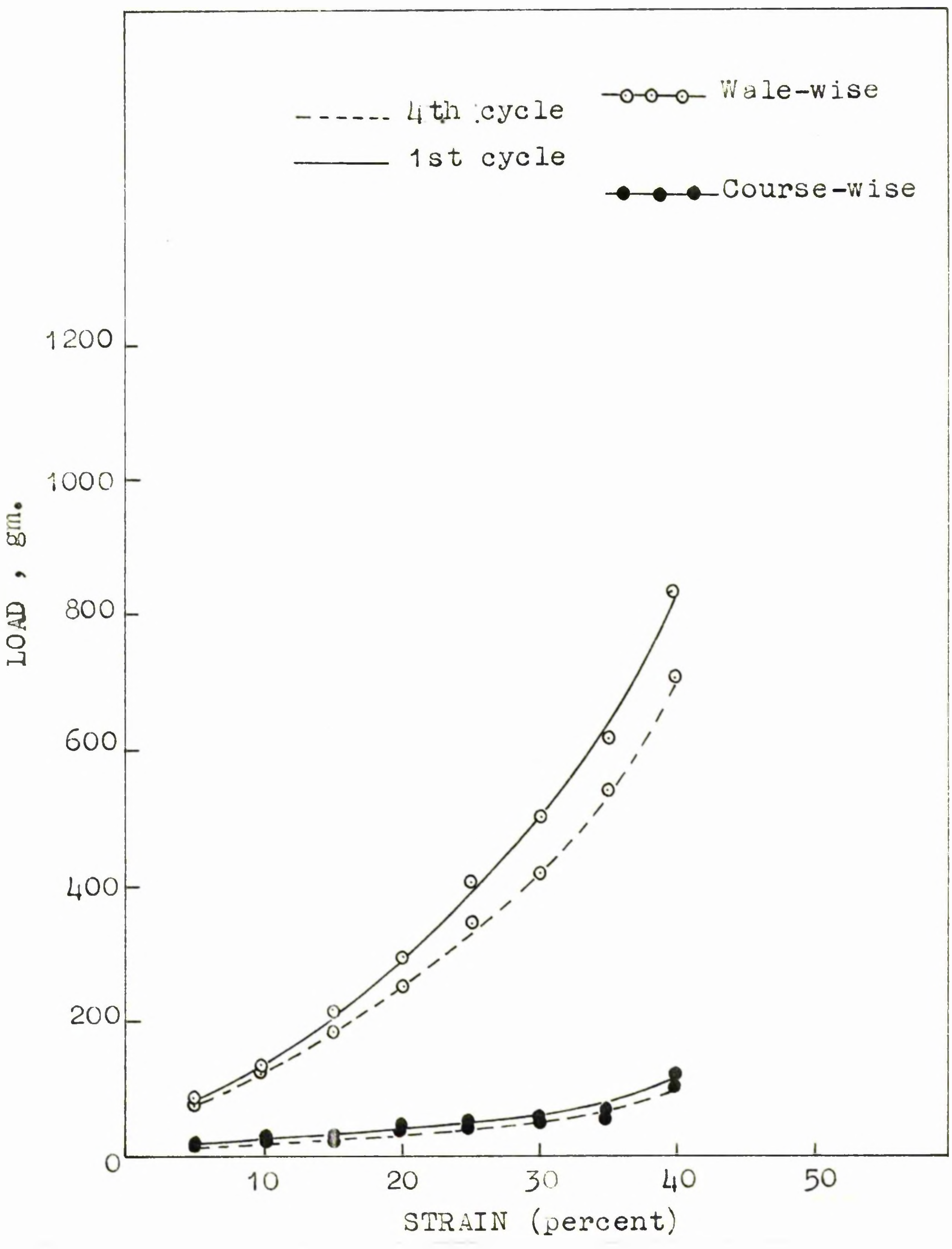


Fig.78(b). Load-strain characterstics of the fabric (steam relaxed) knitted from Textralized yarn (T2) in the wale and course-wise directions.

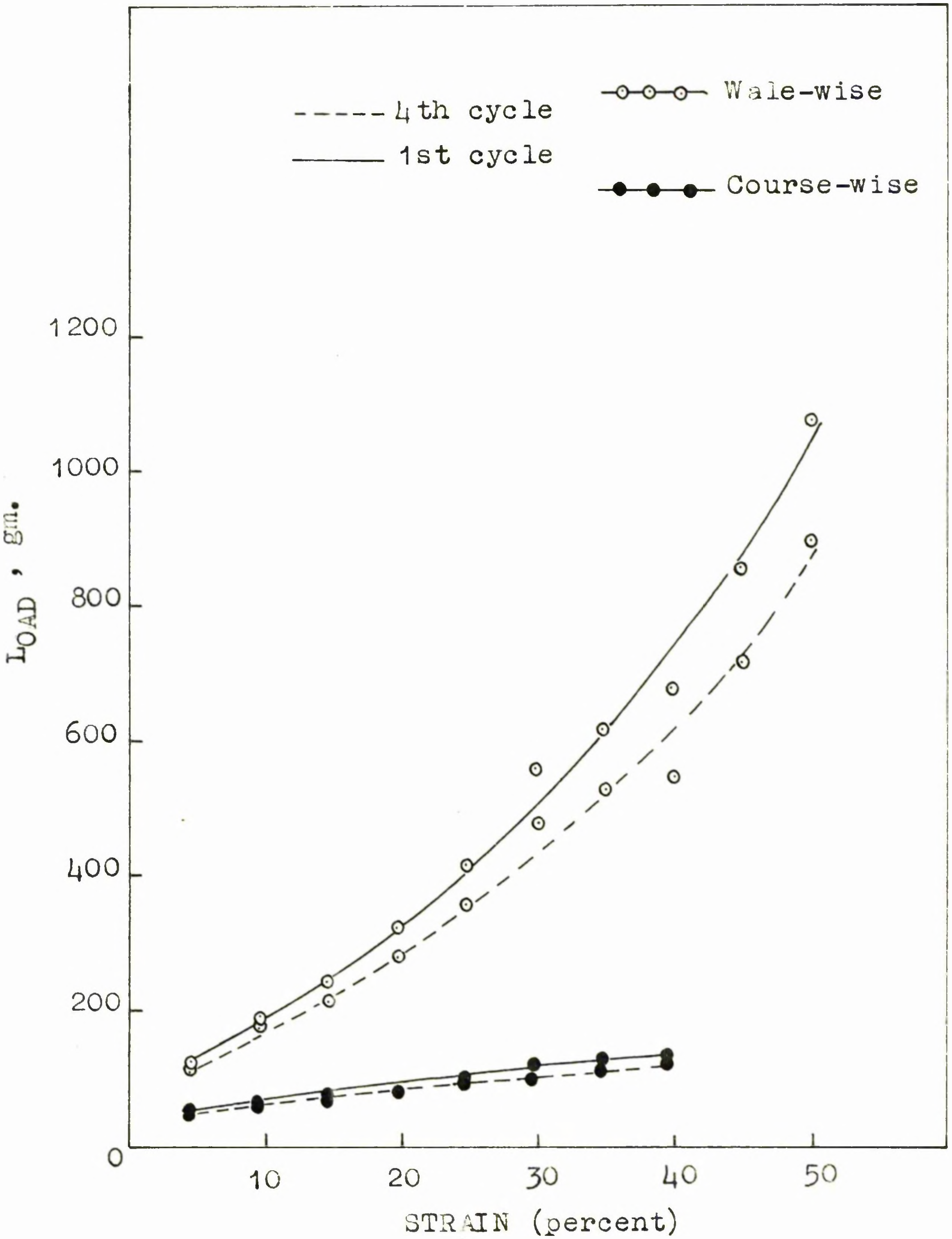


Fig. 78(c). Load-strain characterstics of the fabric (wet relaxed) knitted from Textralized yarn (T2) in the wale and course-wise directions.

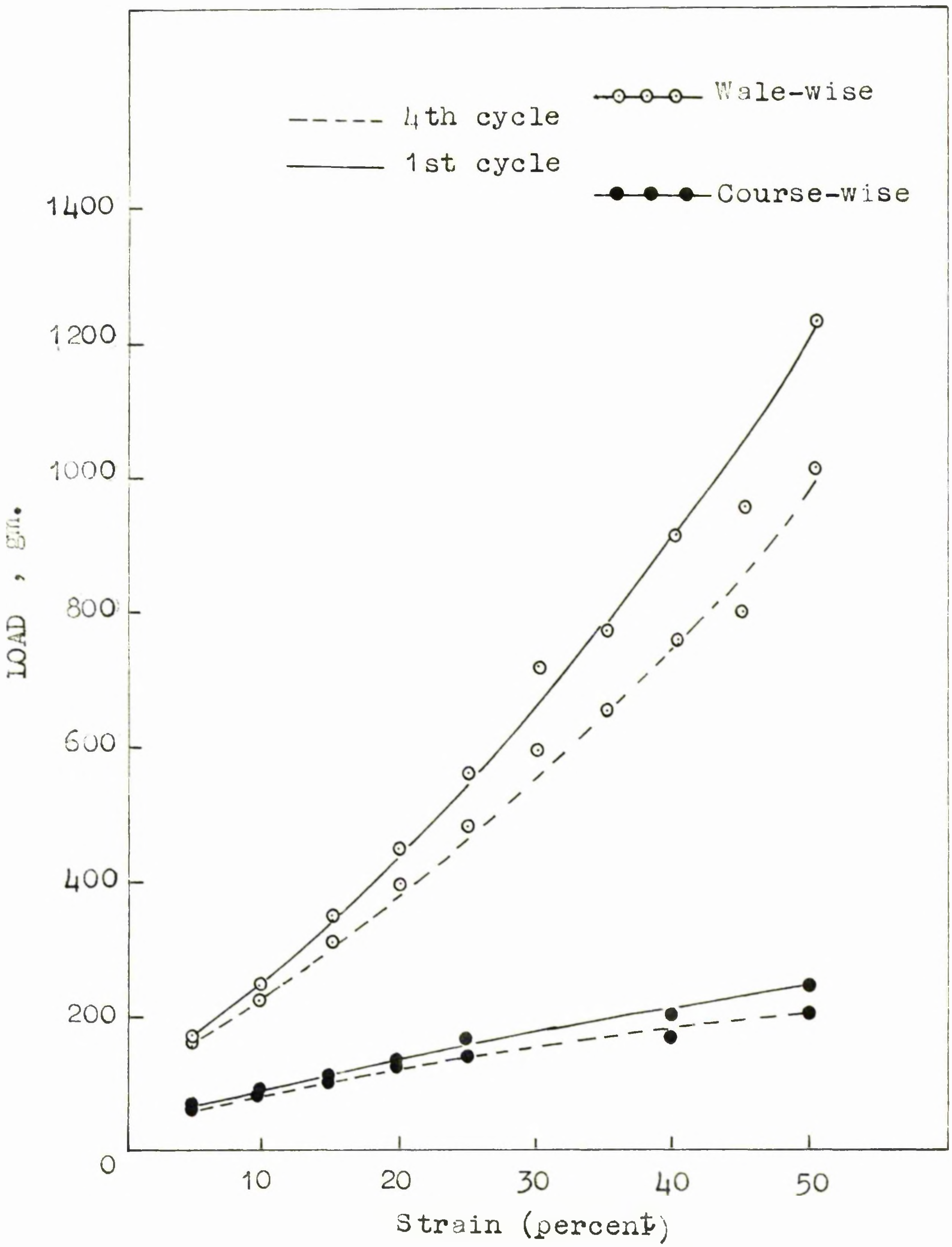


Fig.78(d). Load-strain characterstics of the fabric (dry tumbled) knitted from Textralized yarn (T2) in the wale and course-wise directions.

a fabric in the coursewise direction is only a fraction of the load required to stretch it in the walewise direction. It is also seen that steam relaxation reduces the modulus of the fabric within the range of strains considered and the reasons for this having been discussed earlier with specific reference to filament adhesion caused by steam relaxation.

In discussing the load/extension properties of rib fabrics in the course and wale wise directions, Doyle[59] described the rib structure as a development of the plain structure, formed by reversing alternate stitches or group of stitches. The effect of this reversal was to allow for the natural curling action of the intermediate loops to take place and the width wise collapse of the structure resulted. Thus rib structures offer an increased extension and recovery capacity along the coursewise direction. The high extensibility of these structures arises from the rotation of the links that join the face loops and the back loops. In these fabrics, having a courses per inch to wales per inch ratio of approximately unity, the disparity in load in a coursewise direction compared with that in a walewise direction is due in part to the fact that for every load bearing unit in the former state, there are four load bearing units in the latter state, this being brought about by the type of structure and the course and wale spacing. It is therefore, reasonable to expect lower loads for given degrees of strain in a coursewise direction than in a walewise direction.

6.6 Comparison of 1x1 Rib and Half Cardigan Fabrics, in the Wale and Coursewise Directions, with respect to

6.61 Elastic Recovery of these Fabrics

As the half cardigan structure is one of the most widely used fancy stitches, it is of interest to study its elastic properties in relation to those of 1x1 rib fabrics. Sample fabrics in these structures were knitted from 3 ends of 1/205/34 (T2) denier Textralized yarn and their elastic recovery properties determined in the wale and coursewise directions in the greige and finished states.

It will be seen from Figures 79(a) to 79(d) in which total elastic recovery values for the first cycle of extension are plotted, that half cardigan fabric in its greige and finished states possesses somewhat superior recovery characteristics in the walewise direction when compared with those of 1x1 rib fabric. When recovery along the coursewise direction is considered the 1x1 rib structure appears superior to the half cardigan structure. At low strains the difference in the course and walewise elastic recovery values for half cardigan fabrics is small but at higher strains the recovery in the coursewise direction falls considerably. When the fabrics are finished by dry tumbling, half cardigan and 1x1 rib fabrics exhibit almost similar recovery behaviour. The influence of the finishing treatments, in general, has already been discussed as have also the differences in elastic properties along the wale

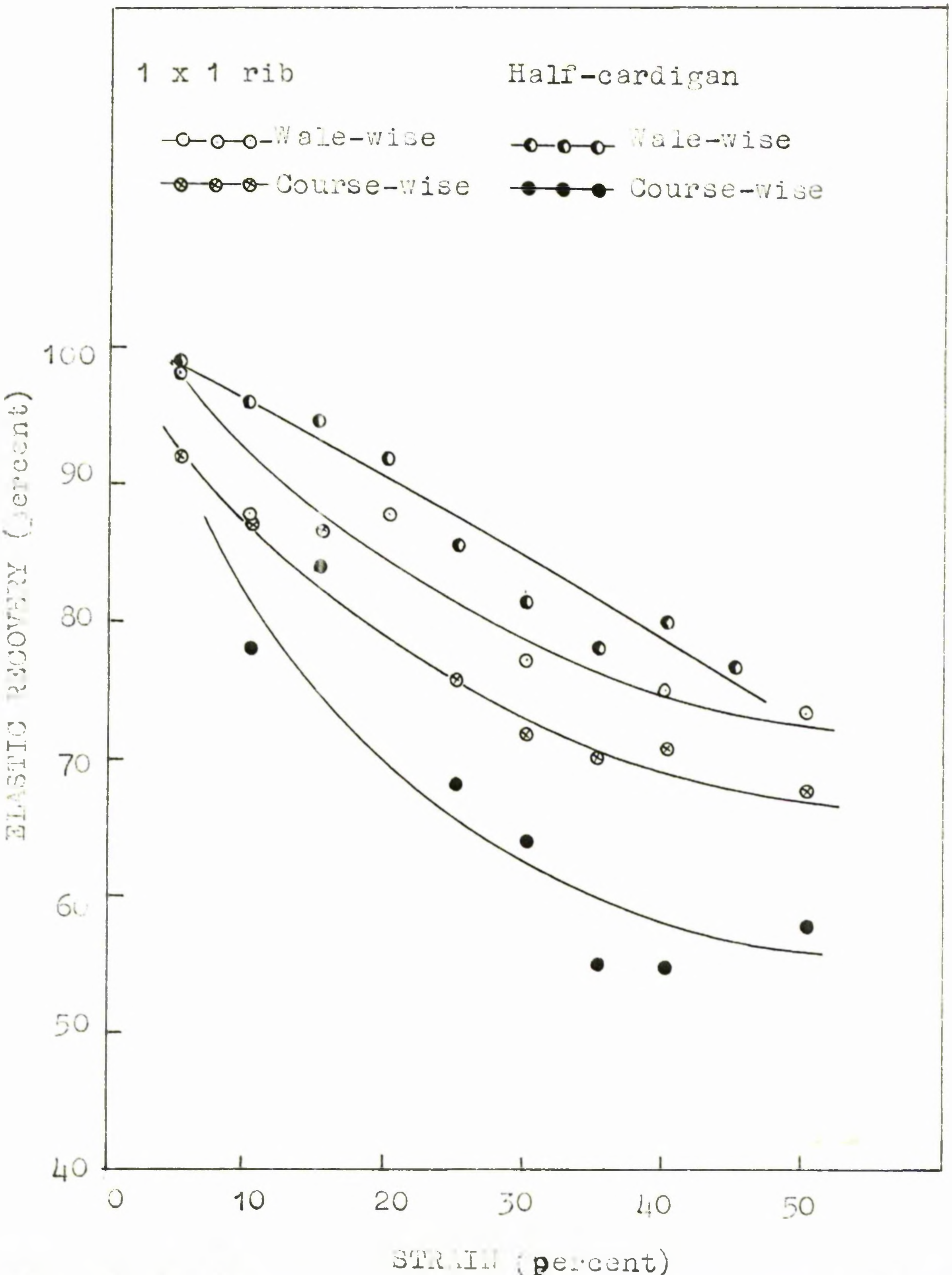


Fig.7[illegible](a). Comparison of the elastic recovery of 1 x 1 rib and half cardigan fabrics (greige state) knitted from Textralized yarn (T2).

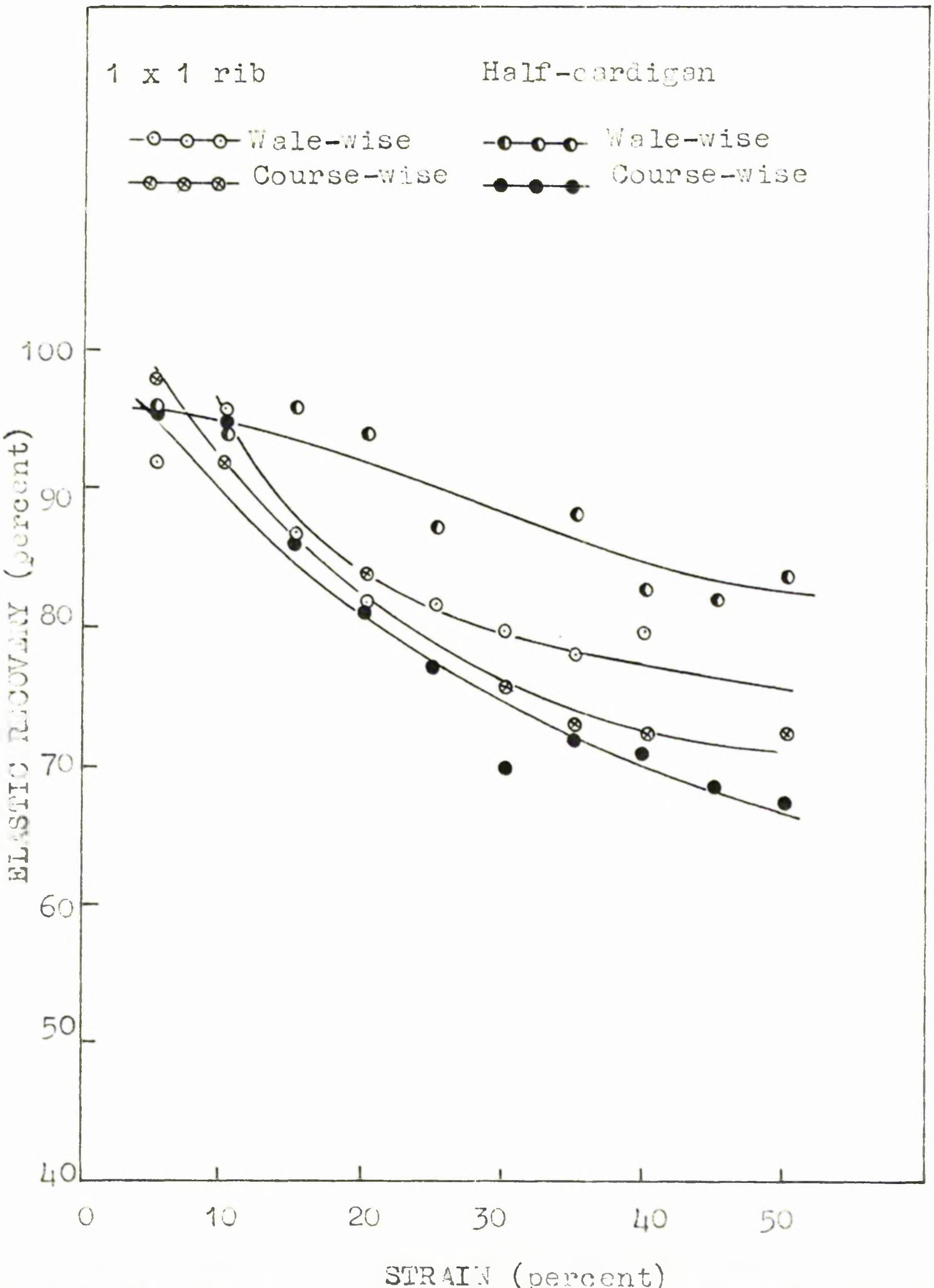


Fig.79(b). Comparison of the elastic recovery of 1 x 1 rib and half cardigan fabrics (steam relaxed) knitted from texturized yarn (T2).

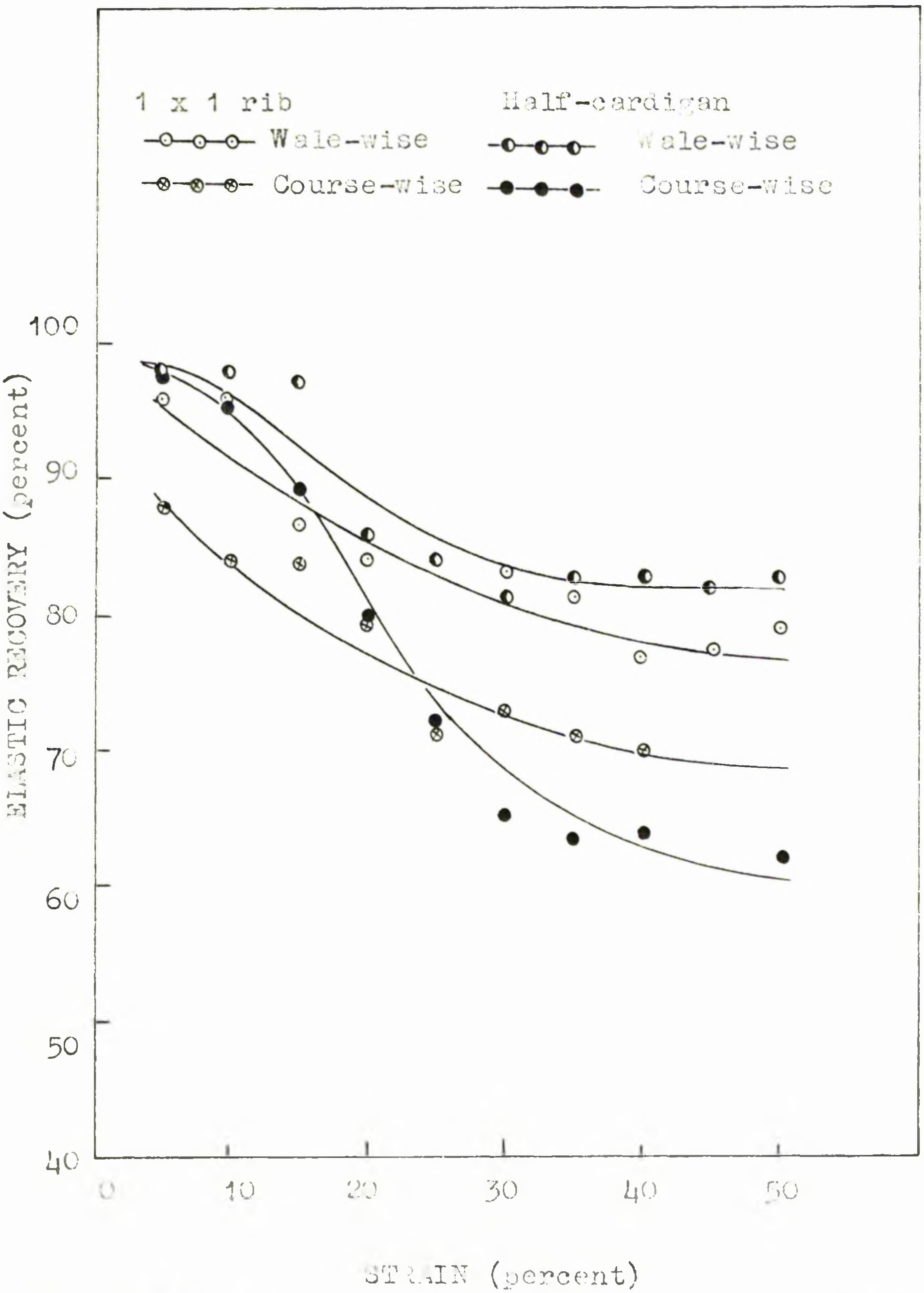


Fig. 79(c). Comparison of the elastic recovery of 1 x 1 rib and half cardigan fabrics (wet relaxed) knitted from Textralized yarn (T2).

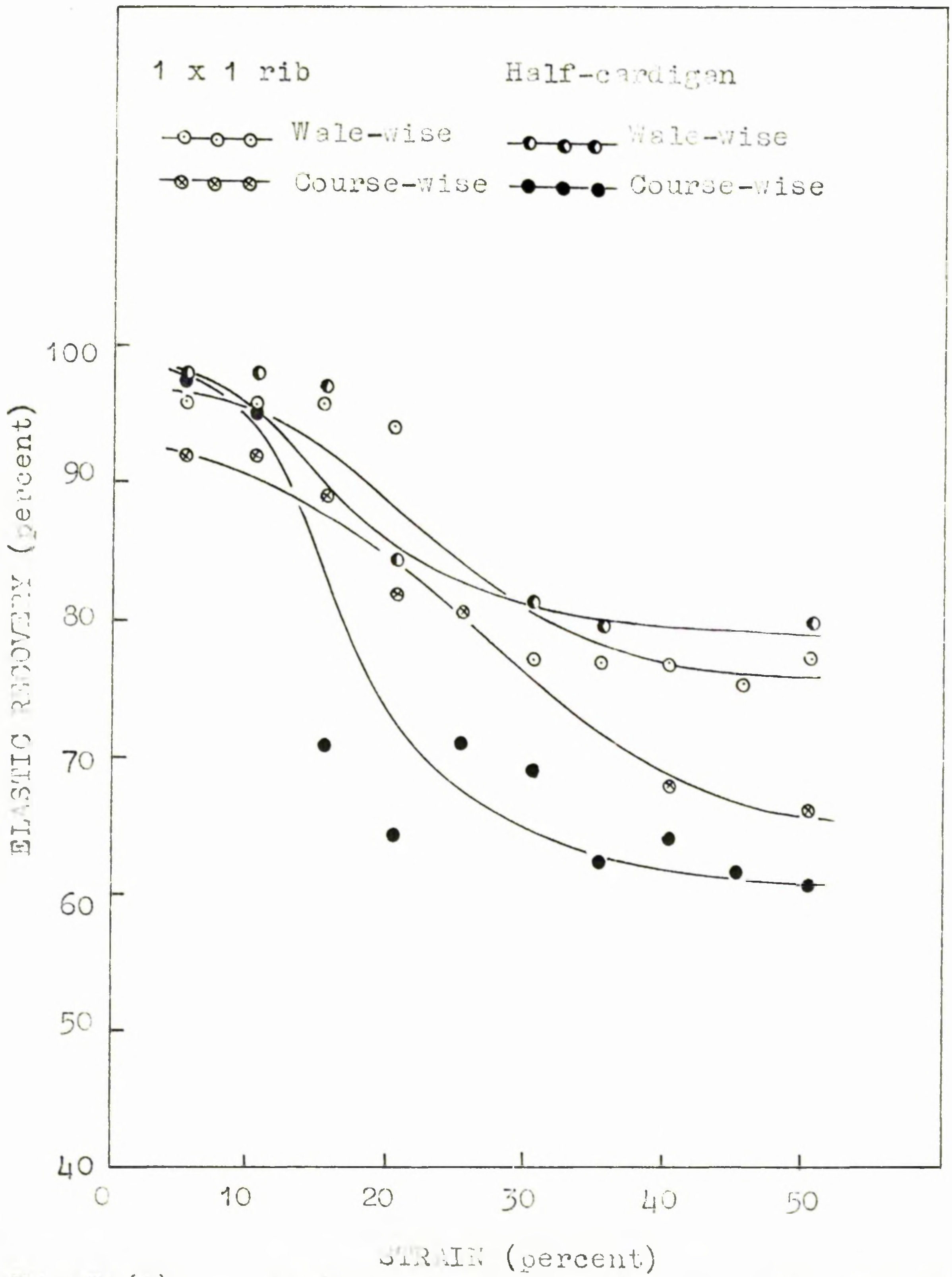


Fig.79(d). Comparison of the elastic recovery of 1 x 1 rib and half cardigan fabrics(dry tumbled) knitted from Textralized yarn (T2).

and coursewise directions.

The fact that elastic recovery properties of half cardigan fabric are different from those of 1x1 rib fabric can probably be ascribed to the difference in fabric structure. Half cardigan fabric contains long 'held' loops on the front of wales on one side of the fabric and tuck loops on the back of the same wales, curving upwards round the top of the 'held' loops and retained in position by the sinker loops of the surrounding stitches.

The effect of the sinker loop rotation which gives coursewise recovery to the 1x1 rib structure is less pronounced in the half cardigan structure wherein portion of the effect of the recovery force is lost by virtue of the direction of moment of that force being angular to the line of the course, due to the path of the yarn in the fabric structure. The sinker loops which in 1x1 rib fabrics have a 'horizontal rotation' are in half cardigan structure, opposed by the tuck loop which forms a 'stressed cantilever' unit pivoted at its centre and restrained at each end. In tuck fabrics produced from conventional unbulked yarns, it is the existence of this unit (in multiples) which increases the width of the fabric relative to 1x1 rib for the same number of needles. An increase in width has also been noted for the half cardigan fabrics considered in this work. It is the existence of the 'stressed cantilever' which appears responsible for the lower coursewise recovery shown by half cardigan fabrics.

The walewise recovery is also affected by the presence of the tuck loop and modified sinker loop, the former (the 'stressed cantilever') trying to regain its straight horizontal form and in doing so, assisting in walewise recovery. The modified sinker loop also assists in this action by trying to form a more conventional shape than the irregular shape imposed upon it by the stresses in the structure.

6.62 Load-strain Characteristics

Figures 80(a) to 80(d) demonstrate the load-strain properties of 1x1 rib and half cardigan fabrics knitted from 3 ends of 1/205/34 (T2) Textralised yarn in the wale and coursewise directions. The curves are plotted for all four states of the fabrics, i.e. greige, steam relaxed, wet relaxed and dry tumbled.

It will be noted from the figures that the half cardigan fabric in all its states requires a smaller load for any given extension in the walewise direction whereas in the coursewise direction it needs a greater load for any given extension as compared with 1x1 rib fabric. The lower walewise load required to produce a given extension may be attributed to the following reasons:

(a) the decrease in stress bearing units in the half cardigan structure for a given test width. This decrease is due to the presence of the 'stressed cantilever' unit which increases the coursewise width of the structure for a given number of needles, thus reducing the number of wales per inch and

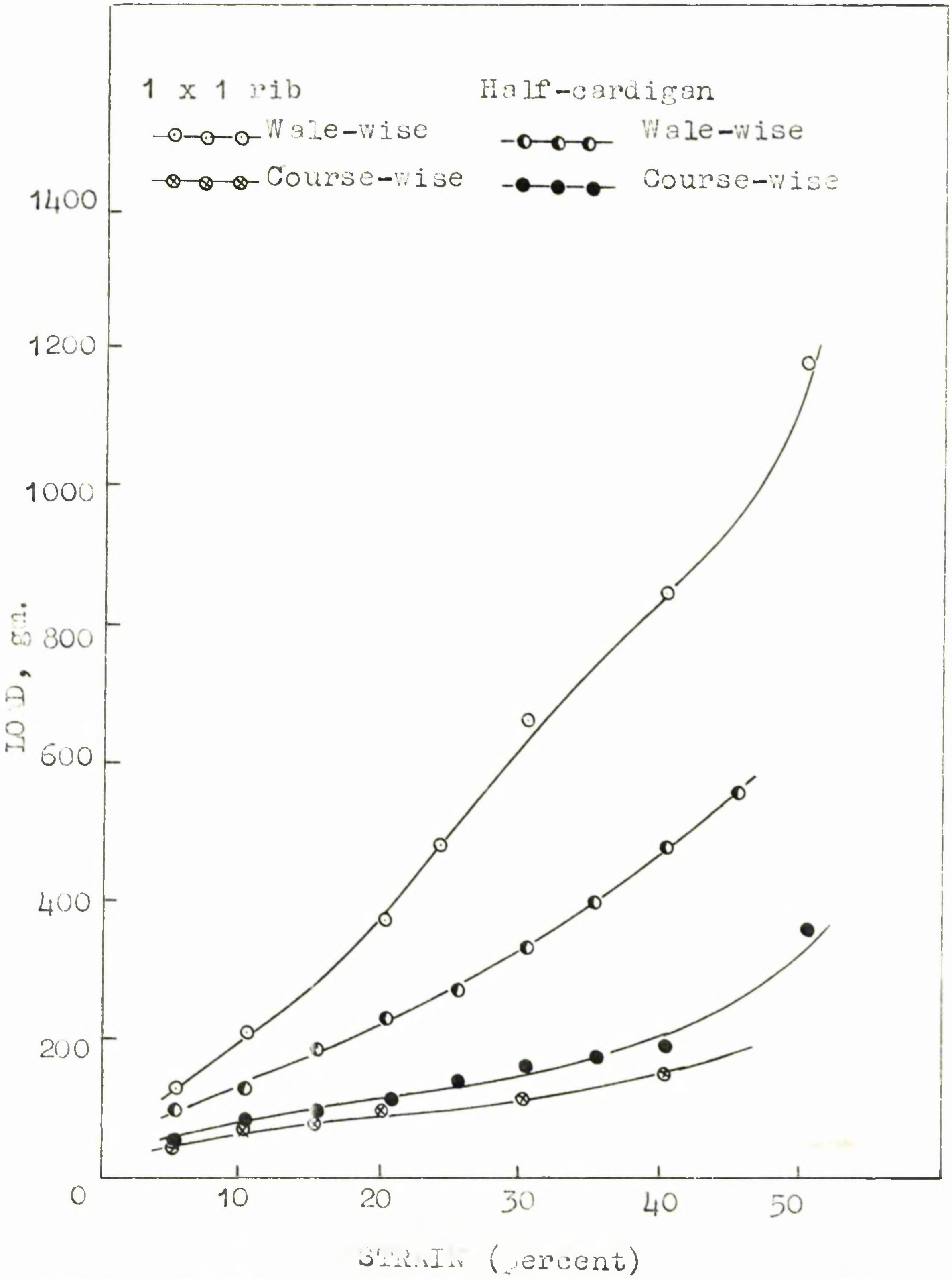


Fig. 8 (a). Load-strain characteristics of 1 x 1 rib and half cardigan fabrics (greige state) knitted from Textralised yarn (T2).

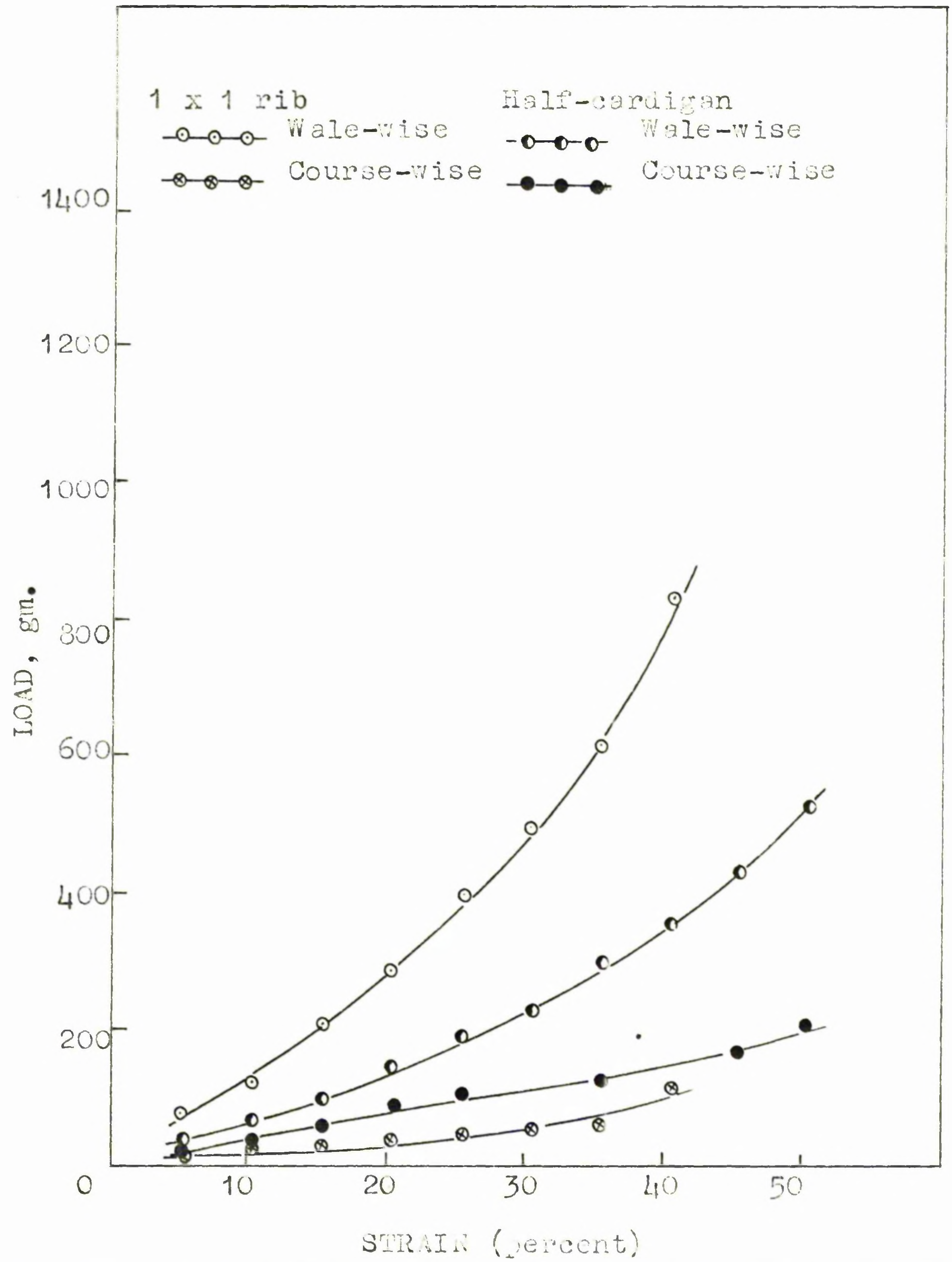


Fig. 80(b). Load-strain characteristics of 1 x 1 rib and half cardigan fabrics (steam relaxed) knitted from Textralized yarn (T2).

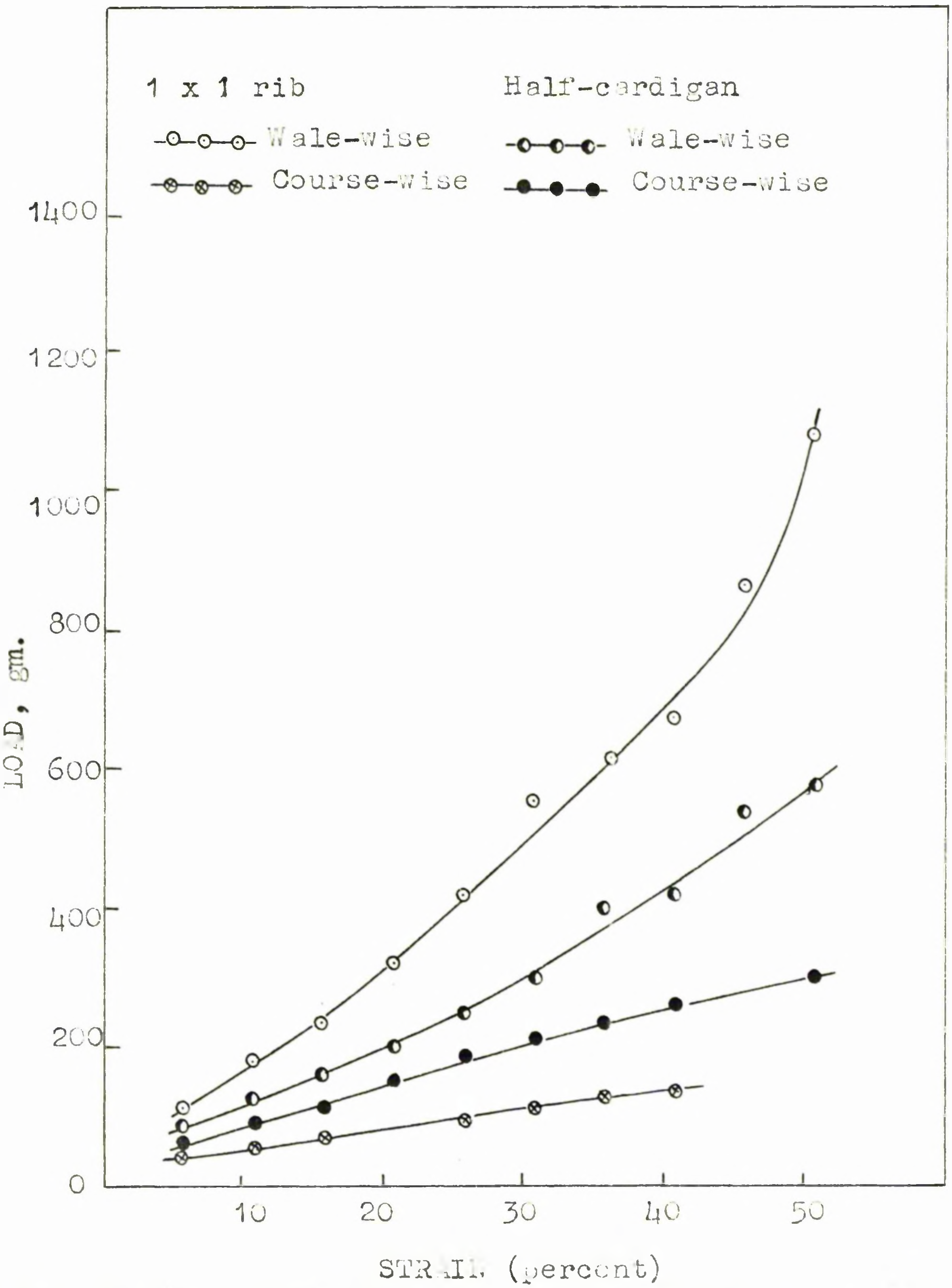


Fig.8[illegible](c). Load-strain characteristics of 1 x 1 rib and half cardigan fabrics (wet relaxed) knitted from Textralized yarn (T[illegible]).

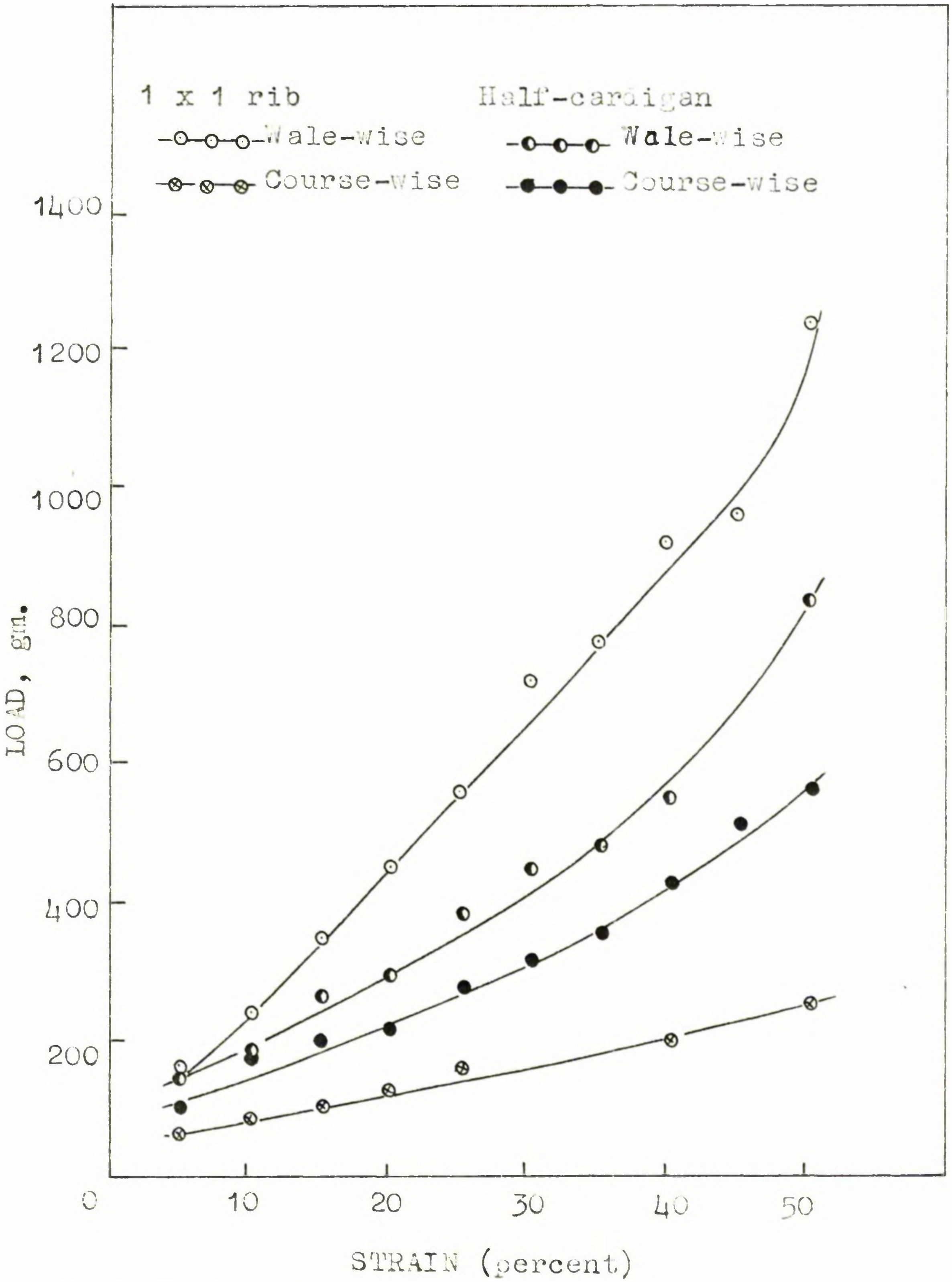


Fig.3.[illegible](d). Load-strain characteristics of 1 x 1 rib and half cardigan fabrics (dry tumbled) knitted from Textrolized yarn(T2).

(b) the presence of the 'stressed cantilever' units and held loops in the tuck wales on one side of the fabric, the stresses in these tuck wales causing vertical buckling of the plain knit wales on the other side of the fabric. This buckling of the plain knit wales permits considerable extension of these wales at low loads, the major portion of that load being carried by the stressed tuck wales until these extend to the unfolded length of the plain knit wales, after which the load may become more evenly distributed.

The higher coursewise load required to produce a given extension in a half cardigan fabric is due to the smaller number of rotatable sinker loops and the inclusion of the straightened cantilever units which would reduce the capacity of the half cardigan fabric to 'unfold' when under coursewise strain as compared with the capacity of 1x1 rib structures to 'unfold' under the same strain, the load being transferred more quickly to the structure in the former case.

The influence of the finishing treatments on the load-strain properties of half cardigan fabrics appears to be the same as that discussed already for 1x1 rib fabrics.

6.7 Comparison of the Elastic Properties of 1x1 Rib and Half Cardigan Wool Fabrics with those of Bulked Yarn Fabrics in the Wale and Coursewise Directions

The introduction of synthetic fibres and more recently the advent of bulked yarns has created new competition for the wool textile industry. Fabrics produced from bulked yarns offer many of the desirable properties which wool fabric possesses but there is little quantitative or qualitative information available as to the recovery characteristics of knitted wool fabrics. To investigate this particular aspect, 1x1 rib and half cardigan fabrics were knitted from 1/205/34 (T2) Textralised yarn employing 3 ends, and 2/24's wool yarn using 2 ends. The resultant fabrics were finished in the usual manner by steam relaxation, wet treatment and dry tumbling and their elastic recovery properties determined in the wale and coursewise directions.

Before discussing the results of elastic recovery measurements, it is considered important to emphasise the difference between the load-elongation characteristics, upon repeated cycling, of fabrics from wool and bulked yarns. Wool fabrics when stretched, produced stable curves i.e., load elongation responses closely reproduced each other upon repeated loading-unloading cycles after initial extension. Shirfitt[134] has reported similar load-elongation behaviour of 1x1 rib fabrics knitted from wool yarns. Fabrics knitted from bulked yarns produce unstable curves which recess for several cycles before becoming stable, this effect being caused by the projecting crimped filaments having difficulty in regaining their pre-strained position. Fabrics producing stable load-deformation curves are those in which the constituent yarns cycle between two specific geometric configurations, one existing at the beginning of the loading and the other at the beginning of the unloading. The yarn in the fabric producing unstable curves does not return to the same position after each complete cycle. It will be appreciated that yarns in a fabric knitted from bulked yarn will tend to deform more so than yarns in knitted wool fabric, consequently the load-deformation curves for the former type of fabrics process in cyclic loading and unloading. Stable behaviour in fabrics can be attributed to small frictional restraints and constructions that tend to minimise yarn movements.

The total elastic recovery (first cycle) of 1x1 rib wool fabrics is compared with that of bulked yarn fabrics in Figures 81(a) to 81(d) and are plotted for fabrics in their greige, steam relaxed, wet treated and dry tumbled states. It will be noted in these figures that wool fabric possesses superior recovery properties in its various states and at all levels of strain. A further interesting feature is that in the coursewise direction the difference in the elastic recovery values between wool and Textralized yarn fabrics is much greater than in the walewise direction. This difference may be attributed to the resistance to extension exerted by the flexural and tortional rigidity components of the sinker loops, the former component being in the 'horizontal rotating' portion of the sinker loop and the latter component being in the 'V' portion of the knitted loop to which the sinker loop is joined. The worsted yarn, by its construction, will have a greater resistance to flexural and tortional

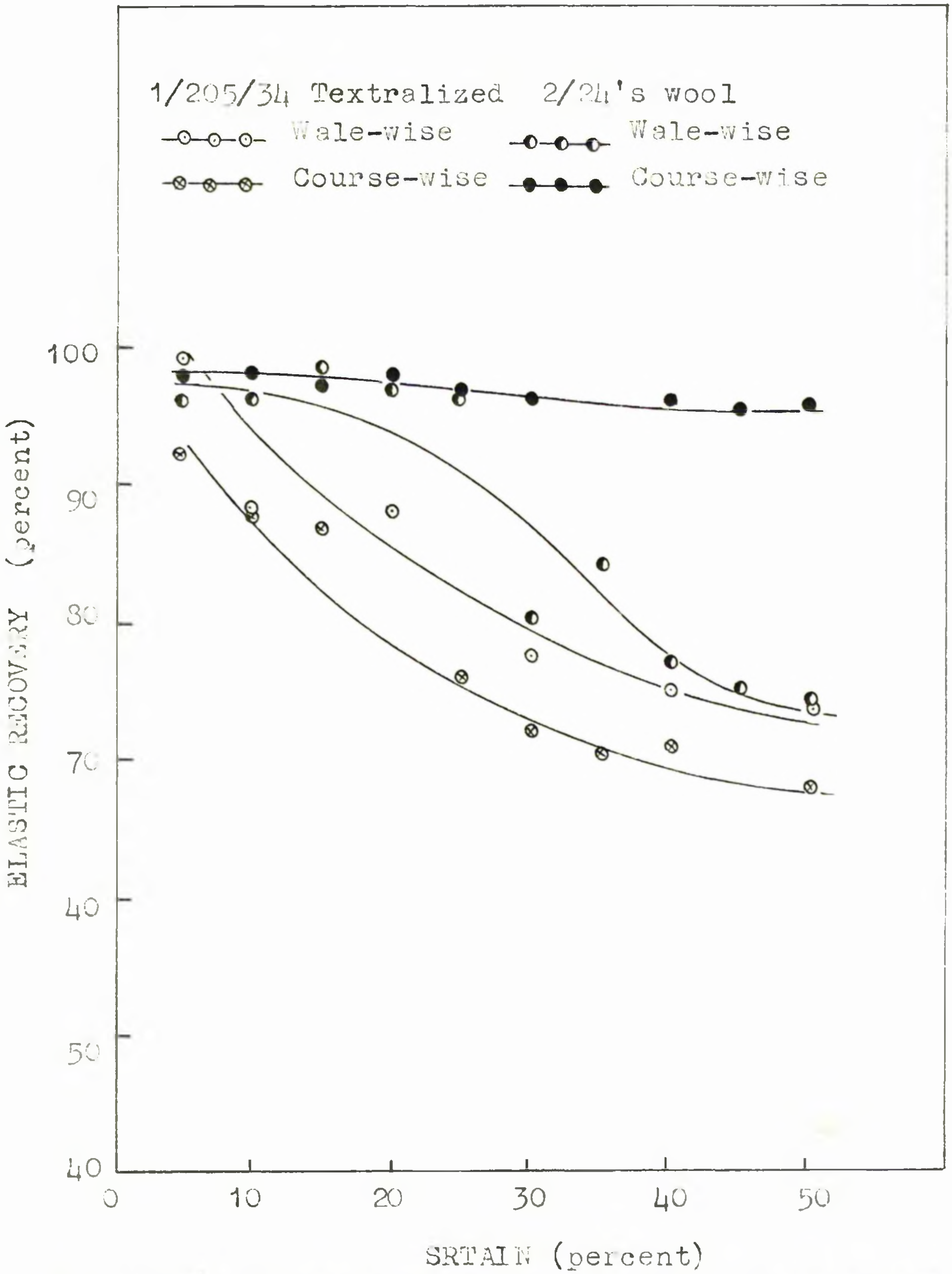


Fig. [illegible]1(a). Comparison of the elastic recovery of 1 x 1 rib fabrics (greige state) knitted from Textralised (TC) and wool yarns.

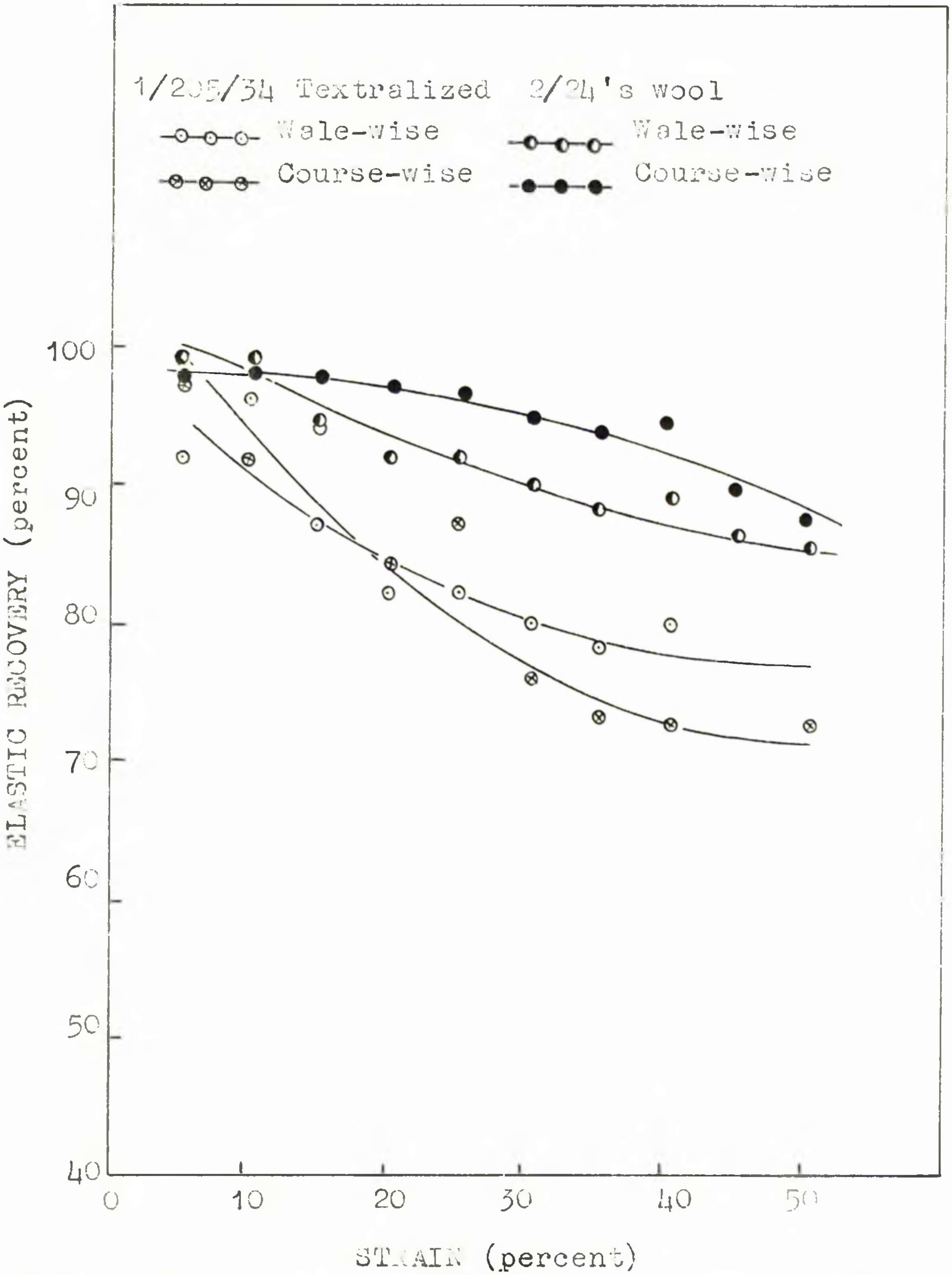


Fig.31(b). Comparison of the elastic recovery of 1 x 1 rib fabrics (steam relaxed) knitted from Textralized (TZ) and wool yarns.

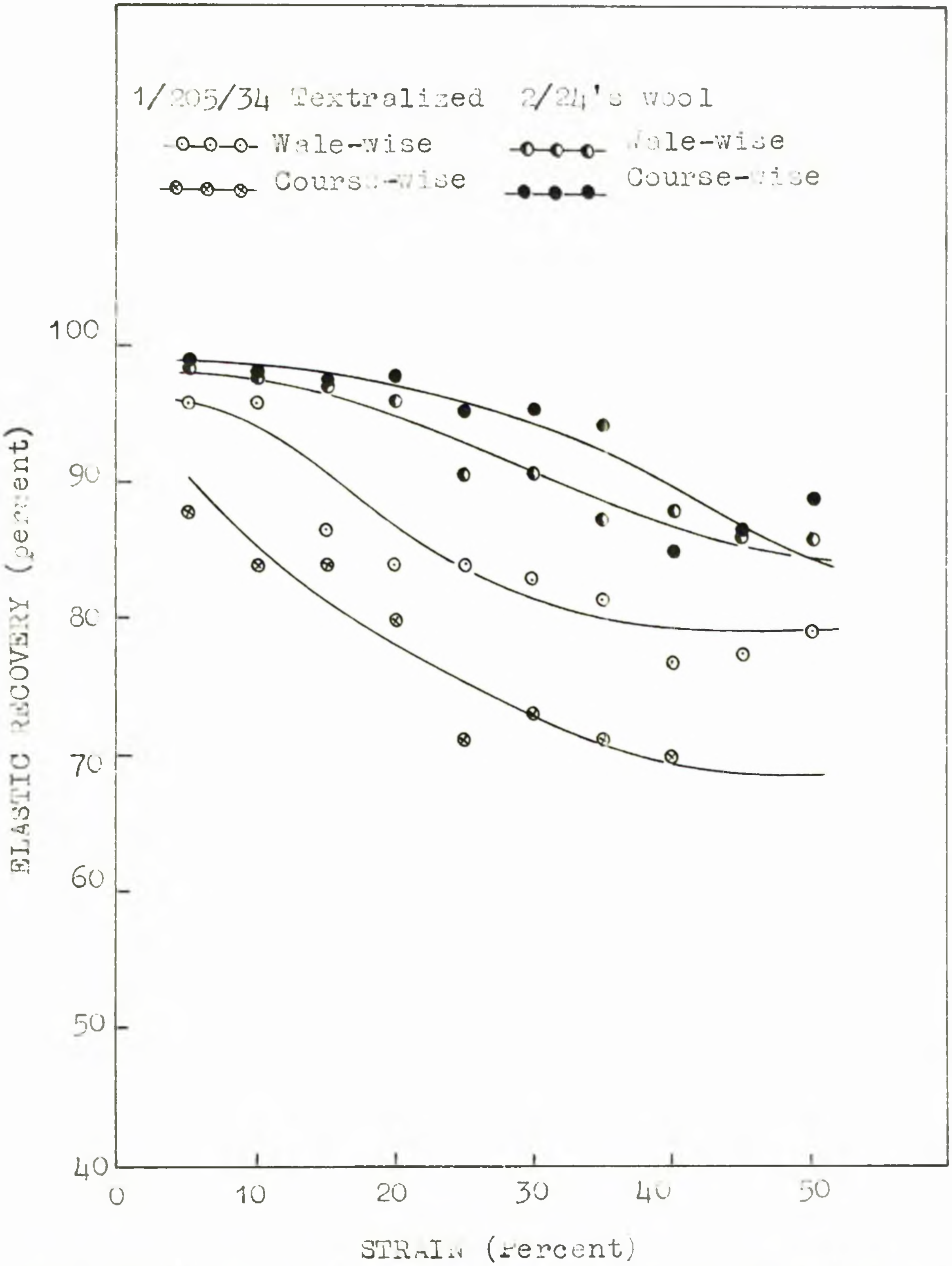


Fig. 31(c). Comparison of elastic recovery of 1 x 1 rib fabrics (wet relaxed) knitted from Textralized (T?) and wool yarns.

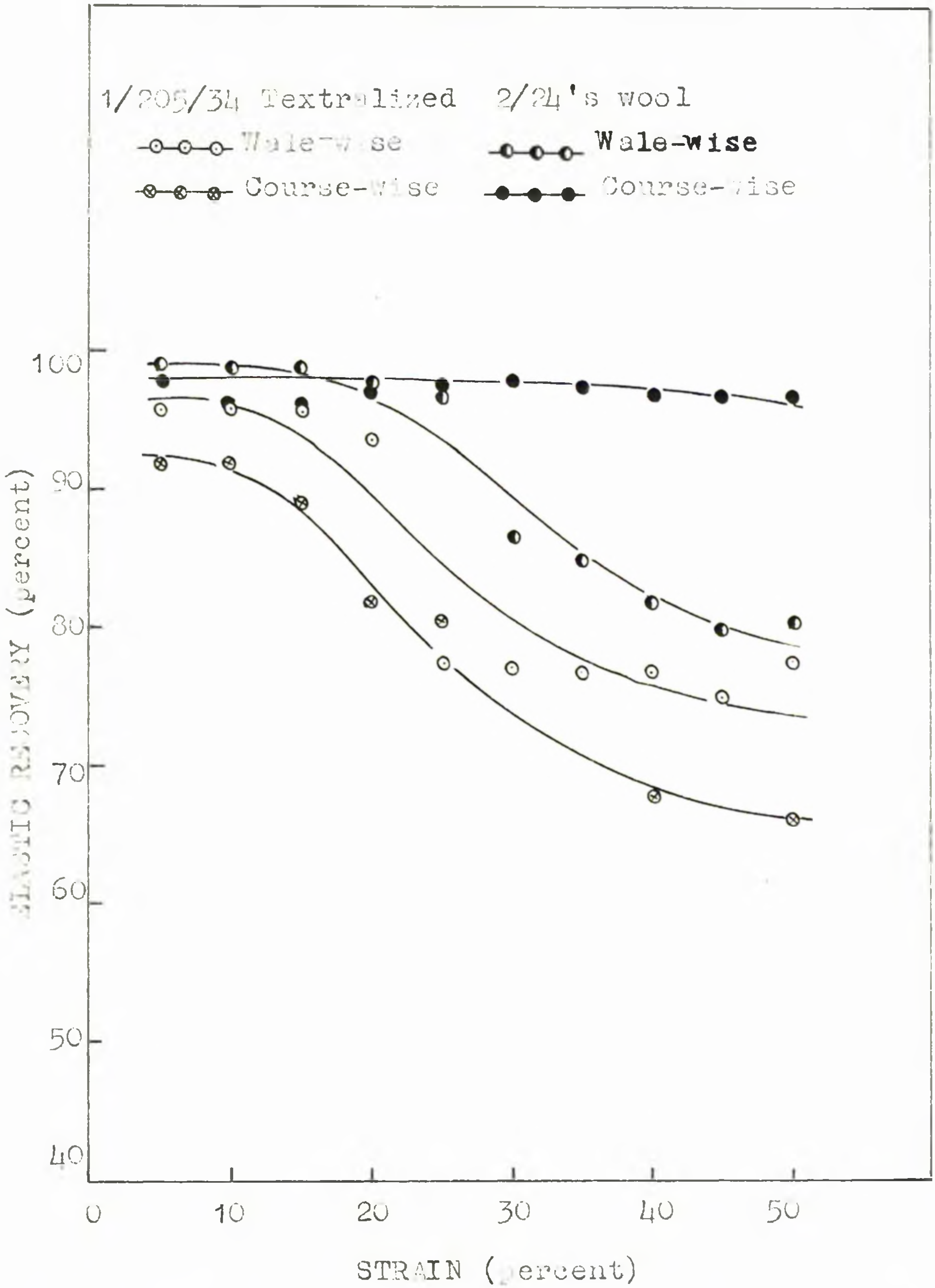


Fig. 51(d). Comparison of the elastic recovery of 1 x 1 rib fabrics (dry tumbled) knitted from Textralized (T2) and wool yarns.

deformation than that possessed by the bulked nylon yarn, the filaments of which are in random order, this reducing the effective number of filaments available to resist deforming loads whereas the majority of the fibres comprising the worsted yarn would jointly contribute to resisting and recovering from the effects of deformation. Attempts were made during this work to ascertain values for the flexural and tortional rigidities of nylon yarns in their bulked state but proved extremely difficult and no reliable results were obtained due to the fact that when even low loads were applied to the bulked yarn structure, deformation of that structure immediately resulted. It has been shown[140] that unbulked nylon filament possesses flexural and tortional properties lower than that of wool fibre. It may be expected that the use of bulked nylon filament in yarn form would lead to even lower values for these components and thus lead to lower fabric values. The results for half cardigan fabrics shown in Figures 82(a) to 82(d) also exhibit similar trends as that for 1x1 rib fabrics. In general, at very low strains, the elastic recovery values for all the fabrics in both wale and coursewise directions appear to be similar but with an increase in per cent. strain, the values become significantly different. 1x1 rib fabrics knitted from wool yarns in their greige and dry tumbled states show, in the walewise direction, a considerable drop in elastic recovery values with an increase in per cent. strain. It was observed that the amount of delayed recovery was very small for

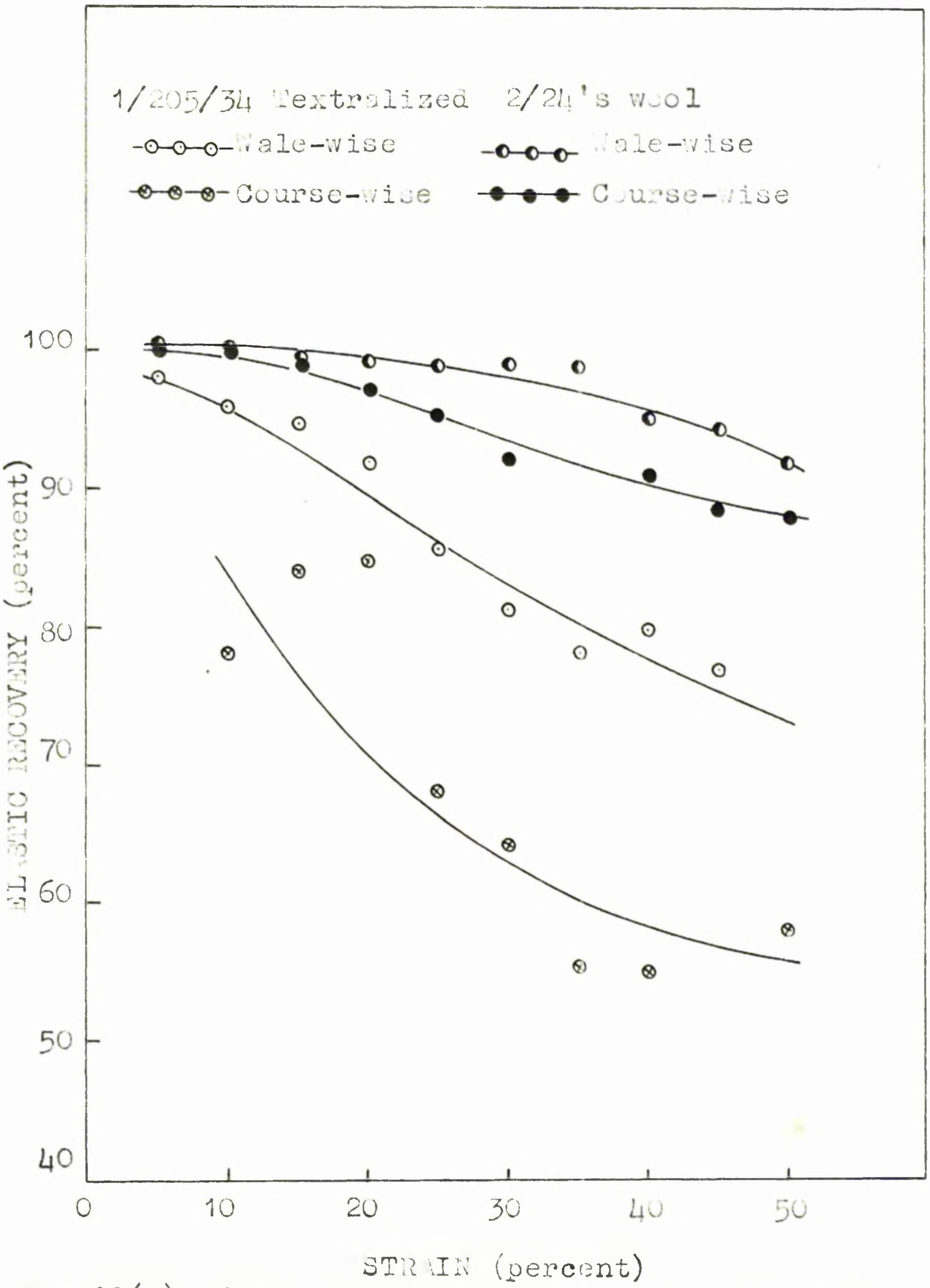


Fig.82(a). Comparison of the elastic recovery of half cardigan fabrics (greige state) knitted from Textralized(T2) and wool yarns.

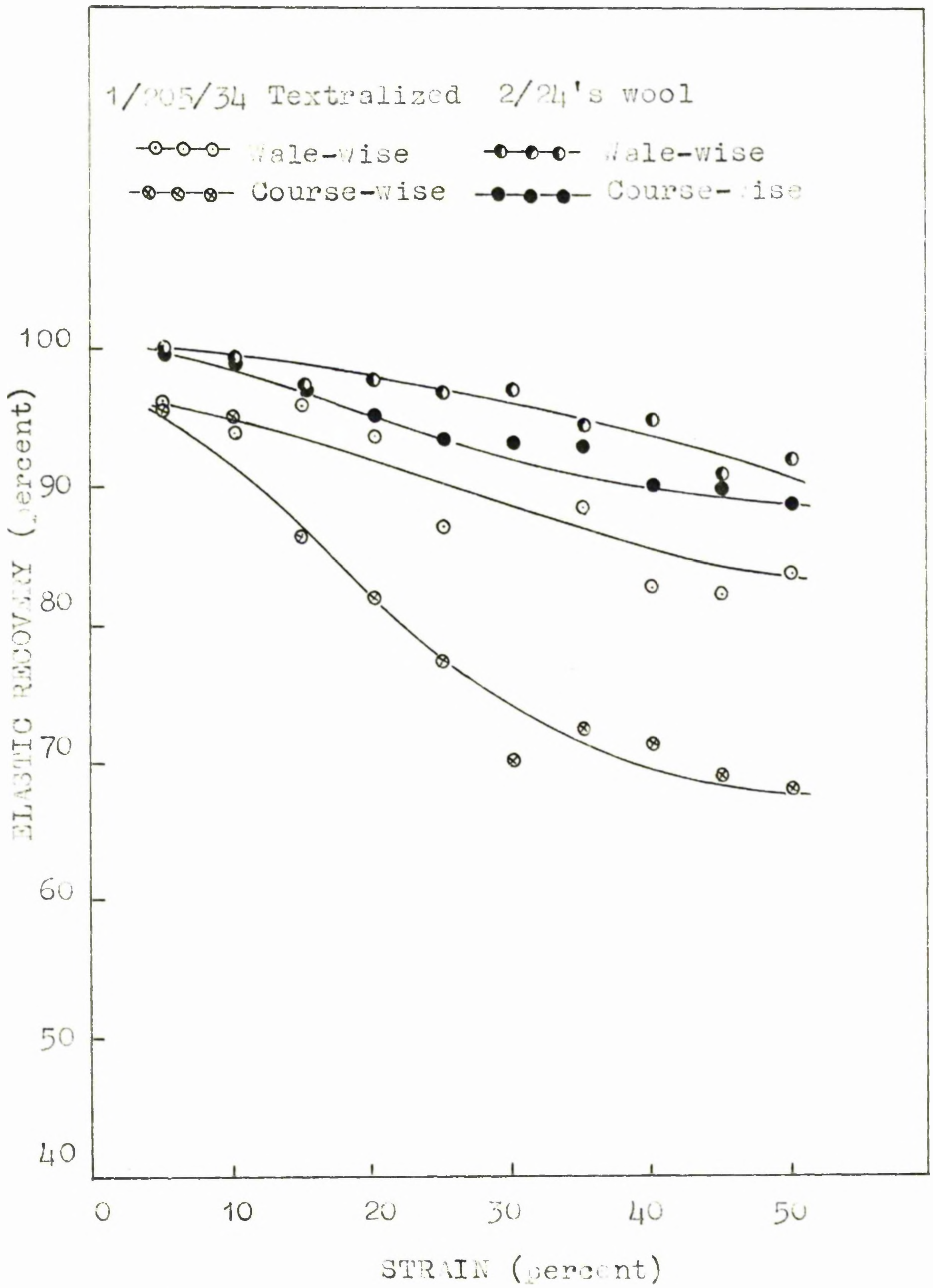


Fig.82(b). Comparison of the elastic recovery of half cardigan fabrics (steam relaxed) knitted from Textralized(T2) and wool yarns.

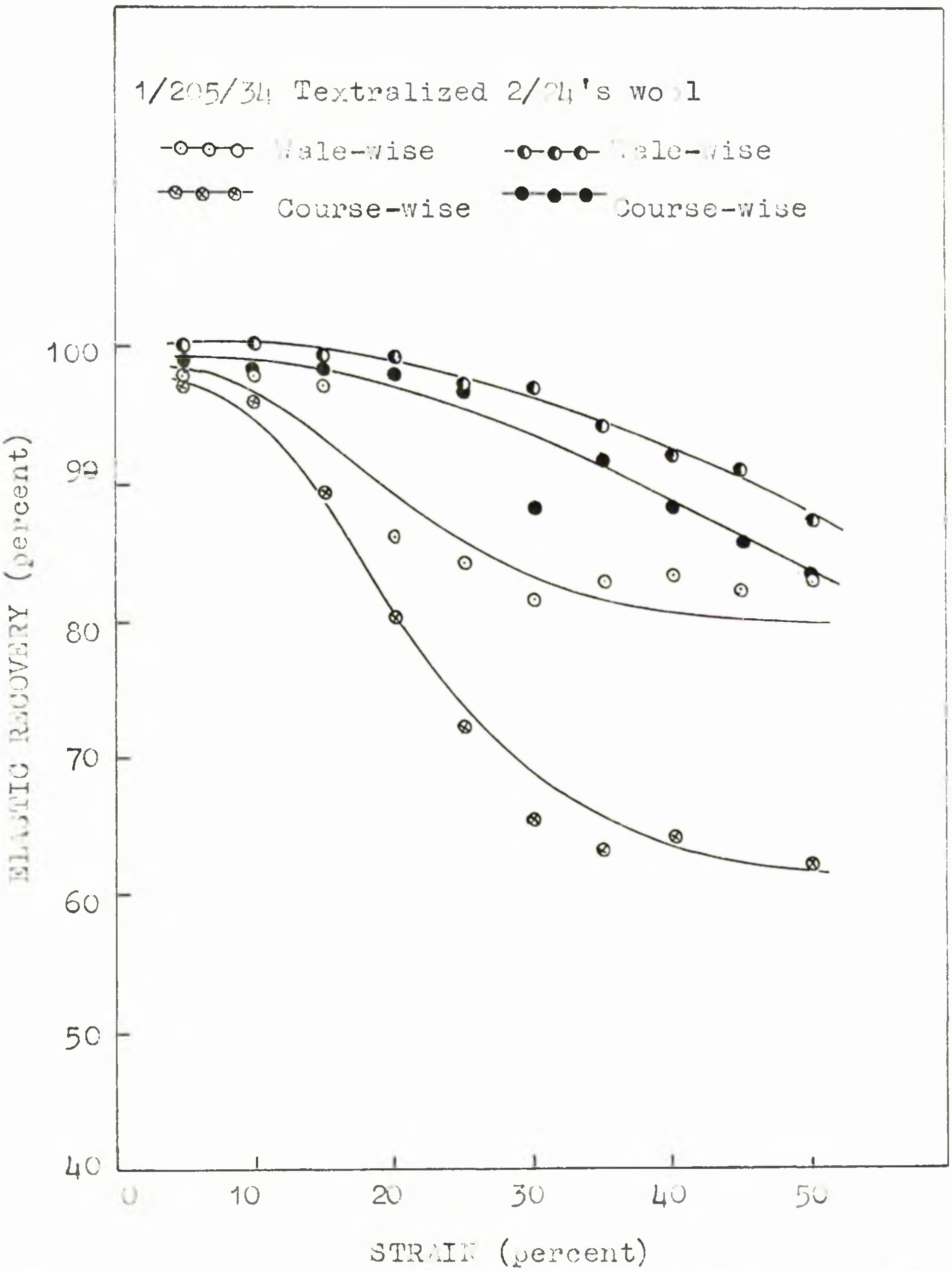


Fig.82(c). Comparison of the elastic recovery of half cardigan fabrics (wet relaxed) knitted from Textralized(T?) and wool yarns.

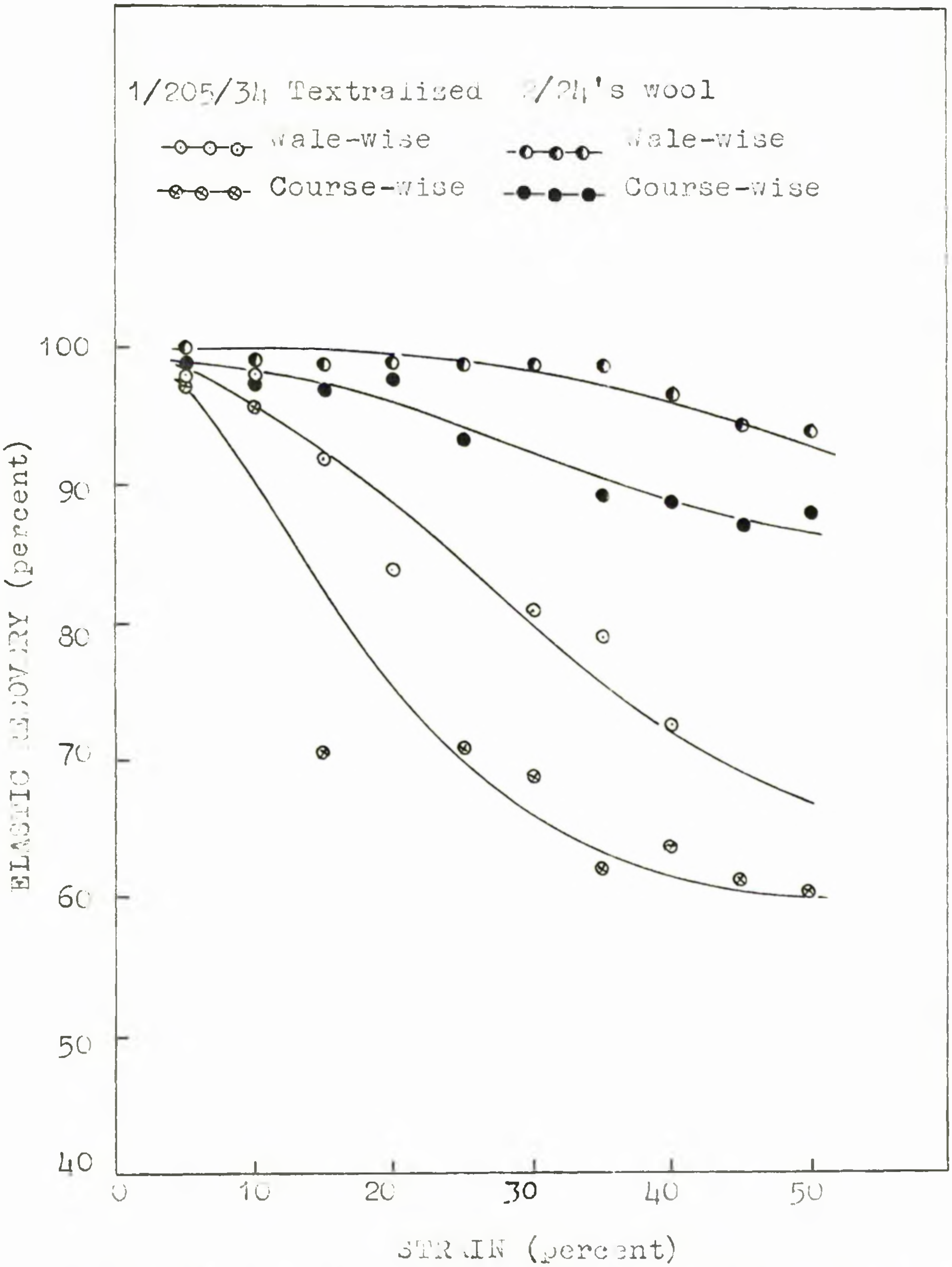


Fig.82(d). Comparison of the elastic recovery of half cardigan fabrics (dry tumbled) knitted from Textralized(T2) and wool yarns.

wool fabrics when compared with fabrics produced from Textralised yarns.

It is reasonable to suppose that the ability of a fabric to recover from deformation will be related to the way the energy to deform that fabric is stored or dissipated[141]. In fabrics in which yarn movements and frictional restraints are small, a larger proportion of the energy of deformation will be stored and will assist in subsequent recovery from deformation. For the same reasons the energy required to return the yarns to their original positions will be small. On the basis of this suggestion the superior elastic recovery behaviour of wool fabrics can be explained since it has been stated earlier that these fabrics produce stable load deformation curves as a result of very little yarn movement. It might be argued that the frictional restraints would be larger for wool fabrics when compared with those of fabrics knitted from Textralised yarns. This is not so as with fabrics produced from bulked yarns, the individual filaments of a yarn tend to separate whenever able to do so thus creating inter-filament entanglement and increasing the effective yarn diameter, both of these factors contributing to higher frictional restraints in such fabrics.

It will also be noted that whereas finished fabrics knitted from bulked yarns show somewhat higher elastic recovery values, the influence of these finishing treatments on wool fabrics is not so marked, as the elastic recovery of the latter is very high, even in the greige state, this allowing of only a small improvement in recovery due to the effect of any finishing operation.

TABLE 24(a)

(Elastic recovery of 1 x 1 rib fabrics from 2/100/34 STAB false twist nylon yarn (F1) C.R. 12%; wale-wise stretch; greige fabric)

No. of ends of yarn	Ext., %	Immediate elastic recovery, %		Total elastic recovery, %		Load, gm.	
		1st cyc.	4th cyc.	1st cyc.	4th cyc.	1st cyc.	4th cyc.
2	10	50.0	40.0	90.0	85.0	92	82
	20	52.5	45.0	80.0	67.5	150	175
	30	56.7	46.7	75.0	66.7	220	190
	40	60.0	46.3	75.0	66.3	290	245
	50	59.0	47.0	74.0	65.0	400	345
3	10	45.0	45.0	98.0	96.0	174	168
	20	60.0	50.0	87.5	82.5	285	255
	30	61.7	56.7	76.7	72.7	750	400
	40	60.0	53.8	75.0	67.5	620	540
	50	61.0	50.0	71.0	68.0	860	730
4	10	64.0	60.0	96.0	92.0	275	265
	20	60.0	48.0	96.0	80.0	410	390
	30	60.7	56.0	90.7	65.3	700	600
	40	68.0	56.0	89.0	69.0	920	1200
	50	66.4	56.0	83.2	68.0	1460	1200
5	10	62.0	56.0	82.0	76.0	370	345
	20	64.0	51.0	75.0	68.0	640	560
	30	61.3	56.7	82.7	70.7	1040	900
	40	63.3	58.3	81.7	75.0	1570	1320
	50	68.0	61.3	81.3	73.3	2760	2160

<u>TABLE 24(b)</u>

(Elastic recovery of 1 x 1 rib fabrics from 2/100/34 STAB false twist nylon yarn, (f1) C.R. 12½; wale-wise stretch; steam relaxed fabric)

No. of ends of yarn	Ext %	Immediate elastic recovery, % 1st cyc.	Immediate elastic recovery, % 4th cyc.	Total elastic recovery, % 1st cyc.	Total elastic recovery, % 4th cyc.	Load, gm. 1st cyc.	Load, gm. 4th cyc.
2	10	60.0	54.0	88.0	68.0	-	60
	20	60.0	50.0	90.0	64.0	106	96
	30	69.3	60.0	74.7	68.0	174	154
	40	66.0	60.0	75.0	67.5	225	205
	50	69.2	62.4	78.0	70.4	300	267
3	10	56.0	52.0	92.0	86.0	116	110
	20	62.0	55.0	74.0	65.0	195	175
	30	68.7	61.3	77.3	69.3	300	272
	40	65.0	62.5	81.0	64.5	405	365
	50	70.4	68.0	78.4	71.2	622	555
4	5	84.0	68.0	96.0	92.0	115	109
	10	60.0	55.0	95.0	75.0	190	170
	20	70.0	56.0	86.0	80.0	330	295
	30	66.7	63.3	84.0	77.3	655	555
	40	65.0	56.5	80.5	74.0	705	640
	50	64.0	56.0	79.2	72.0	1260	1060
5	10	60.0	54.0	96.0	94.0	300	270
	20	68.0	56.0	90.0	78.0	575	510
	30	65.3	60.0	76.7	68.0	960	840
	40	68.0	65.0	77.0	69.0	1520	1260
	50	68.0	62.4	86.6	78.4	2480	2000

TABLE 24 (e)

(Elastic recovery of 1 x 1 rib fabrics from 2/100/34 TAB false twist nylon yarn, (Fl) C. [illegible]. 12 [illegible]; wale-wise stretch; wet relaxed fabric)

o. of nds f arn	Ext. %	Immediate elastic recovery, % 1st cyc.	4th cyc.	Total elastic recovery, % 1st cyc.	4th cyc.	Load, gm. 1st cyc.	4th cyc.
2	5	76.0	68.0	92.0	90.0	51	50
	10	72.0	68.0	96.0	94.0	85	82
	20	62.0	58.0	88.0	80.0	128	116
	30	74.7	62.7	81.3	76.0	186	167
	40	70.0	62.0	79.0	71.5	260	225
	50	69.6	63.2	77.6	71.2	380	325
3	5	68.0	60.0	96.0	92.0	99	97
	10	60.0	56.0	96.0	92.0	150	140
	15	60.0	54.7	92.0	66.7	172	165
	20	70.0	60.0	76.0	68.0	230	205
	30	68.0	60.0	76.0	70.7	330	290
	40	69.0	63.0	77.0	72.0	442	385
	45	71.5	62.7	76.9	69.8	530	455
	50	70.4	66.0	78.4	70.4	600	515
[illegible]	5	60.0	56.0	96.0	92.0	146	143
	10	64.7	60.0	96.0	92.0	192	185
	15	68.0	60.0	97.0	92.0	280	260
	20	66.0	60.0	94.0	92.0	350	310
	30	66.7	61.3	79.3	70.7	500	440
	40	70.0	65.0	78.0	71.0	795	680
	50	72.8	64.0	80.0	72.0	1120	920
	5	76.0	68.0	92.0	88.0	210	205
	10	64.0	62.0	94.0	88.0	305	290
	15	69.3	60.0	93.3	78.7	420	390
	20	66.0	60.0	86.0	80.0	530	475
	30	66.7	61.3	84.7	80.0	860	750
	40	70.0	62.0	80.0	73.0	1430	1190
	45	64.4	60.9	81.3	73.3	1620	1560
	50	68.0	64.0	76.0	67.2	1900	1500

TABLE 24 (d)

(Elastic recovery of 1 x 1 rib fabrics from 2/100/34 STAE false twist nylon yarn, (F1) C.R. 12%; wale-wise stretch; dry-tumbled fabric)

No. of ends of yarn	Ext. %	Immediate elastic recovery, % 1st cyc.	Immediate elastic recovery, % 4th cyc.	Total elastic recovery, % 1st cyc.	Total elastic recovery, % 4th cyc.	Load, gm. 1st cyc.	Load, gm. 4th cyc.
2	10	80.0	64.0	96.0	92.0	92	88
	20	-	70.0	92.0	88.0	150	140
	30	62.7	56.0	72.0	62.7	207	180
	40	65.0	58.0	73.0	64.0	272	230
	50	68.1	60.0	76.0	68.0	365	310
3	5	84.0	68.0	96.0	92.0	114	112
	10	60.0	58.0	92.0	88.0	170	162
	20	62.0	54.0	88.0	80.0	270	245
	30	68.0	58.4	84.0	79.2	357	300
	40	67.0	60.0	-	-	400	365
	50	70.0	60.0	76.8	69.2	790	650
4	5	64.0	72.0	96.0	92.0	176	168
	10	74.0	70.0	96.0	92.0	260	255
	15	60.0	57.3	94.1	92.0	345	320
	20	66.0	58.0	96.0	92.0	422	392
	30	66.7	55.3	73.3	66.7	620	545
	40	64.0	57.0	79.0	72.0	950	805
	45	69.0	64.4	77.8	69.8	1110	920
	50	67.2	60.0	74.4	67.2	1340	1100
5	5	92.0	88.0	98.0	92.0	270	268
	10	84.0	72.0	98.0	92.0	380	367
	15	76.0	73.3	89.3	84.0	525	480
	20	70.0	60.0	83.0	80.0	670	520
	30	62.7	53.3	77.3	72.0	1000	850
	40	63.0	55.0	80.0	70.0	1570	1280
	45	67.1	62.7	77.0	69.8	2400	1960
	50	64.0	60.0	76.0	68.0	2840	2280

TABLE 25 (a)

(Elastic recovery of 1 x 1 rib fabrics, in the wale-wise direction, from

(a) 2/100/34 OFT false twist yarn, C.R. 30.8%, No. of ends = 3
(b) 2/70/34 - do. - C.R. 31.8%, do. = 3
(c) 2/70/20 - do. - C.R. 27.6% do. = 3
GREIGE FABRIC)

Yarn Denier	Ext., %	Immediate elastic recovery, %		Total elastic recovery, %		Load, gm.	
		1st cyc.	4th cyc.	1st cyc.	4th cyc.	1st cyc.	4th cyc.
/100/34	10	60.0	52.0	88.0	84.0	150	142
	20	64.0	50.0	80.0	75.0	257	218
.p.f.=3	30	64.0	54.7	86.7	80.0	337	305
	40	65.0	59.0	74.5	68.0	465	410
F3)	50	68.0	58.0	72.0	66.0	640	540
/70/34	10	48.0	40.0	96.0	92.0	84	78
	20	54.0	50.0	84.0	78.0	130	116
.p.f.=2	30	60.0	49.3	80.0	58.7	197	170
	40	57.0	52.0	69.5	58.7	265	230
[illegible])	50	62.5	54.4	70.8	60.6	370	315
/70/20	10	68.0	52.0	80.0	76.0	82	78
	20	56.0	52.0	92.0	90.0	136	122
.p.f.=3.5	30	57.3	55.3	72.0	65.3	197	170
	40	68.5	55.0	75.0	67.0	350	310
(F5)	50	60.8	56.0	70.4	61.6	425	370

TABLE 25. (b)

(Elastic recovery of 1 x 1 rib fabrics, in the wale-wise direction, from

(a) 2/100/34 OFT false twist yarn, C.R. 30.8%, No. of ends = 3
(b) 2/70/34 OFT - do. - , C.R. 31.8%, - do. - = 3
(c) 2/70/20 OFT - do. -, C.R. 27.6% - do. - = 3

STEAM RELAXED FABRIC)

Yarn denier	Ext., %	Immediate elastic recovery, % 1st cyc.	Immediate elastic recovery, % 4th cyc.	Total elastic recovery, % 1st cyc.	Total elastic recovery, % 4th cyc.	Load, gm. 1st cyc.	Load, gm. 4th cyc.
/100/34	10	64.0	60.0	96.0	92.0	112	107
	20	68.0	64.0	96.0	92.0	190	174
.p.f.3	30	73.3	66.7	86.7	81.3	300	267
	40	72.0	70.0	95.0	92.0	420	382
F3)	50	76.0	65.6	83.2	74.0	570	485
/70/34	5	68.0	60.0	92.0	88.0	44	41
	10	68.0	60.0	92.0	88.0	65	61
.p.f.2	15	73.3	60.0	81.3	76.0	81	70
	20	62.0	60.0	74.0	65.0	100	90
F4)	30	69.3	62.3	77.3	69.3	138	125
	40	68.0	66.0	75.0	67.5	190	165
	45	70.7	64.4	79.1	71.1	225	195
	50	72.0	68.0	78.8	74.0	250	222
/70/20	5	76.0	68.0	92.0	84.0	32	29
	10	68.0	64.0	92.0	80.0	50	47
.p.f.3.5	15	65.3	60.0	84.0	78.3	70	60
	20	70.0	60.0	82.0	75.0	92	83
F5)	30	70.7	63.3	84.0	80.0	140	126
	35	69.1	61.6	85.0	78.3	160	145
	40	70.0	63.0	81.0	71.5	212	185
	50	72.0	65.0	81.2	74.0	285	255

TABLE 25 (c).

(Elastic recovery of 1 x 1 rib fabrics, in the wale-wise direction, from

(a) 2/100/34 OPT false twist yarn, C.R. 30.8%, No. of ends = 3
(b) 2/70/34 OPT - do. - , C.R. 31.8%, - do. - = 3
(c) 2/70/20 OPT - do. - , C.R. 27.6%, - do. - = 3

WET RELAXED FABRIC)

Yarn Denier	Ext., %	Immediate elastic recovery, % 1st cyc.	Immediate elastic recovery, % 4th cyc.	Total elastic recovery, % 1st cyc.	Total elastic recovery, % 4th cyc.	Load, gm. 1st cyc.	Load, gm. 4th cyc.
2/100/34	5	76.0	68.0	98.0	96.0	98	96
	10	70.0	58.0	98.0	96.0	136	133
d.p.f.3	20	68.0	62.0	90.0	70.0	250	212
	30	73.3	66.7	83.2	76.0	327	300
(P3)	40	73.0	67.0	82.0	76.0	440	385
	45	73.3	67.5	82.2	76.0	525	460
	50	74.4	68.8	82.8	76.8	620	540
2/70/34	10	84.0	80.0	96.0	88.0	111	105
	15	70.7	67.0	86.7	81.3	135	128
d.p.f.2	20	70.0	68.0	94.0	90.0	171	162
	30	70.7	64.0	82.7	74.7	230	205
(P4)	40	72.0	64.0	82.0	75.0	305	280
	45	72.4	65.3	81.3	74.2	325	290
	50	72.8	64.8	80.8	74.2	367	330
2/70/20	5	88.0	84.0	96.0	96.0	52	51
	10	88.0	84.0	96.0	96.0	84	78
d.p.f.3.5	15	89.3	87.0	94.7	92.0	100	92
	20	82.0	80.0	94.0	93.0	122	114
(P5)	30	80.0	73.3	90.7	85.3	186	166
	40	77.0	69.0	85.5	78.0	285	250
	45	74.2	68.0	85.5	77.0	335	297
	50	76.0	70.4	85.2	78.4	365	322

TABLE 25 (d).

(Elastic recovery of 1 x 1 rib fabrics, in the wale-wise direction, from

(a) 2/100/34 OFT false twist yarn, C.R. 30.8%, No. of ends = 3
(b) 2/70/34 OFT - do. - , C.R. 31.8%, - do. = 3
(c) 2/70/20 OFT - do. - , C.R. 27.6% - do. = 3

DRY TUMBLED FABRIC)

arn enier	Ext., %	Immediate elastic recovery, % 1st cyc.	Immediate elastic recovery, % 4th cyc.	Total elastic recovery, % 1st cyc.	Total elastic recovery, % 4th cyc.	Load, gm. 1st cyc.	Load, gm. 4th cyc.
/100/34	5	84.0	76.0	96.0	92.0	118	116
	10	80.0	72.0	96.0	92.0	166	157
.p.f.3	20	74.0	70.0	80.0	72.0	262	242
	30	73.3	68.0	84.0	80.0	392	350
(F3)	40	72.0	69.0	78.0	71.0	515	455
	45	74.7	69.0	80.4	74.0	690	595
	50	73.6	72.0	80.0	73.6	770	665
/70/34	5	92.0	84.0	92.0	92.0	80	78
	10	86.0	80.0	94.0	92.0		
.p.f.2	15	71.3	73.3	89.3	86.7	130	126
	20	72.0	68.0	88.0	82.0	151	140
F4)	30	70.0	62.7	73.3	65.3	210	185
	40	67.0	60.0	78.0	66.5	285	260
	45	66.2	60.9	77.6	67.1	325	285
	50	69.2	61.6	76.0	69.2	375	330
/70/20	5	84.0	76.0	96.0	96.0	82	78
	10	80.0	72.0	96.0	94.0	106	99
.p.f.3.5	15	70.6	60.0	93.3	89.3	134	122
	20	68.0	66.0	94.0	88.0	176	158
5)	30	64.0	56.0	76.0	66.7	250	212
	40	67.0	62.0	76.0	67.0	302	263
	45	69.0	62.7	73.3	69.8	335	290
	50	67.2	60.0	76.0	68.0	362	320

TABLE 26 (a)

(Elastic recovery of 1 x 1 rib fabrics, in the wale-wise direction, from

(a) 2/100/34 OFT false twist yarn, C.R. 30.[illegible]%, No. of ends = 3
(b) 2/70/34 OFT - do. - C.R. 31.6%, - do. - = 4
(c) 2/70/20 OFT - do. - C.R. 27.6%, - do. - = 4

GREIGE FABRIC)

Yarn Denier	Ext., %	Immediate elastic recovery, % 1st cyc.	Immediate elastic recovery, % 4th cyc.	Total elastic recovery, % 1st cyc.	Total elastic recovery, % 4th cyc.	Load, gm. 1st cyc.	Load, gm. 4th cyc.
2/100/34	10	60.0	52.0	88.0	84.0	150	142
	20	60.0	50.0	80.0	75.0	237	218
d.p.f.3	30	64.0	54.7	86.7	80.0	337	305
	40	65.0	59.0	74.5	68.0	465	410
(F3)	50	66.0	58.0	72.0	66.0	640	540
2/70/34	10	52.0	48.0	94.0	92.0	96	93
	20	58.0	48.0	96.0	92.0	174	156
d.p.f.2	30	60.0	50.0	70.7	58.7	245	210
	40	58.0	55.0	74.0	61.0	380	325
(F4)	50	60.0	52.0	79.2	62.4	500	425
2/70/20	10	60.0	56.0	98.0	96.0	123	110
	20	60.0	44.0	70.0	60.0	185	160
d.p.f.3.5	30	56.0	50.0	80.0	74.4	310	270
	40	59.0	49.0	68.5	58.0	410	350
(F5)	50	60.0	48.0	70.4	60.0	610	510

TABLE 26 (b)

(Elastic recovery of 1 x 1 rib fabrics, in the wale-wise direction, from

(a) 2/100/34, CPT false twist yarn, C.R. 30.8%, No. of ends = 3
(b) 2/70/34, - do. - C.R. 31.8%, - do. = 4
(c) 2/70/20, - do. - C.R. 27.6%, - do. = 4

STEAM RELAXED FABRIC)

Yarn Denier	Ext., %	Immediate elastic recovery, % 1t cyc.	Immediate elastic recovery, % 4th cyc.	Total elastic recovery, % 1st cyc.	Total elastic recovery, % 4th cyc.	Load, gm. 1st cyc.	Load, gm. 4th cyc.
2/100/34	10	64.0	60.0	96.0	92.0	112	107
	20	68.0	64.0	96.0	92.0	190	174
d.p.f.3	30	73.3	66.7	86.7	81.3	300	267
	40	72.0	70.0	95.0	92.0	420	382
(F3)	50	76.0	65.6	83.2	74.0	570	485
2/70/34	5	68.0	60.0	98.0	98.0	59	58
	10	60.0	56.0	98.0	96.0	90	86
d.p.f.2	15	68.0	62.7	94.7	92.0	122	111
	20	68.0	64.0	90.0	85.0	150	136
(F4)	30	65.3	60.0	86.7	78.7	227	200
	40	71.0	67.0	81.0	74.0	320	290
	50	72.0	65.2	79.2	71.2	405	340
2/70/20	5	88.0	84.0	96.0	88.0	57	53
	10	72.0	72.0	90.0	84.0	79	73
d.p.f.3.5	15	78.7	70.7	87.0	81.3	126	112
	20	78.0	70.0	82.0	74.0	160	140
(F5)	30	70.7	64.7	80.0	73.3	230	210
	40	73.0	66.0	81.0	75.0	325	285
	45	72.4	69.0	84.9	76.9	395	355
	50	78.0	72.0	88.0	85.2	465	410

TABLE 26 (c)

(Elastic recovery of 1 x 1 rib fabrics, in the wale-wise direction, from

(a) 2/100/34, OPT false twist yarn, C.R. 30.8%, No. of ends = 3
(b) 2/70/34, OPT " " " , C.R. 31.8%, " " " = 4
(c) 2/70/20, OPT " " " , C.R. 27.6%, " " " = 4

wet relaxed fabric)

Yarn Denier	Ext., %	Immediate elastic recovery, % 1st cyc.	Immediate elastic recovery, % 4th cyc.	Total elastic recovery, % 1st cyc.	Total elastic recovery, % 4th cyc.	Load, gm. 1st cyc.	Load, gm. 4th cyc.
2/100/34	5	76.0	68.0	98.0	96.0	98	96
	10	70.0	58.0	98.0	96.0	136	133
d.p.f.3	20	68.0	62.0	90.0	70.0	230	212
	30	73.3	66.7	83.2	76.0	327	300
(F3)	40	73.0	67.0	82.0	76.0	440	385
	45	73.3	67.5	82.2	76.0	525	460
	50	74.4	68.8	82.8	76.8	620	540
2/70/34	5	80.0	72.0	96.0	92.0	92	85
	10	72.0	66.0	98.0	96.0	127	125
d.p.f.2	15	70.7	65.3	97.3	96.0	167	160
	20	70.0	66.0	86.0	80.0	205	187
(F4)	30	73.3	68.0	84.0	76.0	250	232
	40	75.0	66.0	80.0	72.0	310	275
	45	75.1	69.0	81.3	74.0	380	332
	50	73.6	69.6	82.4	76.0	452	405
2/70/20	5	84.0	80.0	98.0	98.0	80	78
	10	76.0	72.0	96.0	96.0	122	120
	15	78.7	73.3	97.0	94.7	167	143
	20	72.0	66.0	82.0	76.0	190	175
	30	70.7	68.0	85.3	82.7	292	270
	40	77.0	70.0	85.0	82.0	382	342
	45	76.0	73.3	82.2	77.8	500	460
	50	75.2	72.0	80.8	77.4	590	510

TABLE 26 (d)

(Elastic recovery of 1 x 1 rib fabrics, in the wale-wise direction, from

(a) 2/100/34 [illegible] false twist yarn, C.R. 30.8%, No. of ends = 3
(b) 2/70/34, [illegible] false twist yarn, C.R. 31.8%, No. of ends = 4
(c) 2/70/20, [illegible] false twist yarn, C.R. 27.6%, No. of ends = 4

dry tumbled fabric)

Yarn denier	Ext., %	Immediate elastic recovery, % 1st cyc.	Immediate elastic recovery, % 4th cyc.	Total elastic recovery, % 1st cyc.	Total elastic recovery, % 4th cyc.	Load, gm. 1st cyc.	Load, gm. 4th cyc.
2/100/34	5	84.0	76.0	96.0	92.0	118	116
	10	80.0	72.0	96.0	92.0	166	157
d.p.f.3	20	74.0	70.0	80.0	72.0	262	242
	30	73.3	68.0	84.0	80.0	392	350
(P3)	40	72.0	69.0	78.0	71.0	525	455
	45	74.7	69.0	80.4	74.2	600	595
	50	73.6	72.0	80.0	73.6	770	665
2/70/34	5	84.0	76.0	96.0	92.0	116	113
	10	84.0	76.0	98.0	96.0	152	150
d.p.f.2	15		68.0	92.0	89.5		182
	20	66.0	58.0	84.0	76.0	235	222
(P4)	30	68.0	58.7	78.7	73.3	317	285
	40	68.0	59.0	80.0	72.0	420	375
	45	68.0	64.0	78.6	71.5	540	470
	50	68.8	60.8	77.6	69.6	605	520
2/70/20	5	68.0	60.0	98.0	96.0	118	116
	10	64.0	60.0	98.0	96.0	146	144
d.p.f.3.5	20	62.0	54.0	90.0	86.0	250	230
	30	70.7	62.7	92.0	86.7	395	350
(P5)	40	65.0	61.0	76.5	68.0	486	[illegible]
	45	68.0	58.2	74.2	65.3	540	460
	50	68.0	60.0	74.8	66.4	670	565

TABLE 27 (a)

(Elastic recovery of 1 x 1 rib fabrics, in the wale-wise direction, from

(a) 1/150/50 Textralized yarn, C.R. 16%, No. of ends = 4
(b) 1/205/34 " " , C.R. 16%, " " " = 3

greige fabric)

Yarn Denier	Ext., %	Immediate elastic recovery, % 1st cyc.	Immediate elastic recovery, % 4th cyc.	Total elastic recovery, % 1st cyc.	Total elastic recovery, % 4th cyc.	Load, gm. 1st cyc.	Load, gm. 4th cyc.
1/150/50	5	68.0	60.0	92.0	88.0	140	138
	10	60.0	52.0	94.0	88.0	175	165
d.p.f.3	15	60.0	49.3	89.3	86.7	255	235
	20	68.0	52.0	86.0	88.0	327	290
(T3)	25	58.4	48.0	87.2	76.0	425	365
	30	58.7	49.3	73.3	62.7	472	405
	40	62.0	52.0	73.0	64.0	690	575
	45	65.5	52.9	73.3	62.2	830	690
	50	64.0	53.6	74.4	66.4	1010	850
1/205/34	5	96.0	92.0	99.0	89.0	134	130
	10	64.0	56.0	88.0	80.0	217	195
d.p.f.6	20	66.0	56.0	88.0	90.0	375	320
	30	64.0	53.3	77.3	61.3	670	560
(T2)	40	67.0	55.0	75.0	64.0	850	720
	50	62.4	56.0	73.6	64.0	1180	940

TABLE 27 (b)

(Elastic recovery of 1 x 1 rib fabrics, in the wale-wise direction, from

(a) 1/150/50 Textralized yarn, C.L. 16%, No. of ends = 4
(b) 1/205/34 Textralized yarn, C.L. 16%, No. of ends = 3

steam relaxed fabric).

Yarn Denier	Ext., %	Immediate elastic recovery, %		Total elastic recovery, %		Load, gm.	
		1st cyc.	4th cyc.	1st cyc.	4th cyc.	1st cyc.	4th cyc.
1/150/50	5	60.0	56.0	96.0	92.0	74	69
d.p.f.3	10	60.0	48.0	96.0	86.0	116	105
	15	60.0	49.3	92.0	86.7	166	146
(T3)	20	62.0	52.0	76.0	64.0	242	215
	30	66.7	60.0	77.3	69.3	425	362
	40	70.0	63.0	80.0	72.0	720	590
	45	62.2	60.0	75.1	67.1	840	700
	50	68.0	60.0	79.1	69.6	1170	940
1/205/34	5	68.0	60.0	92.0	88.0	93	77
	10	68.0	60.0	96.0	94.0	129	114
d.p.f.6	15	68.0	60.0	87.0	76.0	215	185
(T2)	20	68.0	60.0	82.0	74.0	295	255
	25	69.5	63.2	82.4	76.0	407	350
	30	66.7	60.0	80.0	70.7	500	420
	35	65.7	61.0	76.3	70.3	620	540
	40	65.0	60.0	80.0	72.0	840	710

TABLE 27. (c)

(Elastic recovery of 1 x 1 rib fabrics, in the wale-wise direction, from

(a) 1/150/50 Textralised yarn, C.R. 16%, No. of ends = 4
(b) 1/205/34 " " , C.R. 16%, " " " = 3
wet relaxed fabric)

Yarn denier	Ext., %	Immediate elastic recovery, % 1st cyc.	Immediate elastic recovery, % 4th cyc.	Total elastic recovery, % 1st cyc.	Total elastic recovery, % 4th cyc.	Load, gm. 1st cyc.	Load, gm. 4th cyc.
1/150/50	5			96.0	92.0	102	96
	10	64.0	56.0	88.0	84.0	132	125
d.p.f.3	15	65.3	56.0	78.7	68.0	180	
	20	66.0	56.0	77.0	66.0	240	212
(T3)	25	66.4	59.2		71.2	310	270
	30	64.7	58.7	82.7	70.0	385	337
	35	68.0	60.0	78.0	68.0	620	520
	40	70.0	60.0	78.0	68.0	620	520
	50	72.0	68.0	83.2	74.4	890	745
1/205/34	5	64.0	60.0	96.0	92.0	116	11[illegible]
	10	80.0	68.0	96.0	92.0	188	172
d.p.f.6	15	68.0	62.7	86.7	84.0	240	215
	20	62.0	56.0	84.0	[illegible]	325	287
(T2)	25	64.8	57.6	84.0	[illegible]	415	360
	30	73.3	69.3	83.3	76.0	560	480
	35	71.4	67.0	81.7	74.9	62[illegible]	530
	40	71.0	58.0	77.0	68.0	680	550
	45	69.0	64.4	77.0	59.6	860	720
	50	72.8	68.0	79.2	70.4	[illegible]	900

TABLE 27 (d)

(Elastic recovery of 1 x 1 rib fabrics, in the wale-wise direction, from
(a) 1/150/50 Textralized yarn, C.R. 16%, No. of ends = 4
(b) 1/205/34 , C.R. 16%, No. of ends = 3
dry tumbled fabric)

Yarn denier	Ext., %	Immediate elastic recovery, % 1st cyc.	Immediate elastic recovery, % 4th cyc.	Total elastic recovery, % 1st cyc.	Total elastic recovery, % 4th cyc.	Load, gm. 1st cyc.	Load, gm. 4th cyc.
1/150/50	5	92.0	88.0	98.0	96.0	124	120
	10	80.0	68.0	96.0	94.0	196	185
	15	65.3	57.3	-	-	257	220
	20	68.0	60.0	82.0	72.0	372	322
(T3)	25	62.4	52.0	72.0	62.4	440	360
	30	65.3	56.0	76.0	65.3	560	470
	35	68.0	58.9	78.3	68.0	700	550
	40	67.0	60.0	77.0	68.0	840	670
	45	67.1	60.0	76.0	68.0	1015	800
	50	68.0		76.0	68.0	1260	960
1/205/34	5	84.0	76.0	96.0	92.0	166	160
	10	64.0	60.0	96.0	92.0	245	225
d.p.f.6	15	68.0	62.7	96.0	94.7	350	312
	20	67.0	62.0	94.0	92.0	450	395
(T2)	25	70.4	64.8	77.6	69.6	560	480
	30	69.3	61.3	77.3	68.0	720	600
	35	69.1	65.4	77.1	68.0	775	660
	40	70.1	65.0	77.0	68.5	920	760
	45	68.9	62.2	75.5	67.0	960	800
	50	68.8	64.0	77.6	68.5	1240	1020

TABLE 28 (a)

(Elastic recovery of 1 x 1 rib fabrics, in the wale-wise direction, knitted from

(a) 2/100/34 false twist nylon yarn, C.R. 12%, No. of ends = 3
(b) - do. - , C.R. 19.8% do. =3
(c) - do. - , C.R. 30.8% do. = 3

Greige fabric)

Crimp rigidity %	Ext., %	Immediate elastic recovery, % 1st cyc.	4th cyc.	Total elastic recovery, % 1st cyc.	4th cyc.	Load, gm. 1st cyc.	4th cyc.
12.0	10	45.0	45.0	98.0	96.0	174	168
	20	60.0	50.0	87.5	82.5	285	255
(F1)	30	61.7	56.7	76.7	71.7	450	400
	40	60.0	53.8	75.0	67.5	620	540
	50	61.0	50.0	71.0	68.0	860	730
19.8	10	76.0	64.0	92.0	86.0	145	135
	20	60.0	58.0	86.0	78.0	197	180
(F2)	30	62.0	55.3	88.7	80.7	320	290
	40	65.0	59.0	80.0	75.0	420	370
	50	67.0	56.8	76.4	67.2	775	650
30.8	10	60.0	52.0	88.0	84.0	150	142
	20	60.0	50.0	80.0	75.0	237	218
(F3)	30	64.0	54.7	86.7	80.0	337	305
	40	65.0	59.0	74.5	68.0	465	410
	50	68.0	58.0	72.0	66.4	640	540

TABLE 28 (b)

(Elastic recovery of 1 x 1 rib fabrics, in the wale-wise direction, knitted from

(a) 2/100/34 false twist nylon yarn, C.R. 12%, No. of ends = 3
(b) - do. - C.R. 19.8% do. = 3
(c) - do. - C.R. 30.8% = 3

steam relaxed fabric)

Crimp rigidity %	Ext., %	Immediate elastic recovery, % 1st cyc.	Immediate elastic recovery, % 4th cyc.	Total elastic recovery, % 1st cyc.	Total elastic recovery, % 4th cyc.	Load, gm. 1st cyc.	Load, gm. 4th cyc.
12.0	10	56.0	52.0	92.0	86.0	116	110
	20	62.0	53.0	74.0	65.0	195	175
(P1)	30	68.7	61.3	77.3	69.3	300	272
	40	65.0	62.5	81.0	64.5	405	365
	50	70.4	68.0	78.4	71.2	622	555
19.8	10	68.0	64.0	88.0	72.0	86	80
	20	66.0	62.0	84.0	72.0	166	145
(P2)	30	73.5	64.0	80.0	72.0	275	242
	40	74.0	68.0	82.0	75.0	455	382
	50	72.0	68.0	85.2	75.6	570	495
30.8	10	64.0	60.0	96.0	92.0	112	107
	20	68.0	64.0	96.0	92.0	190	174
(P3)	30	73.3	66.7	86.7	81.3	300	267
	40	72.0	70.0	95.0	92.0	420	382
	50	76.0	65.6	83.2	74.0	570	485

TABLE 28 (b)

(Elastic recovery of 1 x 1 rib fabrics, in the wale-wise direction, knitted from

(a) 2/100/34 false twist nylon yarn, C.R. 12%, No. of ends = 3
(b) - do. - C.R. 19.8% do. = 3
(c) - do. - C.R. 30.8% = 3

steam relaxed fabric)

Crimp rigidity %	Ext., %	Immediate elastic recovery, % 1st cyc.	Immediate elastic recovery, % 4th cyc.	Total elastic recovery, % 1st cyc.	Total elastic recovery, % 4th cyc.	Load, gm. 1st cyc.	Load, gm. 4th cyc.
12.0	10	56.0	52.0	92.0	86.0	116	110
	20	62.0	53.0	74.0	65.0	195	175
(F1)	30	68.7	61.3	77.3	69.3	300	272
	40	65.0	62.5	81.0	64.5	405	365
	50	70.4	68.0	78.4	71.2	622	555
19.8	10	68.0	64.0	88.0	72.0	86	80
	20	66.0	62.0	84.0	72.0	166	145
(F2)	30	73.3	64.0	80.0	72.0	275	242
	40	74.0	68.0	82.0	75.0	455	382
	50	72.0	68.0	83.2	75.6	570	495
30.8	10	64.0	60.0	96.0	92.0	112	107
	20	68.0	64.0	96.0	92.0	190	174
(F3)	30	73.3	66.7	96.7	81.3	300	267
	40	72.0	70.0	95.0	92.0	420	382
	50	76.0	65.6	83.2	74.0	570	485

TABLE 28 (c)

(Elastic recovery of 1 x 1 rib fabrics, in the wale-wise direction, knitted from

(a) 2/100/34 false twist nylon yarn, C.R. 12%, No. of ends = 3
(b) - do. - C.R. 19.8% do. = 3
(c) - do. - C.R. 30.8% do. = 3

wet relaxed fabric)

Crimp rigidity %	Ext., %	Immediate elastic recovery, % 1st cyc.	Immediate elastic recovery, % 4th cyc.	Total elastic recovery, % 1st cyc.	Total elastic recovery, % 4th cyc.	Load, gm. 1st cyc.	Load, gm. 4th cyc.
12.0	5	68.0	60.0	96.0	92.0	99	97
	10	60.0	56.0	96.0	92.0	150	140
(F1)	15	60.0	54.7	92.0	66.7	172	165
	20	70.0	60.0	76.0	68.0	230	205
	30	68.0	60.0	76.0	70.7	330	290
	40	69.0	63.0	77.0	72.0	442	385
	45	71.5	62.7	76.9	69.8	530	455
	50	70.4	68.0	78.4	70.4	600	515
19.8	5	84.0	76.0	96.0	92.0	90	88
	10	74.0	64.0	94.0	92.0	106	995
(F2)	20	76.0	70.0	94.0	90.0	172	154
	30	74.4	64.0	81.3	70.4	250	215
	40	74.0	68.0	85.0	79.0	387	337
	50	72.0	68.0	80.8	73.6	495	410
30.8	5	76.0	68.0	98.0	96.0	98	96
(F3)	10	70.0	58.0	98.0	96.0	136	133
	20	68.0	62.0	90.0	70.0	230	212
	30	73.3	66.7	83.3	76.0	327	300
	40	73.0	67.0	82.0	76.0	440	385
	45	73.3	67.5	82.2	76.0	525	460
	50	74.4	68.8	82.8	76.8	620	540

TABLE 28 (d)

(Elastic recovery of 1 x 1 rib fabrics, in the wale-wise dir-

(a) 2/100/34 false twist nylon yarn, C.R. 12%, No. of ends =
(b) - do. - , C.R. 19.8% - do. - = 3
(c) - do. - , C.R. 30.8% - do. - = 3

dry tumbled fabric)

Crimp rigidity %	Ext., %	Immediate elastic recovery, % 1st cyc.	Immediate elastic recovery, % 4th cyc.	Total elastic recovery, % 1st cyc.	Total elastic recovery, % 4th cyc.	Load, gm. 1st cyc.	Load, gm. 4th cyc.
12.0	5	84.0	68.0	96.0	92.0	114	112
	10	60.0	58.0	92.0	88.0	170	162
(F1)	20	62.0	54.0	88.0	80.0	270	245
	25	68.0	58.4	84.0	79.2	337	300
	30	66.7	61.5			400	365
	40	67.0	60.0	79.0	72.0	585	490
	50	70.0	60.0	76.8	69.2	790	650
19.8	5	84.0	80.0	98.0	96.0	104	102
	10	76.0	72.0	98.0	96.0	147	144
(F2)	20	76.0	70.0	90.0	80.0	252	230
	30	76.0	61.3	84.0	77.3	370	320
	40	72.0	67.0	78.0	71.0	480	415
	50	73.6	69.2	78.4	71.2	630	540
30.8	5	84.0	76.0	96.0	92.0	118	116
	10	80.0	72.0	96.0	92.0	166	157
(F3)	20	74.0	70.0	80.0	72.0	262	242
	30	73.3	68.0	84.0	80.0	392	350
	40	72.0	69.0	76.0	71.0	515	455
	45	74.7	69.0	80.4	74.2	690	595
	50	73.6	72.0	80.0	73.6	770	665

TABLE 29. (a)

(Elastic recovery of 1 x 1 rib fabrics, in the wale-wise direction, from

(a) 1/70/20 Textralized yarn (stuffer-box bulked), No. of ends = 6
(b) 2/70/20 CFT false twist yarn , No. of ends = 3

greige fabric)

Yarn denier	Ext., %	Immediate elastic recovery, % 1st cyc.	Immediate elastic recovery, % 4th cyc.	Total elastic recovery, % 1st cyc.	Total elastic recovery, % 4th cyc.	Load, gm. 1st cyc.	Load, gm. 4th cyc.
1/70/20	5	56.0	50.0	98.0	96.0	69	65
Textralised	10	58.0	48.0	98.0	92.0	92	87
(T1)	15	60.0	46.7	89.3	86.7	120	106
	20	54.0	42.0	92.0	86.0	154	136
	25	60.0	45.6	76.0	69.6	184	156
	30	58.7	49.3	70.7	56.0	218	185
	35	60.0	49.7	60.6	57.7	290	250
	40	61.0	52.0	75.0	63.0	362	312
	45	58.2	51.1	72.9	61.8	400	350
	50	55.0	48.0	68.8	58.8	500	410
2/70/20	10	68.0	52.0	80.0	76.0	82	70
False twist	20	56.0	52.0	92.0	90.0	136	122
(F5)	30	57.3	53.3	72.0	65.3	197	170
	40	68.5	55.0	75.0	67.0	360	310
	50	60.8	56.0	70.4	61.6	425	370

TABLE 29 (b)

(Elastic recovery of 1 x 1 rib fabrics, in the wale-wise direction, from

(a) 1/70/20 Textralized yarn (stuffer-box bulked), No. of ends = 6
(b) 2/70/20 CPT false twist yarn , No. of ends = 3

steam relaxed fabric)

Yarn Denier	Ext., %	Immediate elastic recovery, %		Total elastic recovery, %		Load, gm.	
		1st cyc.	4th cyc.	1st cyc.	4th cyc.	1st cyc.	4th cyc.
1/70/20	5	72.0	60.0	92.0	88.0	31	28
Textralized	10	69.0	60.0	84.0	72.0	535	48
	15	60.0	52.0	81.3	68.0	75	66
(T1)	20	68.0	56.0	80.0	66.0	108	96
	25	64.8	53.6	76.0	64.8	129	113
	30	68.0	57.3	80.0	70.7	180	160
	35	67.0	60.0	77.0	68.0	255	205
	40	66.0	60.0	78.0	69.0	267	250
	50	70.0	62.0	81.2	73.6	400	410
2/70/20	5	76.0	68.0	92.0	84.0	32	29
False	10	68.0	64.0	92.0	80.0	50	47
twist	15	65.3	60.0	84.0	78.3	70	60
(F5)	20	70.0	60.0	82.0	75.0	92	85
	30	70.7	63.3	84.0	80.0	140	126
	35	69.1	61.6	85.1	78.3	160	145
	40	70.0	63.0	81.0	71.5	212	195
	50	72.0	65.0	81.2	74.0	205	255

TABLE 29 (c)

(Elastic recovery of 1 x 1 rib fabrics, in the wale-wise direction, from

(a) 1/70/20 Textralized yarn (stuffer-box bulked), No. of ends = 6
(b) 2/70/20 OPT false twist yarn , No. of ends = 3

wet relaxed fabric)

Yarn denier	Ext., %	Immediate elastic recovery, %		Total elastic recovery, %		Load, gm.	
		1st cyc.	4th cyc.	1st cyc.	4th cyc.	1st cyc.	4th cyc.
1/70/20	5	84.0	76.0	96.0	88.0	52	50
Textrali-	10	60.0	56.0	80.0	72.0	78	74
zed	15	60.0	54.7	76.0	68.0	98	88
(T1)	20	62.0	52.0	74.0	63.0	120	108
	25	63.2	60.0	77.6	68.0	155	136
	30	69.2	62.7	72.0	66.7	185	162
	35	65.1	60.6	72.0	64.0	207	175
	40	70.0	62.5	75.0	67.0	265	230
	45	68.0	58.2	75.5	67.1	300	255
	50	68.0	60.0	78.4	67.2	360	300
2/70/20	5	88.0	84.0	96.0	96.0	52	51
False	10	88.0	84.0	96.0	96.0	84	78
twist	15	89.3	87.0	94.7	92.0	100	92
(F5)	20	82.0	80.0	94.0	93.0	122	114
	30	80.0	73.3	90.7	85.3	156	166
	40	77.0	69.0	85.5	78.0	285	250
	45	74.2	68.0	82.5	77.0	335	297
	50	76.0	70.4	85.2	78.4	365	322

TABLE 29 (d)

(Elastic recovery of 1 x 1 rib fabrics, in the wale-wise direction, from

(a) 1/70/20 Textralized yarn (stuffer-box bulked), No. of ends = 6
(b) 2/70/20 OPT false twist yarn , No. of ends = 3

dry tumbled fabric)

Yarn denier	Ext., %	Immediate elastic recovery, % 1st cyc.	Immediate elastic recovery, % 4th cyc.	Total elastic recovery, % 1st cyc.	Total elastic recovery, % 4th cyc.	Load, gm. 1st cyc.	Load, gm. 4th cyc.
1/70/20	5	88.0	80.0	98.0	92.0	66	62
Textralized	10	64.0	60.0	96.0	88.0	109	100
(T1)	15	60.0	54.3	92.0	89.3	140	129
	20	66.0	60.0	90.0	86.0	166	150
	25	69.6	56.8	77.6	69.6	220	190
	30	66.7	57.3	80.0	70.7	275	240
	35	68.0	62.3	81.7	73.7	342	285
	40	70.0	58.0	78.0	70.0	375	305
	45	67.1	60.0	74.2	65.3	385	310
	50	65.6	56.0	76.0	67.2	480	390
2/70/20	5	84.0	76.0	96.0	96.0	82	78
False twist	10	80.0	72.0	96.0	94.0	106	99
(F5)	15	70.6	60.0	93.3	89.3	134	122
	20	68.0	66.0	94.0	88.0	176	158
	30	64.0	56.0	76.0	66.7	250	212
	40	67.0	62.0	76.0	6[illegible].0	302	263
	45	69.0	62.7	73.3	69.6	335	290
	50	67.2	60.0	76.0	68.0	362	320

(Elastic recovery of I x I rib fabrics, in the wale-wise direction, from

(a) 1/205/34 Textralized yarn, C.R. 16%, No. of ends = 3
(b) 1/150/50 " ", C.R. 16%, No. of ends = 4

greige fabric)

Yarn denier	Ext., %	Immediate elastic recovery, %				Total elastic recovery, %				Load, gm.			
		Wale-wise		Course-wise		Wale-wise		Course-wise		Wale-wise		Course-wise	
		1st c.	4th c.	1st c.	4th c.	1st c.	4th c.	1st c.	4th c.	1st c.	4th c.	1st c.	4th c.
1/205/34 Textralized (T2)	5	96.0	92.0	92.0	87.0	99.0	99.0	92.0	84.0	134	130	56	52
	10	64.0	56.0	80.0	72.0	88.0	80.0	88.0	80.0	217	195	73	70
	15			70.7	65.3			86.7	73.3			86	83
	20	66.0	56.0	76.0	70.0	88.0	90.0	90.0	80.0	375	320	112	103
	25			71.2	60.0			76.0	66.7				
	30	64.0	53.3	62.7	53.3	77.3	61.3	72.0	60.0	670	560		
	35			60.0	52.0			70.3	60.0				
	40	67.0	55.0	61.0	55.0	75.0	64.0	71.0	62.0	850	720	156	140
	50	62.4	56.0	61.6	52.0	73.6	64.8	68.0	57.6	1180	940		
1/150/50 Textralized (T3)	5	68.0	60.0	60.0	59.0	92.0	88.0	72.0	60.0	140	138	42	40
	10	60.0	52.0	64.0	60.0	94.0	88.0	84.0	80.0	175	165	58	56
	15	60.0	49.3	69.3	52.0	89.3	86.7	73.3	69.5	255	235	70	65
	20	68.0	52.0	54.0	50.0	86.0	88.0	74.0	65.0	327	290	81	77
	25	58.4	48.8			87.2	76.0			425	365		
	30	58.7	49.3	54.0	48.7	73.3	62.7	76.7	66.7	472	405	100	89
	40	62.0	52.0	56.0	47.0	73.0	64.0	70.0	58.0	690	575	140	116
	45	63.5	52.9	55.6	46.7	73.3	62.2	68.0	55.6	830	690	142	120
	50	64.0	53.6	56.8	46.4	74.4	66.7	64.0	55.2	1010	850	153	126

TABLE 30 (b)

(Elastic recovery of 1 x 1 rib fabrics, in the course, and wale-wise direction, from

(a) 1/205/34 Textralized yarn, C.R. 16%, No. of ends = 3
(b) 1/150/50 Textralized yarn, C.R. 16%, No. of ends = 4

Steam relaxed fabric)

Yarn Denier	Ext., %	Immediate elastic recovery, %				Total elastic recovery, %				Load, gm.			
		Wale-wise		Course-wise		Wale-wise		Course-wise		Wale-wise		Course-wise	
		1st c.	4th c.	1st c.	4th c.	1st c.	4th c.	1st c.	4th c.	1st c.	4th c.	1st c.	4th c.
1/205/34 Textralized T2	5	68.0	60.0	92.0	84.0	92.0	88.0	98.0	96.0	85	77	20	19
	10	68.0	60.0	76.0	68.0	96.0	94.0	92.0	84.0	129	114	30	29
	15	68.0	60.0	73.3	68.0	87.0	76.0	94.7	89.3	215	185	35	32
	20	68.0	60.0	64.0	56.0	82.0	74.0	84.0	72.0	295	255	45	40
	25	69.3	63.2	63.2	58.4	82.4	76.0	87.2	87.0	407	350	53	46
	30	66.7	60.0	62.0	53.3	80.0	70.7	76.0	66.7	500	420	59	50
	35	65.7	61.0		60.0	78.3	70.3	73.7	65.7	620	540	65	56
	40	65.0	60.0	62.0	55.0	80.0	72.0	73.0	62.0	840	710	124	105
	50			64.0	58.0			73.6	61.6				
1/150/50 Textralized T3	5	60.0	56.0			96.0	92.0			74	69		
	10	60.0	48.0	68.0	67.0	96.0	86.0	84.0	76.0	116	105	25	24
	15	60.0	49.3	72.0	64.0	92.0	86.7	77.3	66.7	166	146	27	25
	20	62.0	52.0	66.0	58.0	76.0	64.0	74.0	64.0	242	215	40	36
	25			60.0	50.4			72.2	61.6			40	
	30	66.7	60.0	61.3	48.0	77.3	69.3	74.7	60.0	425	362	50	41
	40	70.0	63.0	62.0	50.0	80.0	72.0	73.0	59.0	720	590	72	57
	45	66.2	60.0	60.4	49.8	75.1	67.1	71.1	58.7	840	700		
	50	68.0	60.0	64.8	55.8	79.1	69.6	75.2	64.0	1170	940	85	67

TABLE 30 (c)

(Elastic recovery of 1 x 1 rib fabrics, in the wale and course-wise directions, from

(a) 1/225/34 Textralised yarn, C.R. 16%, No. of ends = 5
(b) 1/150/50 Textralised yarn, C.R. 16%, No. of ends = 4

wet relaxed fabric)

Yarn Denier	Ext., %	Immediate elastic recovery, %				Total elastic recovery, %				Load, gm.			
		Wale-wise		Course-wise		Wale-wise		Course-wise		Wale-wise		Course-wise	
		1st c.	4th c.	1st c.	4th c.	1st c.	4th c.	1st c.	4th c.	1st c.	4th c.	1st c.	4th c.
1/225/34 Textralised (T2)	5	64.0	60.0	84.0	76.0	96.0	92.0	88.0	80.0	116	110	44	42
	10	80.0	68.0	72.0	68.0	96.0	92.0	84.0	74.0	180	172	55	53
	15	68.0	62.7	65.3	61.3	86.7	84.0	84.0	73.3	240	215	77	74
	20	62.0	56.0	60.0	55.0	84.0	80.0	80.0	70.0	325	287		82
	25	64.8	57.6	63.2	55.2	86.0	80.8	71.2	64.8	415	360	78	86
	30	73.3	69.3	64.0	54.7	85.3	76.0	73.3	64.0	560	480	116	104
	35	71.7	67.0	61.1	52.0	81.7	74.0	71.4	60.0	620	530	132	116
	40	71.0	56.0	61.0	51.0	77.0	68.0	70.0	60.0	680	550	152	116
	45	69.0	64.4			77.8	59.6			860	720		
	50	72.8	68.0			79.2	70.7			1080	900		
1/150/50 Textralised (T5)	5			84.0	68.0	96.0	92.0	84.0	66.0	102	96	40	37
	10	64.0	56.0	68.0	60.0	88.0	84.0	72.0	64.0	152	125	62	59
	15	65.3	56.0	68.0	57.3	78.7	68.0	78.7	65.3	180		85	76
	20	66.0	56.0	62.0	64.0	77.0	66.0	74.0	64.0	240	212	100	94
	25	66.7	59.2	60.0	52.0		71.2	64.8	55.2	310	270		
	30	64.7	58.7	60.0	49.3	82.7	70.0	69.3	56.7	365	357	122	109
	35	60.0	60.0	57.7	48.6	79.4	68.0	64.6	54.3	480	410	138	121
	40	70.0	60.0	57.0	51.0	78.0	68.0	67.0	56.0	620	520	156	136
	45			56.4	49.3			67.1	55.5			184	156
	50	72.0	68.0	59.2	52.0	85.2	74.4	65.6	54.8	890	745	200	162

TABLE 30(d).

(Elastic recovery of 1 x 1 rib fabrics, in the wale and course-wise directions, from

(a) 1/205/34 Textralised yarn, C.R. 16%, No. of ends = 3
(b) 1/150/50 Textralised yarn, C.R. 16%, No. of ends = 4

dry tumbled fabric)

Yarn Denier	Ext., %	Immediate elastic recovery, %				Total elastic recovery, %				Load, gm.			
		Wale-wise		Course-wise		Wale-wise		Course-wise		Wale-wise		Course-wise	
		1st c.	4th c.	1st c.	4th c.	1st c.	4th c.	1st c.	4th c.	1st c.	4th c.	1st c.	4th c.
1/205/34 Textral-ised (T2)	5	84.0	76.0	88.0	80.0	96.0	92.0	92.0	84.0	166	160	64	60
	10	64.0	60.0	80.0	68.0	96.0	92.0	92.0	80.0	245	225	84	80
	15	68.0	62.7	76.0	68.0	96.0	94.7	89.3	75.3	350	312	105	98
	20	67.0	62.0	78.0	62.0	94.0	92.0	83.0	72.0	450	395	130	120
	25	70.4	64.8	69.6	46.0	77.6	69.6	80.8	71.2	560	480	166	147
	30	69.3	61.3			77.3	68.0			720	600		
	35	69.1	65.4			77.1	68.0			775	660		
	40	70.1	65.0	61.0	53.0	77.0	68.5	68.0	58.0	920	760	200	170
	45	68.9	62.2			75.5	67.0			960	800		
	50	68.8	64.0	59.2	50.4	77.6	68.8	66.4	56.8	1240	1020	255	210
1/150/50 Textral-ised (T3)	5	92.0	88.0			98.0	96.0	84.0	80.0	124	120	54	49
	10	80.0	68.0	66.0	62.0	96.0	94.0	76.0	64.0	196	165	78	71
	15	65.3	57.3	65.3	54.7			68.0	58.7	257	220	95	88
	20	68.0	60.0	60.0	56.0	82.0	72.0	70.0	64.0	372	322	104	99
	25	62.4	52.0			72.0	62.4			440	360		
	30	65.3	56.0	60.0	53.3	76.0	65.3	66.7	57.3	560	470	163	147
	35	68.0	58.9			78.3	68.0			700	550		
	40	67.0	60.0	56.0	51.0	77.0	68.0	70.0	58.0	840	670	175	160
	45	67.1	60.0	55.6	46.5	76.0	68.0	62.2	54.2	1015	800	200	168
	50	68.0		56.8	48.0	76.0	68.0	65.2	55.2	1260	960	240	200

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