THE ROLE OF SHRINKAGE AND EXTENSIBILITY IN THE COMFORT AND FIT OF KNITTED COTTON GARMENTS

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1. INTRODUCTION

Cotton is by far the world's most important textile fibre with an annual consumption of more than 18 million tonnes - about 48% of all textile fibres. In spite of fierce competition from man-made fibres, cotton consumption continues to grow steadily so that the present level of utilisation is more than 30% greater than that of only 10 years ago (Fig 1). The correspondingly large growth in production of raw cotton fibre has been achieved without any increase in the area of farm land, which has been virtually constant since the 1950's due to increases in the productivity of cotton farming (Fig 2). A detailed analysis of projected population growth and agricultural resources undertaken some years ago revealed that there is no reason to doubt that cotton producers can continue to supply the appropriate quantities of cotton well into the next century without straining the food production capacity of the world agricultural system.

Within this global trend of rising cotton consumption, the key market areas of Western Europe and Japan, where the International Institute for Cotton (IIC) has been most active, have seen the most dramatic shifts in demand during the 1980's. For example, according to the United Nations Food and Agriculture Organisation (FAO), between 1981 and 1987 the amount of cotton available for final consumption in the IIC programme area of Western Europe and Japan rose by some 1.22 million tonnes, or by 51.2 %, while cotton's market share grew from less than 36% to more than 43% (Fig 3). In Japan the performance of cotton in the supply of textiles for domestic consumption has been very impressive over the last few years compared to the synthetic substitutes (Fig 4).

The explanation for cotton's outstanding performance in the market over the last decade is not very difficult to understand. In the first place it remains as true as ever that people prefer cotton - it is simply the most pleasant and comfortable fibre to wear. After a relatively brief period of rapid growth in synthetic substitutes - due to their novelty, their good easy care performance, and the strong technical and market support supplied by the chemical companies - consumers are returning to a more relaxed lifestyle where comfort and cotton are natural partners.

In the second place, cotton interests have not been idle in meeting the challenge of synthetic fibres. Great efforts have been expended in providing improved market support for cotton with the result that it now has a modern fashion image. The results of closely targeted technical research and development are also coming through to market so that cotton fabrics are increasingly better able to compete in terms of performance requirements.

The question of technical performance is a very important one because one clear result of the intrusion of man made fibres into the market has been their demonstration that the performance of many textile products could be improved substantially. The result is that, although the modern consumer is demanding the comfort of cotton textiles, she is also demanding better performance from them.

An important growth area for cotton is knitted garments for casual leisure wear where comfort is a key aspect of performance. There are many factors which affect the comfort of a garment, but one of the most important aspects is the fit - i.e. the relationship between the size of the garment and the body size of the wearer - and the way that the fit changes over the lifetime of the garment. This paper will outline some of the research and development work which is aimed at improving the performance of knitted cotton garments in respect of fit and fit retention, particularly for close fitting garments such as T-shirts, polo shirts, sports shirts, and ladies tops.

2 BASIC CONCEPTS

The comfort of a close fitting garment depends to a large extent on how tightly it hugs the body. These garments are designed to be close fitting but not tight. Therefore the size of a given item has to be large enough to fit comfortably around the largest body expected in a given size range, but small enough so that the smallest member of that size range also has a close fitting garment. Because garments are normally produced in only a limited number of size ranges, this usually means that they will have to be able to stretch somewhat when worn over a body which is relatively large for the given size range.

Workers at the Swedish Textile Research Institute (TEFO) have shown that a close fitting garment becomes uncomfortable when it exerts more than a certain level of pressure on the body. The precise comfort threshold obviously varies with different individuals (and fashions) but, after a large series of practical test measurements, TEFO found that a garment will normally be felt to be comfortable when the tension developed in the fabric is not greater than about 0.25 Newtons per centimetre of garment length, when the garment is stretched over the body. This value therefore sets one constraint upon the amount of stretching which can be allowed in the width of a garment when it is being worn by an individual with the largest body in the given size range.

Obviously, in order to calculate the maximum allowable stretch, we need to know something about the stress-strain characteristics of the fabric. TEFO have developed test equipment and procedures for evaluating fabrics and garments for the tension developed when they are stretched to a given body size.

Another constraint on garment size is provided by width shrinkage in the fabric as a result of home laundering procedures. If the fabric shrinks to a significant degree then, during the lifetime of the garment, its width will be reduced and hence the amount of extension which is imposed by placing the garment over its owner's body will increase. This would be expected to result in a higher level of pressure being generated by the garment on the body. The greater the shrinkage, the greater the increase in pressure of the washed garment compared to the new one.

Shrinkage in the length direction can also not be neglected in terms of comfort. In the first place, excessive length shrinkage will cause the garment hem to rise towards the waist line which (if not intended as a deliberate fashion feature) can be inconvenient, possibly uncomfortable. In the second place, stretching a garment in its width direction will usually cause some contraction in the length. Thus a further consequence of excessive width shrinkage in a close fitting garment can be additional shrinkage in the length, over and above that which may have been measured by quality control laboratories at the fabric or garment production stage.

Spirality in plain jersey fabrics, caused by twist liveliness in the yarn, can also be a problem if it causes the garment to twist to such an extent that the side seams are displaced by a significant amount.

A final, though less obvious constraint is the weight per unit area of the fabric demanded by the customer (e.g. the retailer) at the time the fabric or garments are first commissioned. Surprisingly enough in our modern technological age, it is not always appreciated by customers that, for a given knitting quality (i.e. for a given yarn knitted to a given tightness on a given machine and processed through a given finishing sequence), there is a strict relationship between the weight and width which is specified by the customer and the shrinkages which will be developed in the fabric after washing. Often a customer will demand improvements in the level of shrinkage without allowing any change in the weight per unit area or the width. Since this is an impossible demand when the quality is maintained unchanged, it follows that the manufacturer has to undertake a new fabric development programme to discover what changes have to be made at the knitting stage in order to accommodate the demand for improved shrinkages in the garment.

This is already difficult enough but, in fact, changes in the knitting conditions will also change the extensibility and the spirality of the fabric. Therefore if the further constraint of maintaining the proper comfort and fit of the garment through its lifetime is added to the problem of improving the shrinkages, then a further level of complication is imposed.

The engineering of knitted fabric constructions to yield a predictable array of performance characteristics is a very imperfect science in the knitting industry today. In most cases, development of new or improved qualities proceeds largely on an empirical trial and error basis. In the majority of companies there will be a separate fabric development department which, depending on the size of the company, may comprise several senior staff members who have access to their own pilot scale processing equipment or who consume a significant proportion of the operating time of the standard production machinery.

It is a well known fact that the demands of customers are often based largely upon wishful thinking rather than solid experience, or careful engineering design of the product that they have in mind. Often a product will be commissioned on the basis of a trial sample because it looks and feels good with much less regard for the technical performance, on the assumption that this can be put right later. This kind of situation is almost inevitable under present conditions and has to be accepted as a fact of life - part of the process of product evolution and improvement in response to market opportunities.

However, it was this situation which led us at IIC to the conclusion some time ago that what the industry needs is a predictive system for fabric development. If we could predict in advance of manufacture what would be the dimensions, the extensibility and the shrinkage of any fabric quality then a great deal of time and effort could be saved. Not only would costs be saved in developing new or improved products but also it would be possible to arrive at a firm idea of whether a particular set of customer demands could actually be met in practice and, more importantly, where compromises would have to be made.

3. DEVELOPMENT OF A PREDICTIVE SYSTEM

Bringing all of these (and other) considerations together, it turns out that the following information is needed in order to construct a product development system for knitted cotton fabrics and garments which will allow a rational choice of manufacturing conditions in order to guarantee good performance in terms of reasonable levels of shrinkage together with proper comfort and fit of knitted cotton garments throughout their lifetime.

i) A standard relaxation procedure which will deliver the fabric into its fully relaxed state i.e. the state in which essentially no further shrinkage is possible. This fully relaxed state is one which a manufacturer or retailer very seldom sees, because he does not have time to indulge in multiple laundering trials, but the consumer always experiences sooner or later. This will be our reference state in which all of our empirical measurements will be made and upon which our predictive equations will be based.

ii) A comprehensive data base comprising large numbers of measurements made on a wide range of qualities of fabrics, all in their reference state of relaxation. The measurements will include the major manufacturing parameters such as yarn count and knitted stitch length (which will be our inputs) and the fabric dimensional properties of interest such as stitch density, weight per unit area, spirality and extensibility (which will be our outputs).

iii) A set of equations, developed from the data base, which link the manufacturing parameters to the desired output properties. A major feature of these equations is that they must contain only those variables which a manufacturer is likely to know, or can obtain quickly and easily in advance of manufacture. Parameters which are too difficult or too tedious to measure using current technology are of little value since they will not actually be known.

iv) A computer programme which is capable of manipulating the equations in such a way as to allow a technologist to simulate the production and processing of the fabrics modelled in the data base and to deliver the expected performance attributes of the simulated fabrics.

For the past twelve years or so, IIC has been collecting such a data base and constructing such a computer programme. We have proceeded so far to the stage where fabric dimensions and shrinkages can be modelled pretty accurately for a wide range of plain jersey, interlock, and lx1 rib fabrics. Data in the pipeline will soon allow the simulation of certain single jersey crosstuck fabrics. However, progress in data collection and modelling of the spirality and extensibility of these fabrics has been slower so that, although a good deal of data are available, the final analysis has not been completed and the computer software has not yet been constructed which would allow predictions for garment sizing to be made. It is hoped to complete this part of the model over the next few years.

4. EXAMPLES

A few examples can be given of the kind of data which have resulted from this research and the kind of relationships which have emerged.

Figure 5 shows the effect of the knitted yarn count and stitch length upon the number of courses and wales per unit length of a dyed and finished plain jersey fabric in its reference state. These effects are modelled by equations of the form

$$Y = a/S + f(Tex) \qquad [1]$$

Where	Y	is the course or wale density,
	S	is the reference stitch length,
	a	is a coefficient which depends mainly on the fabric type,
	$f(Tex)$	is a function which depends on the basic yarn properties and the way that these are modified by the wet processing route.

The evaluation of these functions requires very large volumes of data. In small data sets it can appear that there is no system to the coefficients. It is only when large data sets are available that patterns begin to emerge of the way that the coefficients vary systematically across yarn types, fabric types, and wet process routes.

Once the density of courses and wales in the reference state of relaxation are available from equation [1], then the other major dimensional properties can all be simply found, since :-

> Width is given by the number of wales per cm and the number of needles in the knitting machine,
>
> Weight per unit area is given by the product of yarn count, stitch length, courses per unit length, and wales per unit width,
>
> Shrinkages are given by the differences in courses and wales in the as delivered fabric and the reference state.

Figures 6 and 7 show that the type of yarn has an influence on final fabric dimensions. The use of twofold yarns, or OE rotor yarns in place of ring yarns makes a significant difference to the end result.

Figure 8 shows that the level of twist in a yarn also affects the dimensional properties. This is due to twist liveliness in the yarn causing bending and twisting of the loops out of the plane of the fabric. These effects are not directly modelled in the current computer programme; partly because we need more data and partly because all of our existing data have not yet been analysed. In fact this is not a serious limitation because only a rather narrow range of twist factors is actually used in the trade for a given yarn count. Thus the action of twist can be absorbed into the yarn tex function for the time being.

Figure 9 shows the effect of different wet processing treatments. We have data for a rather large number of wet processing types and it turns out (so far) that the relative effects of a given finishing procedure are rather consistent across fabric types.

Figures 10 and 11 show the effect of yarn count and stitch length on the extensibility of 14g 1x1 rib fabrics at applied loads of 0.15 and 0.30 N/cm respectively i.e. at loads which straddle the average comfort threshold. The measurements were made at TEFO using a test rig which simulates the stretching of a garment over a body. For a given load, these data can be adequately modelled by expressions of the type

$$E = a + b \, . \, S^2/Tex \qquad [2]$$

Where	E	is the percent extension at the given load,
	S	is the stitch length,
	a and b	are coefficients whose generalised application (across yarn types, fabric types, and wet processes) has yet to be elucidated.

Since the square root of tex divided by the stitch length is known as the Tightness Factor, K, equation [2] reduces to

$$Ext\% = a + b/K^2 \qquad [3]$$

Figure 12 shows a plot of the extensibility at a load of 0.3 N/cm as a function of the Tightness Factor which confirms the strong influence of this parameter and also shows that the fully shrunk fabric does not extend as far as the unwashed material at a given load. Similar curve forms are found for other levels of loading, for other fabric types, and for fabrics which have had other wet finishing treatments.

If such data are transposed so that extensibility is expressed in terms of relative width, Wr, (i.e. the extended width divided by the fully relaxed reference width), and all of the data for different fabric constructions and loading levels are included in the analysis, then expressions of the following form are found to model the data pretty well (Fig 13).

$$Wr = 1 + L^a \, . \, \exp(-bK) \qquad [4]$$

Where	K	is the tightness factor
	L	is the load in N/cm
	a and b	are coefficients whose values depend mainly on the fabric type and the degree of relaxation.

Figure 14 shows the relationship between width extension and length contraction under a load of 0.3 N/cm for a range of lx1 rib fabrics. Results are given for the unwashed fabrics and for the fully relaxed, reference state materials. In the latter case, two curves are shown. In the upper curve, the width extensions and length contractions are expressed on the basis of the original, unwashed dimensions. Thus in this case the contractions in length include both those due to shrinkage and those due to the extension in the width. The average shrinkages in the fabrics were about 10% in both length and width directions (although there was considerable variation over the range). In the lower curve, the extensions and contractions are based on the relaxed dimensions. Thus in this case the contraction in length is caused only by extension in width.

In each of these data sets, it is quite remarkable how closely the data follow a single trend line, which appears to be a simple exponential function, even though a wide range of constructions and (in the case of the unwashed series) shrinkage levels are present.

Figure 15 shows the relationship between the length and width of a series of single jersey T-shirts when they were stretched over a rectangular frame according to a test procedure developed by Marks and Spencer (based on the TEFO static garment test equipment). In this graph, both length and width are expressed as a percentage of the Reference, fully relaxed dimensions. The data for the washed garments are averages from several sets of specimens which had been subjected to different methods of laundering. With T-shirts, it is not uncommon for the washed garment to be called upon to stretch by 15 to 20% in order to fit over a relatively large body in a given size range. For the garments in this data set, the consequence would be an additional length shrinkage of two to four percent.

Figure 16 shows the angle of spirality, A, measured in the reference fully relaxed state on a series of dyed and finished plain jersey fabrics made from Ne16 to Ne 40 yarns, all with similar twist factors (3.6 to 3.8), plotted as a function of the tightness factor.

These data can be modelled approximately by a simple exponential function of the form

$$A = a \cdot \exp(-bK) - c \qquad [5]$$

where a and b depend mainly on the twist liveliness of the yarn and the way that this is modified by the wet processing treatment.

Twist liveliness in ring yarns is directly related to the number of turns per metre in singles yarn or the difference between singles and folding twist in two fold yarns. Twist liveliness in singles yarn is invariably reduced by wet processing but, in twofold yarns it can be significantly increased.

Although equation [5] is an adequate model for practical purposes, the data can actually be represented more satisfactorily by using more complex equations which take explicit account of the twist level, and which acknowledge the probable boundary conditions of spirality.

Figure 17 shows spirality plotted against the stitch length for three of the seven yarns. The model which is being investigated for such data has the following form

$$A = a \cdot (1 - \exp[-bL^{c} \cdot (1 - L)^{-d}]) \qquad [6]$$

where

A	is the spiral angle,
a	is a simple function of the yarn twist whose coefficients depend on the yarn type and the wet process route
b	is a coefficient which appears to be a simple function of the yarn tex
c and d	are probably constants.

The relationship between spirality and the amount of twisting or seam displacement (SD) which can develop in a garment after laundering is a simple geometrical one which can be derived from the spiral angle (B) in the new garment, the spiral angle (A) in the laundered garment, and the length (Lf) of that part of the garment which is free to twist.

It is given approximately by

$$SD = Lf\,(\tan A - \tan B) \qquad [7]$$

For most garments, the free length is significantly less than the total garment length. For T-shirts it seems to correspond roughly to the distance from the hem to the underside of the arm.

For practical purposes, equation [7] can be simplified further since, for the small angles which are normally encountered in fabric spirality, (tan A - tan B) is given approximately by

$$(\tan A / A) \cdot (A - B)$$

and (tanA / A) is approximately equal to 0.0176

Thus the following equation can be used with negligible loss of accuracy to predict the seam displacement in laundered garments.

$$SD = 0.0176\, Lf \,.\, (A - B) \qquad [8]$$

Figure 18 shows the results of some measurements of seam displacement made on a series of plain jersey T-shirts compared to those predicted by equation [8].

5. CONCLUSIONS

From the data which have been gathered so far, it seems quite clear that the required dimensional and stress-strain relationships can be modelled with an acceptable level of precision using only those production parameters which are readily available to the manufacturer. Therefore a practical predictive design engineering system can be constructed for knitted cotton fabrics and garments.

A user-friendly computer programme has already been developed which allows the prediction of dimensional properties and shrinkages. It is called STARFISH, which is short for "Start as you mean to finish", and is currently (1990) in use by more than thirty companies and institutes all around the world.

In addition, a good start has been made with the collection and analysis of corresponding data on extensibility and spirality so that the computer programme-should be capable of being extended into predictions of optimum garment size, and hence to garment comfort and fit, in the medium term future.

ACKNOWLEDGEMENT

The extensibility data reported here were collected in the course of a collaborative research programme between IIC and TEFO some years ago. Particular thanks are due to Bernt Johansen and Zdenek Dusek for their supervision of the extensibility measurements which were made on specially designed apparatus at TEFO.

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Figure 1

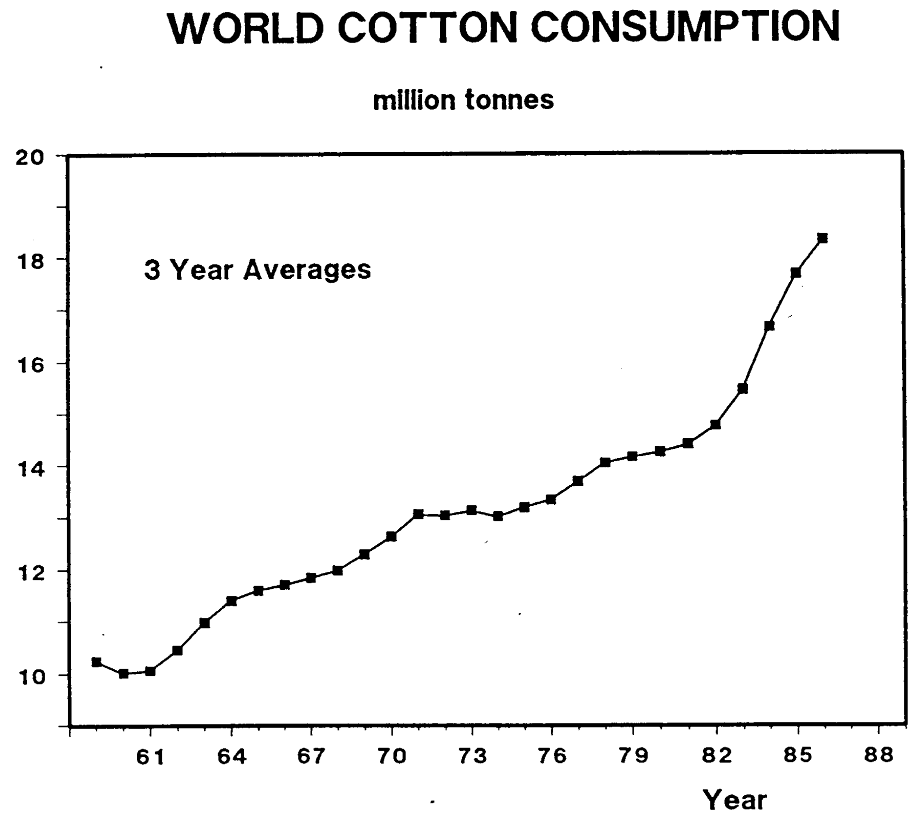


Figure 2

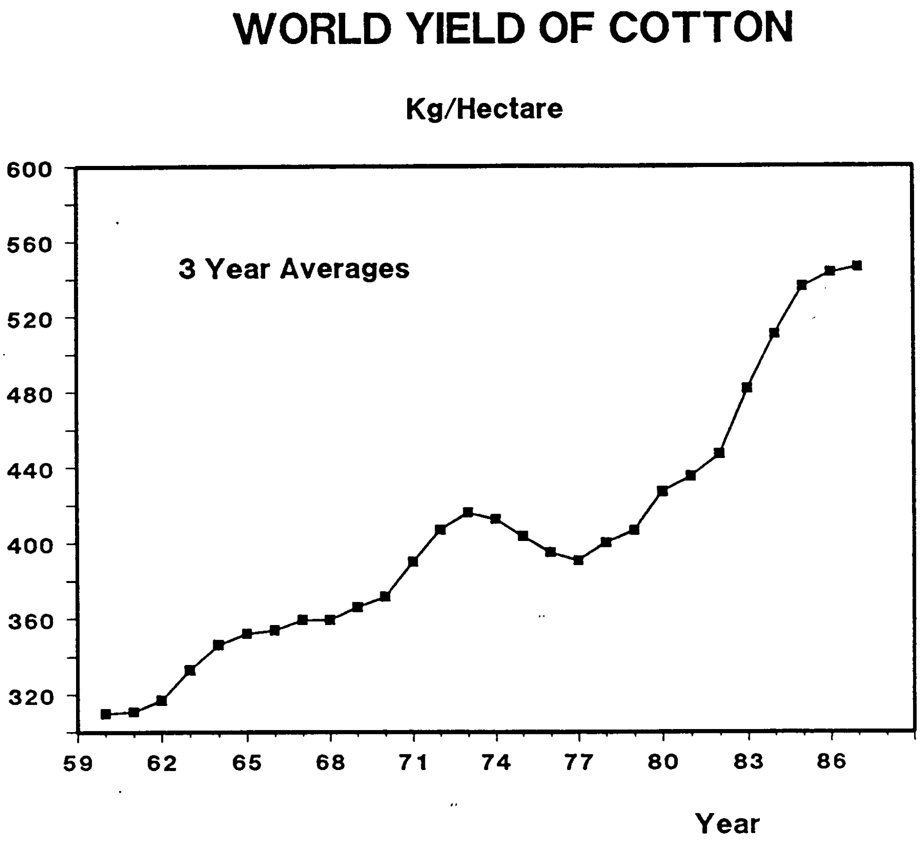
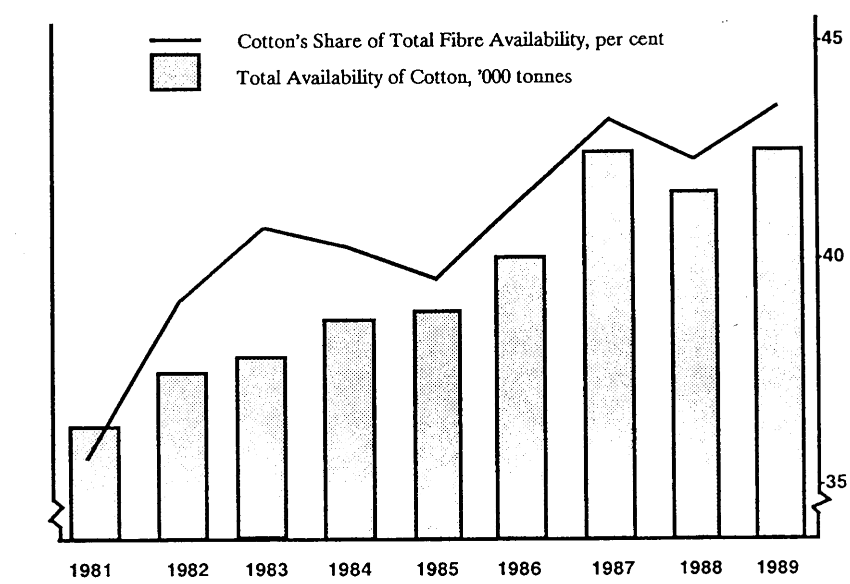


Figure 3

Availability of Cotton in the IIC Programme Area

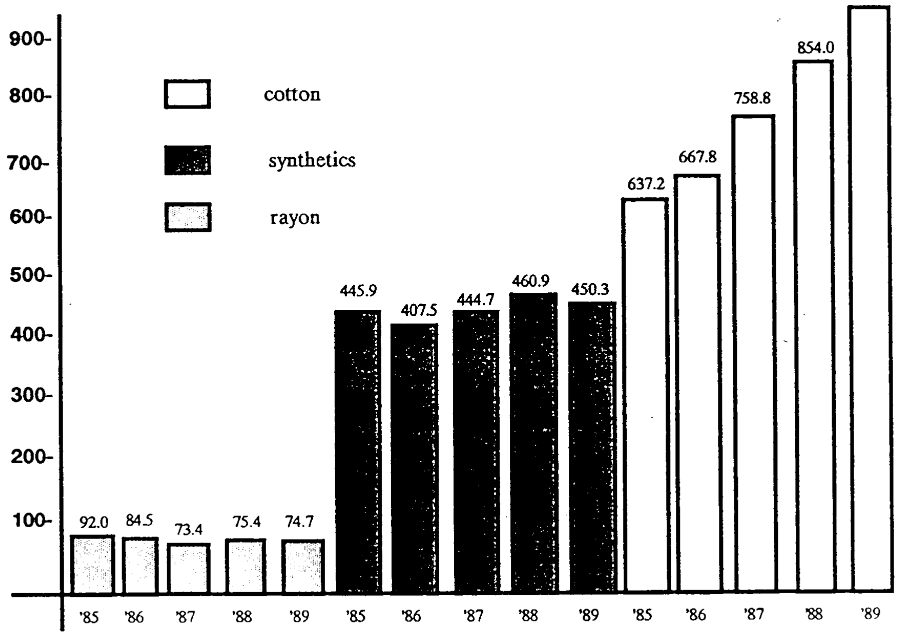


Sources:

World Apparel Fibre Consumption Survey (various years),
Food and Agriculture Organisation of the United Nations;
IIC Estimates .

Figure 4

Supply of Textiles for Domestic Consumption in Japan
('000 tonnes spun yarn equivalents)



Source: Ministry of International Trade and Industry, Japan

Figure 5

PLAIN JERSEY DYED & FINISHED

Reference Course and Wale Densities

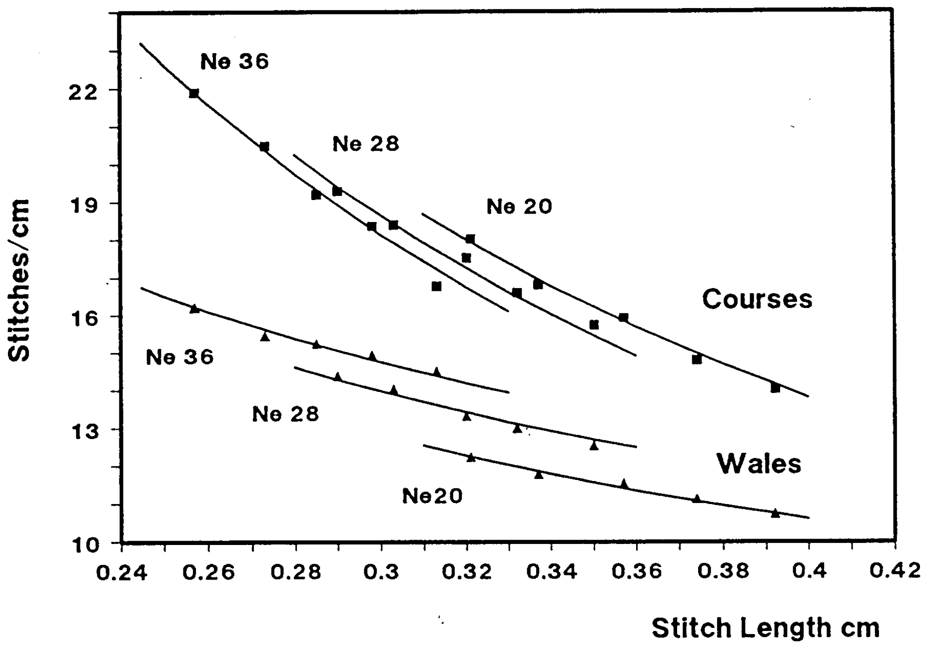


Figure 6

EFFECT OF YARN TYPE: SINGLES vs FOLDED

Single Jersey Grey Reference

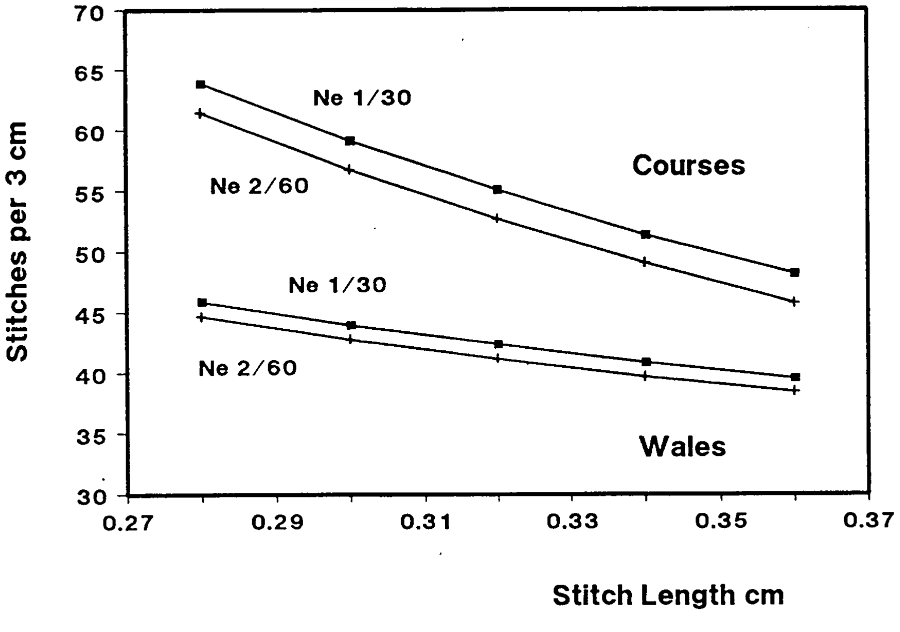


Figure 7

EFFECT OF YARN TYPE : RING vs ROTOR

Single Jersey Ne 1/30 Grey Reference

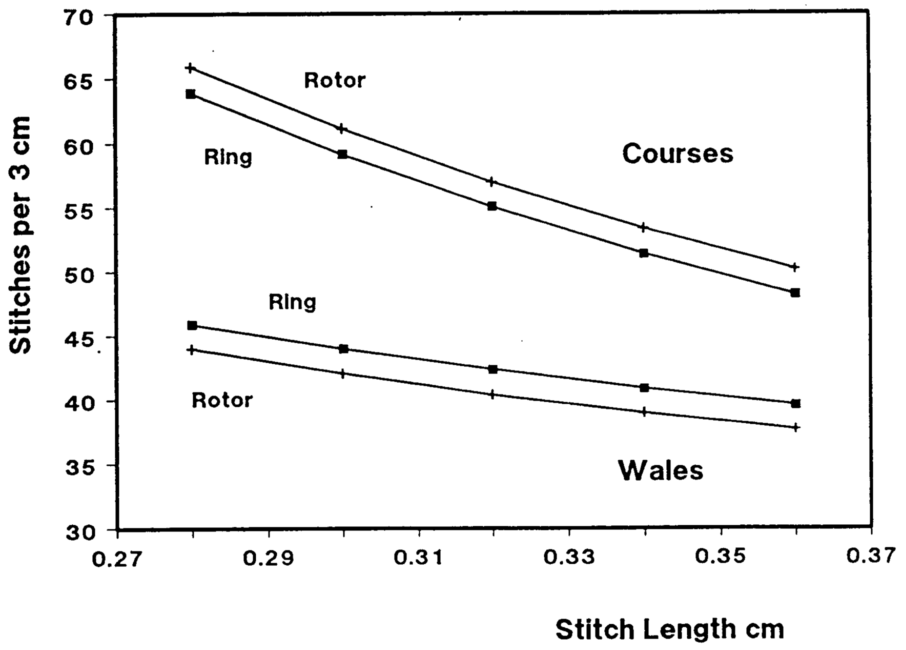


Figure 8

EFFECT OF YARN TWIST ON COURSES

Interlock Ne 1/30 Winch Bleach Reference

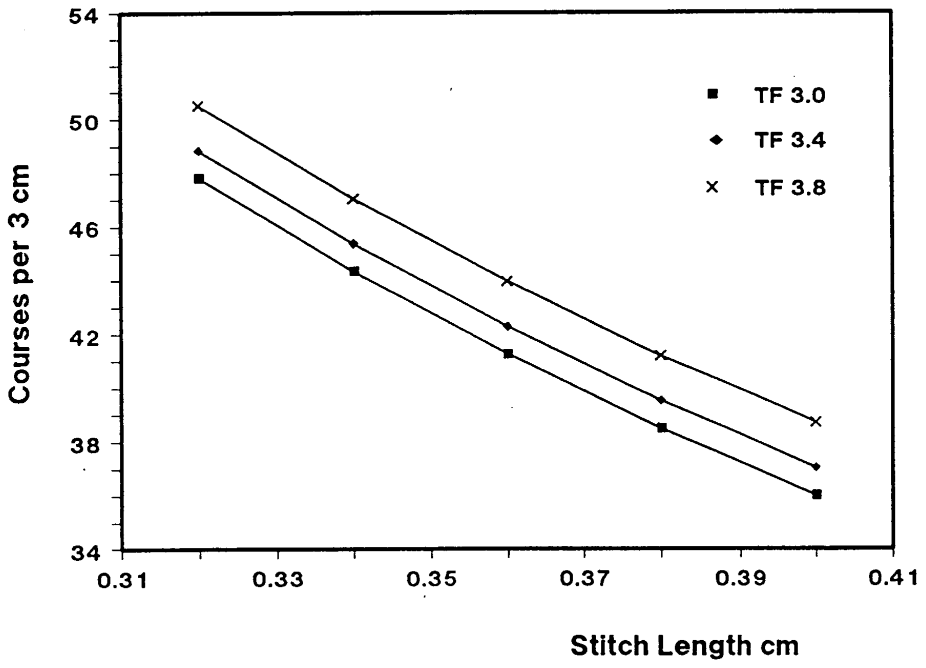


Figure 9

EFFECT OF PROCESS ROUTE

Single Jersey Ne 1/30 Reference State

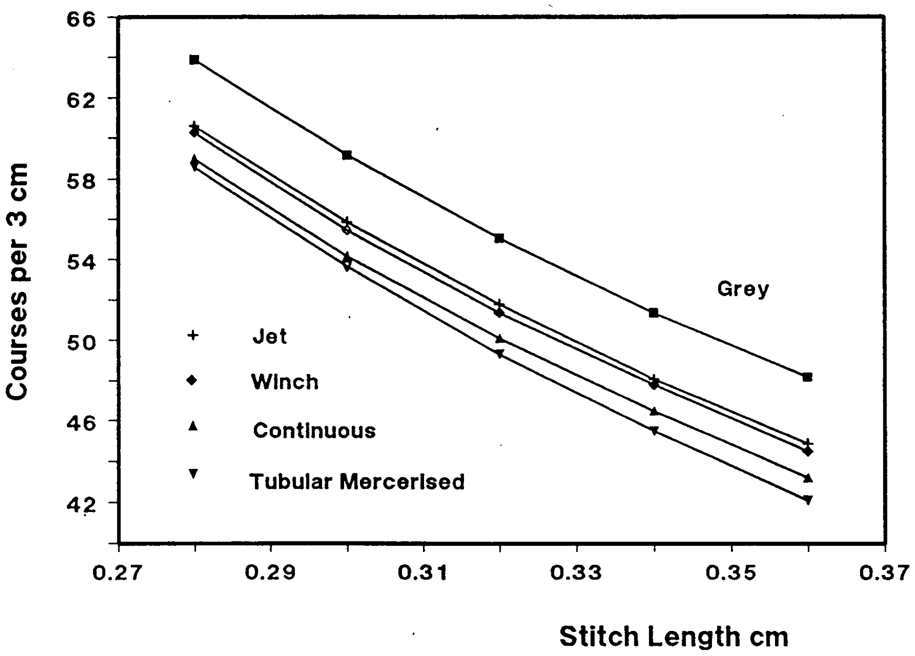


Figure 10

WIDTH EXTENSION : 1x1 RIB WINCH DYED

Load = 0.15 N/cm

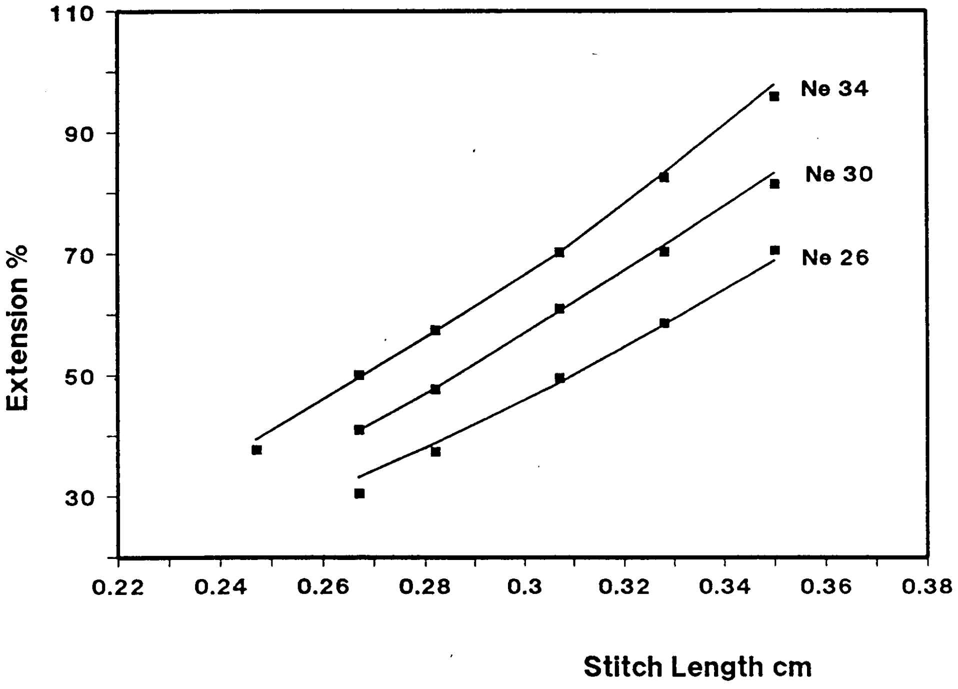


Figure 11

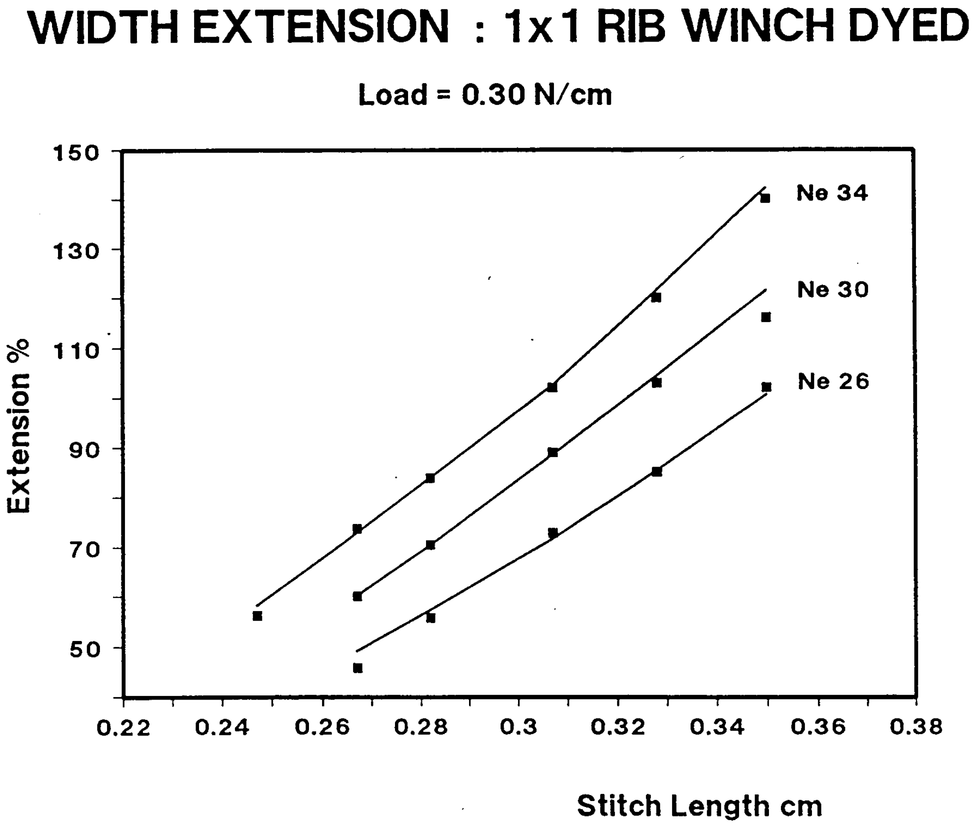


Figure 12

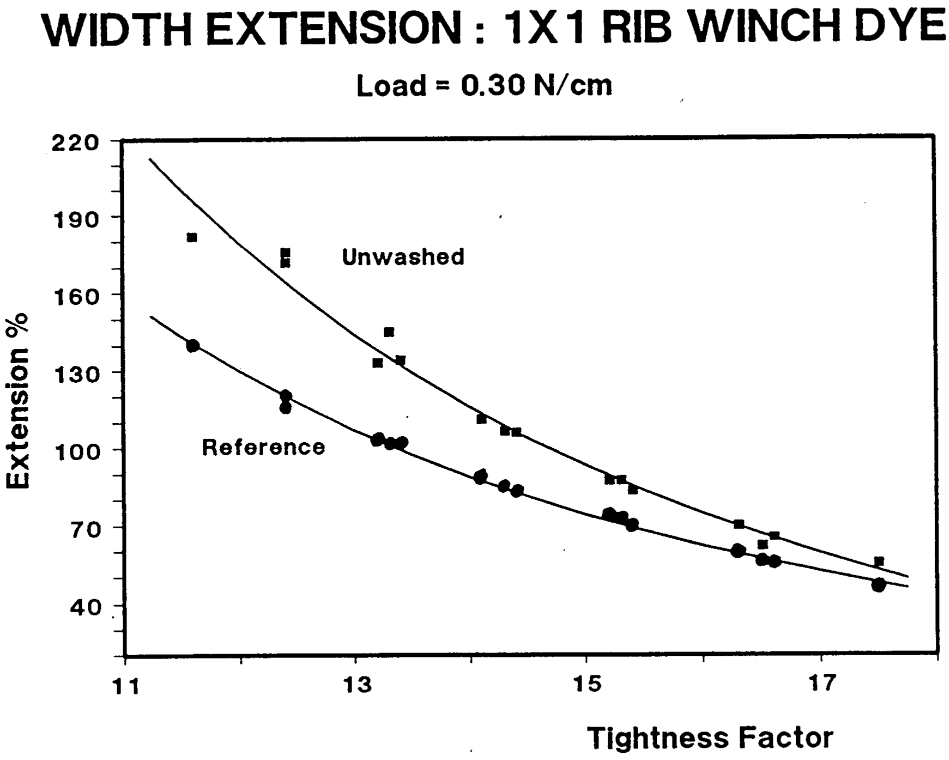


Figure 13

RELATIVE WIDTH : RIB WINCH DYED

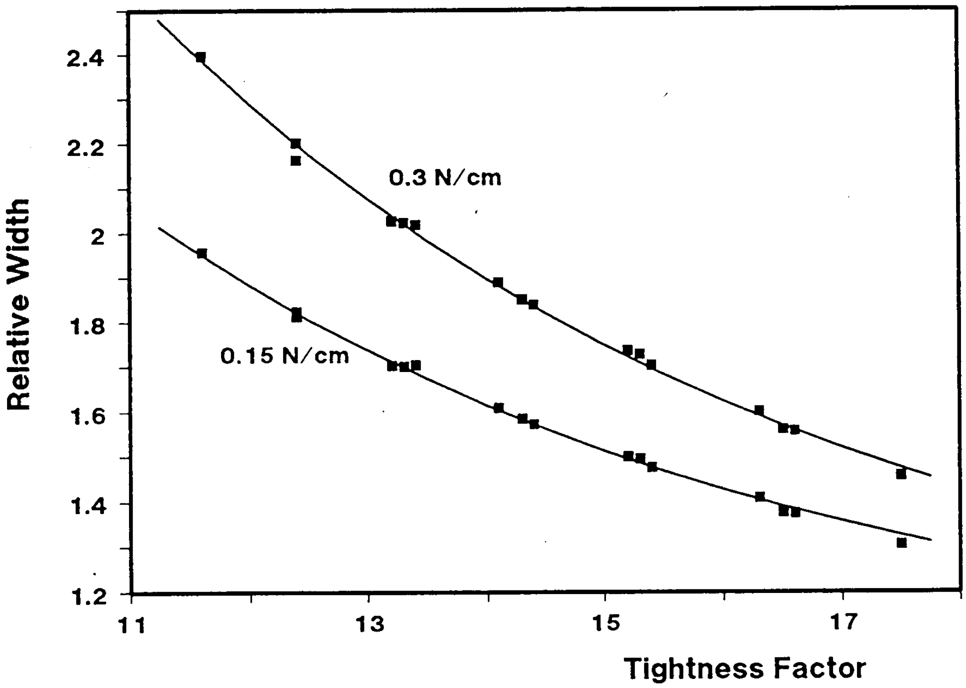


Figure 14

LENGTH CONTRACTION : RIB WINCH DYED

Load = 0.30 N/cm

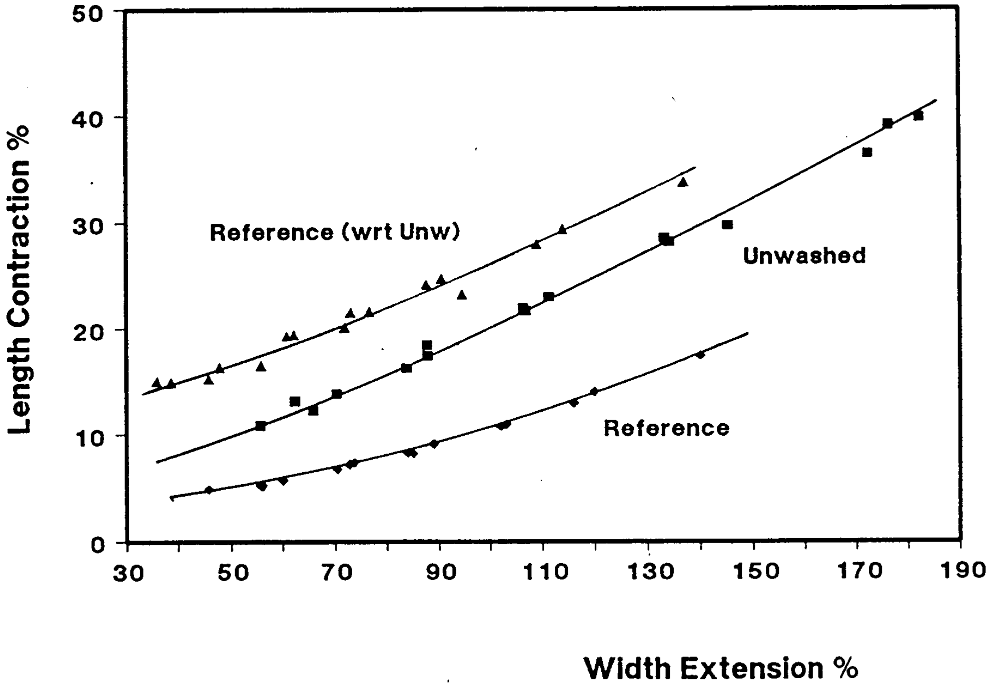


Figure 15

GARMENT LENGTH ON THE M&S FRAME

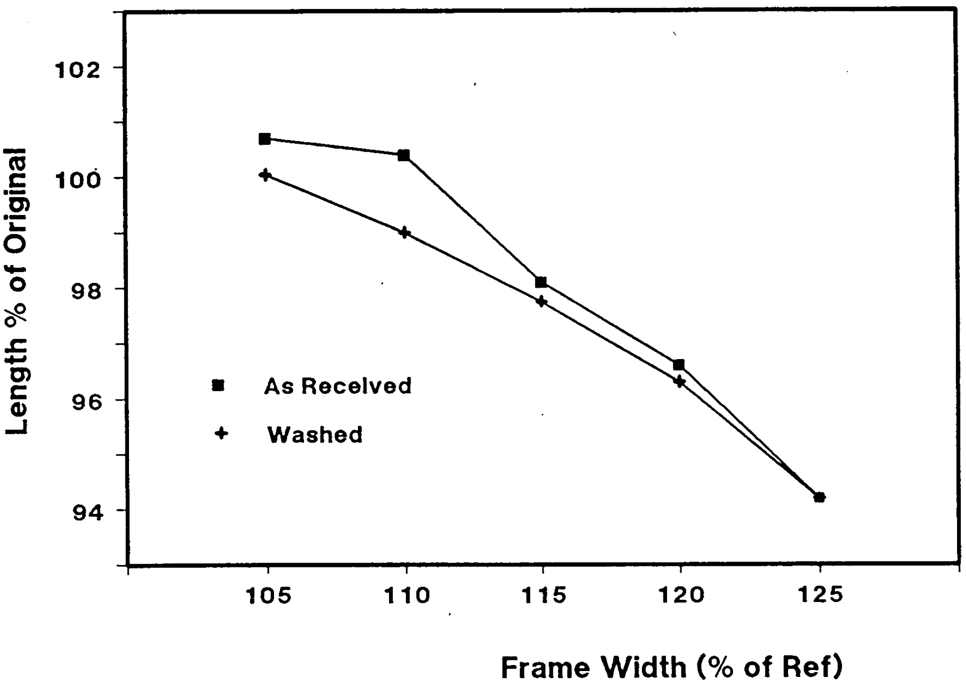


Figure 16

SPIRALITY vs TIGHTNESS FACTOR

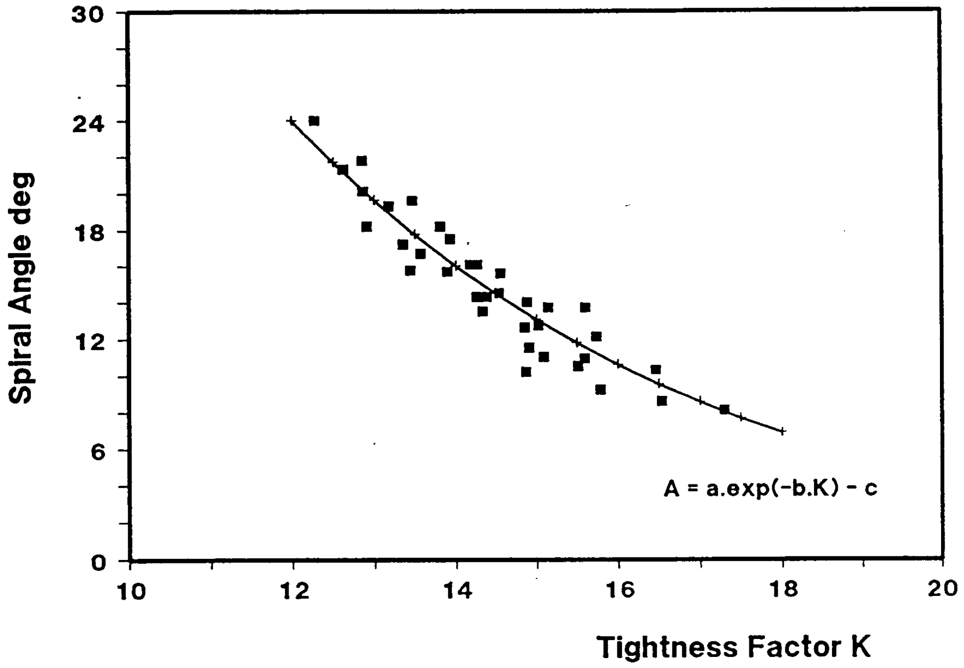


Figure 17

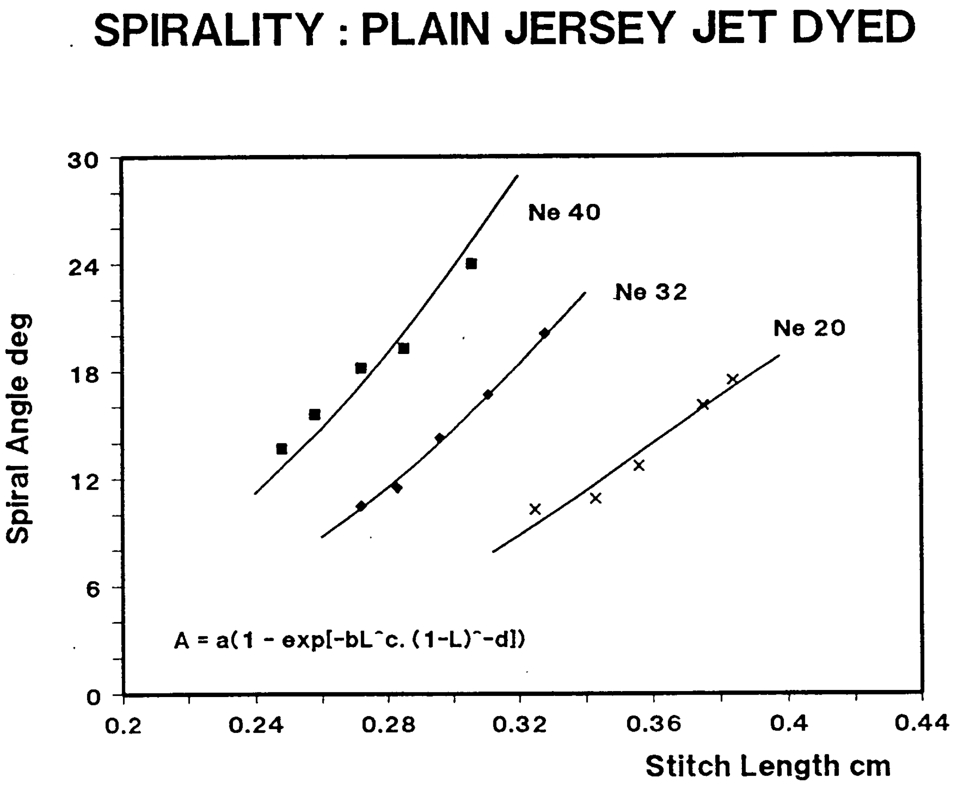


Figure 18