FRICTIONAL CONSTRAINTS AT YARN INTERLACINGS IN WOVEN FABRICS AND THE EFFECT ON TEAR STRENGTH

A thesis submitted for the degree of

Master of Science

by

JAMES CHATTA

being an account of work carried, out at the Department of Textile Industries under the supervision of Dr. G.A.V. Leaf, M.Sc, D.Sc, F.S.S., F.T.I.

Department of Textile Industries,
The University of Leeds,
Leeds,
LS2 9JT

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Dedicated to

my wife, Elizabeth Nene Chatta, in deepest gratitude

for her sacrifices, prayers, moral support and encouragement.

CHAPTER 1

GENERAL INTRODUCTION

The mechanical failure of materials is complicated and depends very strongly on the conditions of use or testing under which it occurs. This is particularly true of tearing failure. A characteristic feature of the tearing process is that it is a response to a non-uniform tensile stress. If the stress pattern can be defined, it is then possible in principle to relate to behaviour of the material to its performance under a uniform stress.

In determining how a fabric fails in tear it is necessary first to define this mechanism. Tearing may be described as the progressive tensile failure of yarns or groups of yarns along a line through a fabric. The tearing force required to propagate a tear is directly involved in the assessment of serviceability of the textile material. In contrast to the tensile strength, which involves the force capable of breaking many threads simultaneously and which is relatively insensitive to yarn and fabric structural parameters, the tearing strength is considerably affected by changes in yarn and fabric geometry, their frictional characteristics and slight variations of finish that are modified when the cloth is put to use.

There have been several methods used by fabric researchers for tear strength measurement. Those commonly used are trapezoidal tests, the single rip test and the tongue tear test. In tongue tear and single rip tests, tension is applied directly to the cloth in a direction at right angles to the threads to be torn, whilst in the trapezoidal test the tension being applied is along the direction of the threads to be ruptured. N.A. Teixeira, M.M. Platt and W.J.

Hamburger[1] observed that these tear test methods possess certain similar features and, most importantly, since the cloth fails by the breaking of the threads one at a time or in small groups, the occurrence of slippage of one set of threads over the other. they further discovered that the tear result is very much dependent on the single yarn strength and the ease with which yarns can slip over one another.

Apart from yarn strength, the yarn breaking elongation, yarn twist, fabric density, weave pattern and the type of finishing treatment also contribute to the fabric behaviour during tear strength tests. It was also found that yarn breaking elongation has an influence on the size of the del, the name given to the triangular space formed between adjacent threads at the point of tear, and the total number of yarns involved in the break. Consequently, a high elongation at break normally produces a high tearing strength. The tightness of the fabric structure has a large effect on the tearing strength. For instance, in a high density fabric structure there is less free space for yarn movement which results in high interyarn frictional forces that lower the deformation potential.

CHAPTER 2

REVIEW OF PREVIOUS WORK

The first study to determine the mechanism of failure in the tongue tear test was undertaken by Krook and Fox[2] in 1945. Their paper included photographs of the del-shaped opening under tearing stresses and these are shown in Figures 1 and 2. An understanding of what takes place in the specimen during rupture was given by them. They found that the yarns held longitudinally between the jaws stretched and lost crimp and then started slipping across the traverse yarns, forming a del shaped (∇) opening structure in which there were no longitudinal yarns. A closer observation showed that as the load was increased the longitudinal yarns continued to slip and crowd together and the size of the del increased, forming a large number of frictional points of contact in a small area. As the number of these contact points build up it becomes more difficult for slippage to occur, and therefore the force is progressively transferred to the transverse yarns which are already under tension and the yarns eventually fail.

Ten years later, Teixeira, Platt and Hamburger[1] found some analytical relationships between certain fabric factors such as weave, texture, yarn twist, yarn structure and tear strength. They first defined the del, as used by Krook and Fox, as the triangular shaped distortion at the active region of tearing shown diagrammatically in Figures 3 and 4.

Here, L = Total jaw separation

ℓ_T = Length of tail

ℓ_∇ = Length of the del

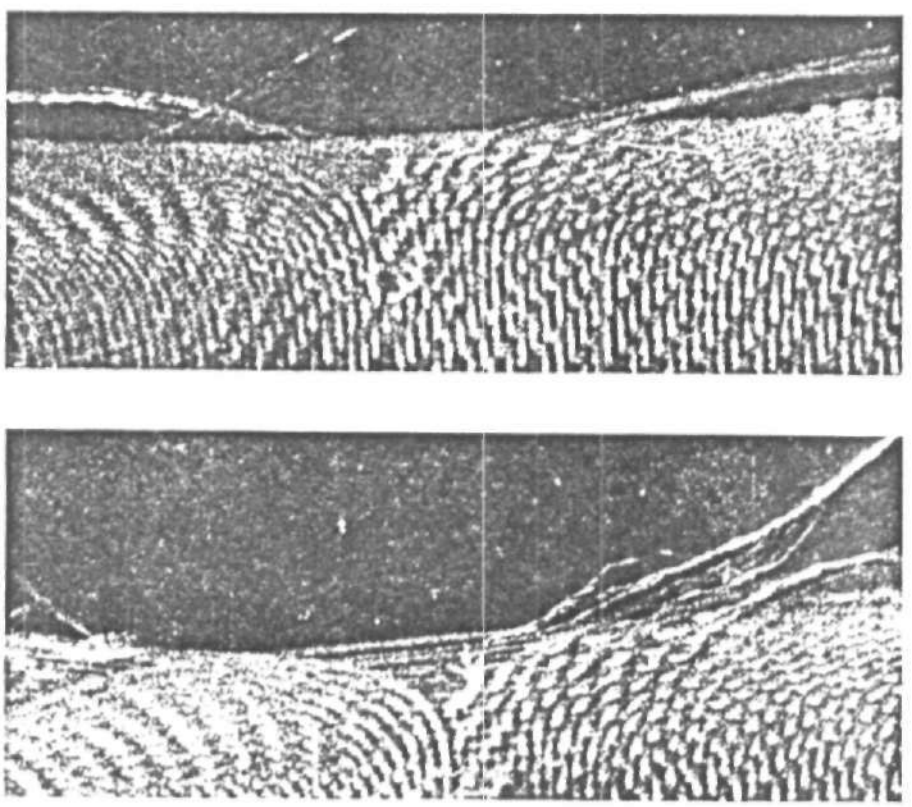


FIG. 1

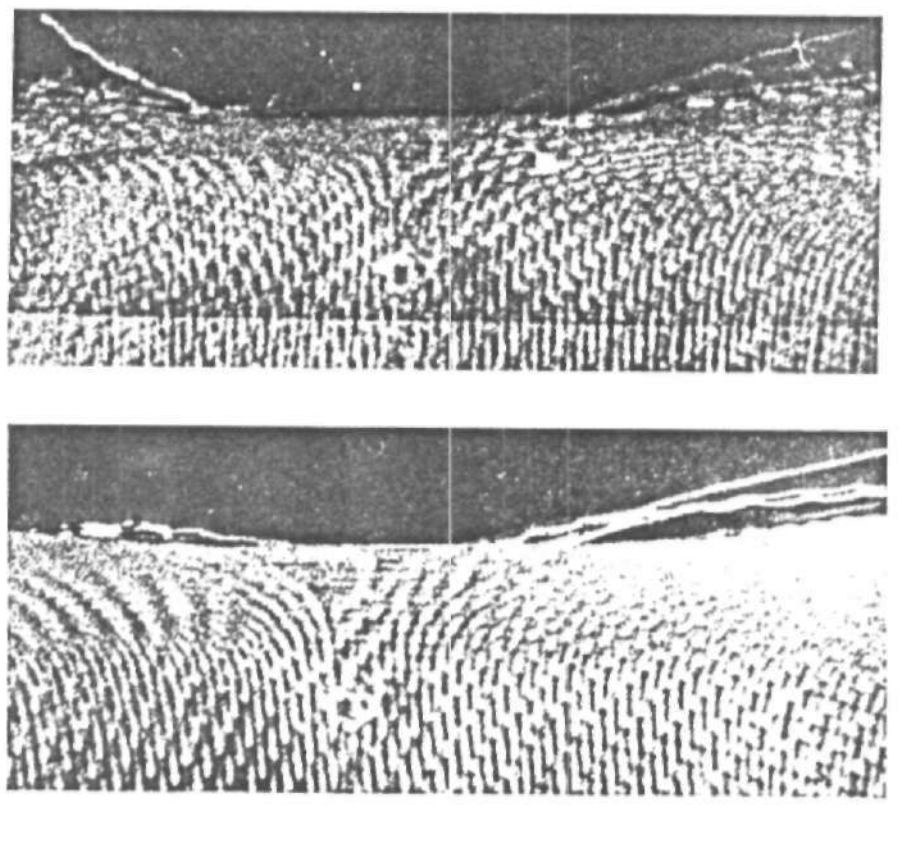


FIG. 2

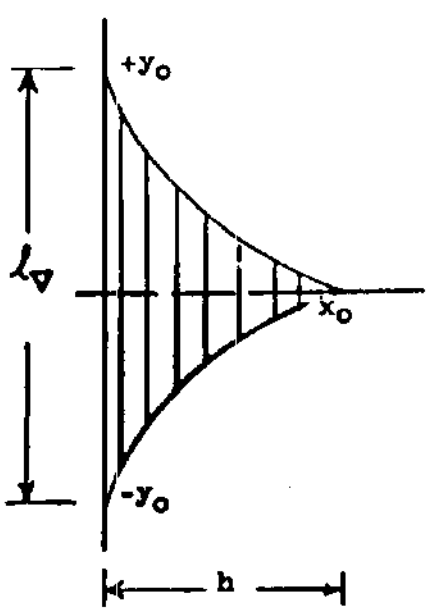


Fig.

FIG. 3

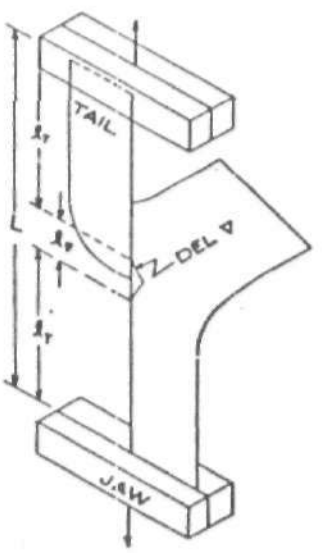


FIG. 4

In order to determine the manner in which the yarns being ruptured are brought under load an investigation was carried out on the del-shaped region where the tearing action occurs. They discovered that the yarns within the del are not evenly spaced and are actually perpendicular to the direction of tear. Their length and spacing are said to be dependent upon the del geometry and Teixeira et al noted that the closer these yarns are to each other the better the elongation balance among them and the greater their combined load-carrying capacity. Figure 5 shows a schematic diagram prepared by Hamburger to illustrate the distortion of the fabric structure in the region of tear. Closer observation of real fabrics being torn shows that the transverse threads under tension slip out of the cloth to some extent. Though the yarns are expected to break singly, nonetheless many in the del region are already under strain. This results in the expected tearing strength being slightly greater than the single-thread strength.

Figure 6, which represents a cross-section of cloth, is used to illustrate the relation of the force applied to a thread in a cloth to cause slippage and the tension along the thread.

In the analysis made by Taylor[3] and repeated by Skelton[4] it is assumed that a force T is applied to a thread A as shown in the diagram with the front crossing thread E_1 being prevented from moving. It was shown that if at a certain point of the test the value of T is great enough, the tensioned thread will slip over E_1 and draw the fabric towards the direction of application of the force T so that E_2 now approaches E_1. As the number of threads slipped over increases so does the tension in the yarn until the applied force is equal to the breaking strength of the yarn and the yarn eventually breaks. Taylor

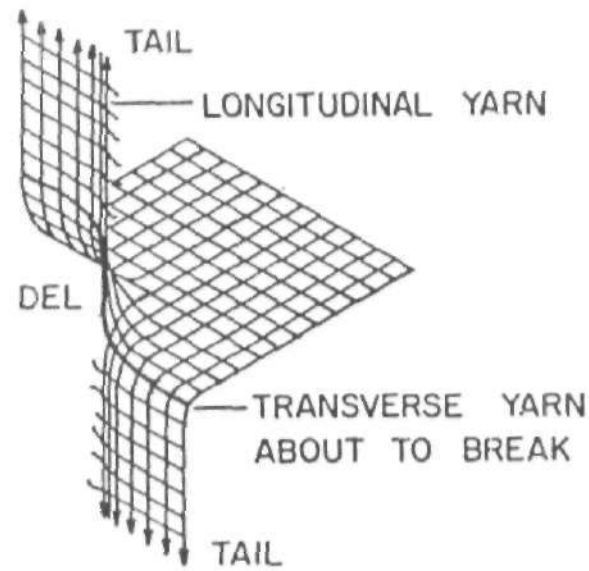


Fig. 5 Tear test configuration.

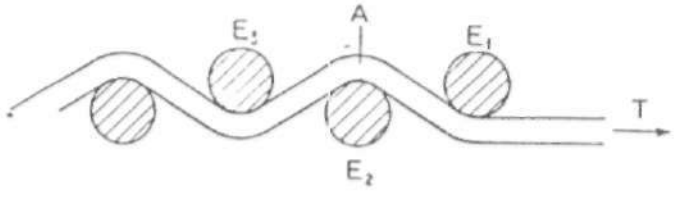


FIG. 6

assumed that the slipping threads are perfectly flexible and that the crossing threads are fixed cylinders. With this assumption the tension in the slipping thread was found to be multiplied by a constant factor β at each crossing thread. However, the yarns also exercise a mutual pressure P at each intersection which gives an additional force αP arising because of friction. With these various forces occurring at each intersection it was deduced that the tension in the space between crossing threads where slipping is about to occur will be αP and in the next space the value will be $\alpha\beta P + \alpha P$. At each intersection the previous tension is multiplied by β and a further force αP added to the tension. Therefore if slipping occurs at the Nth crossing threat the tension at the thread end would be

$$\alpha P\ (1 + \beta + \beta^2 + \text{----} + \beta^N) \text{ equals } \frac{\alpha P\ (\beta^{N+1} - 1)}{\beta - 1}$$

which may be equated to the value of the breaking strength (f) of the thread, that is,

$$f = \frac{\alpha P\ (\beta^{N+1} - 1)}{\beta - 1} \qquad (1)$$

In the subsequent analysis the tension (f) was assumed to pull out a length of thread NS where S is the average distance by which the space between the threads may be reduced, measured along the slipping thread. Taylor showed that the thread subjected to the highest strain within the del structure slipped out of the fabric a distance Ns from each side and gave the maximum number of parallel threads in the del to be Nst + 1 where t is the reduction in the thread length in the del. The total force exerted on each of the tails fluctuates as the threads break one by one, and the maximum force was given as (Nst +

2)f, and this is the force required to tear the fabric in a tongue tear test.

The values of α and β were estimated by measuring the force (fs) necessary to withdraw a known length of thread from the woven fabric. The relation between (fs) and the number of crossing threads in the known length is, following the above theory

$$fs = \frac{\alpha P\ (\beta^{N+1} - 1)}{\beta - 1} \qquad (2)$$

Dividing equations (1) and (2) gives

$$\frac{\beta^{N+1} - 1}{\beta^{n+1} - 1} = \frac{f}{fs}$$

from which β may be found when N, n, f and fs are known. The equation is not easy to solve and Taylor assumed that both β^{N+1} and β^{n+1} are much larger than unity. In this case the value of N equals

$$\frac{\log f/fs}{\log \beta} + n .$$

Consequently the tearing strength was found to be

$$\left[\left(\frac{\log f/fs}{\log \beta} + n \right)_{st} + 2 \right]_{f}$$

which shows how T depends on β, f, etc.

The above analysis shows that, amongst other things, the tearing strength depends on the values of β and αP, which must therefore be estimated. Taylor's suggested method involves assuming β^{n+1} greater

than 1. This is not necessarily so, and this thesis investigates other methods of estimation.

CHAPTER 3

FACTORS AFFECTING THE TEAR STRENGTH

Before starting the work it is worth examining the factors affecting the tear measurement as observed in previous work. In the analysis of the geometry of the del structure Platt and Hamburger emphasised the important role of the yarn distribution within the del on the tear test results. In a tongue tear test, when the specimen is subjected to a certain load the longer yarns are observed to be closer together than are shorter del yarns. Figure 7 shows the distribution of the crossing yarns within the del structure and the yarn spacing was observed to increase linearly towards the narrow end of the del. According to Hamburger, the longer yarns will only approach each other closely when the ratio of the length of the del ℓ_V, to its depth h, is large and this influences their combined load-carrying capacity.

In looking at the influence of fabric geometry on the load characteristics of the del, Teixeira, Platt and Hamburger noted that at the beginning of a tongue tear test several forms of distortion are exhibited.

The cross-yarns pull out of the fabric and become del yarns. The more easily the cross yarns pull out of the fabric the longer is the del.

A loose fabric with low twist yarns will be found to deform with a long del structure.

The untorn fabric ahead of the del becomes jammed in the direction of tear which means further elongation of the del would depend upon how far the original undistorted fabric was from the jammed state in the direction of tear.

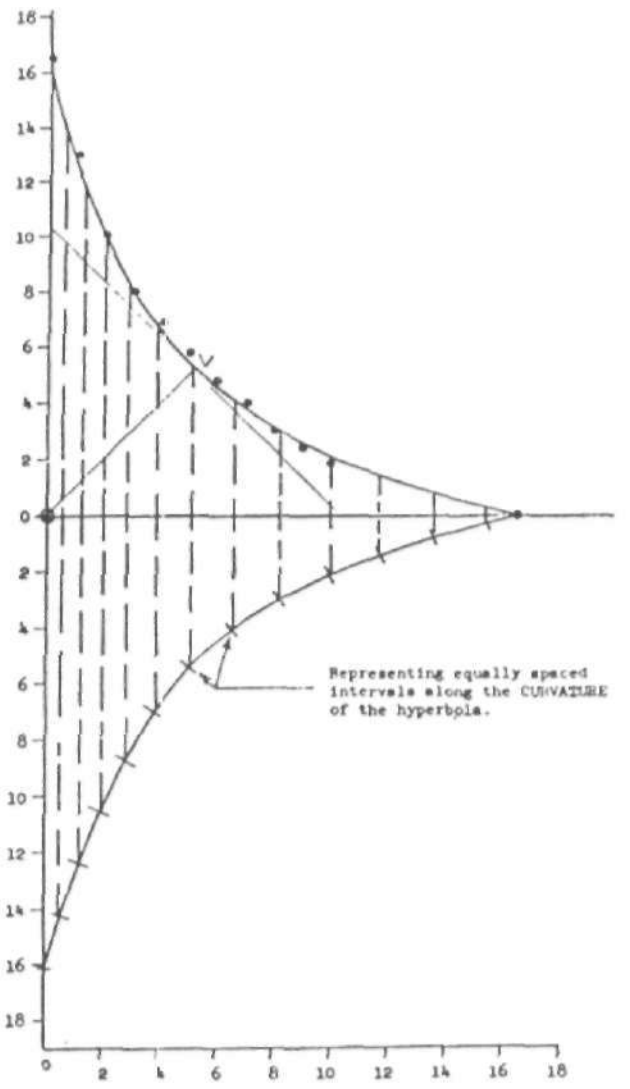

Representing equally spaced
intervals along the CURVATURE
of the hyperbola.

FIG. 7

The effect of weave is another factor contributing to the response of a fabric to a tear force. A weave structure with many crossovers per unit length gives an increased gripping action between warp and weft threads; thus the expected yarn pull-out force would be higher than fabric with long floats. This in effect decreases the tear strength of the fabric, and so plain weave is weaker in tear than basket weave, for instance. Even if the cover factor be high, a weave with many long floats will allow greater distortion due to the jamming action.

Hamburger, Platt and Teixeira made some visual examinations of plain weave and basket weave tong-tear specimens. The fabric samples were constructed from the same yarns. In comparison, they showed how much more deformable the basket weave is and how the deformed structure in the basket weave distributes the load between the fabric and the del more uniformly than in the plain weave. They observed that the del structure in the basket weave allows more yarns to share the tear force, and they showed that the effect of weave on tear strength becomes greater as the thread count decreases.

Usually fabrics woven from continuous filament yarns are stronger in tear than those made of staple fibre yarns, although this assertion depends very much upon the twist in the yarns. Hamburger's experimental results showed that the continuous filament fabrics are superior only when the yarn twist is less than 13 turns per inch and are inferior when the twist is greater than about 17 turns per inch. Therefore twist influences the tear test value of any fabric structure. However, the yarn to fabric friction was found to contribute immensely to the tear strength of fabrics.

The helix angle formed by the fibres in the yarns and the degree of flattening of the yarn may also be important parameters. In short, to achieve a high tear strength the yarns in the fabric structure must be strong and of relatively low friction.

CHAPTER 4

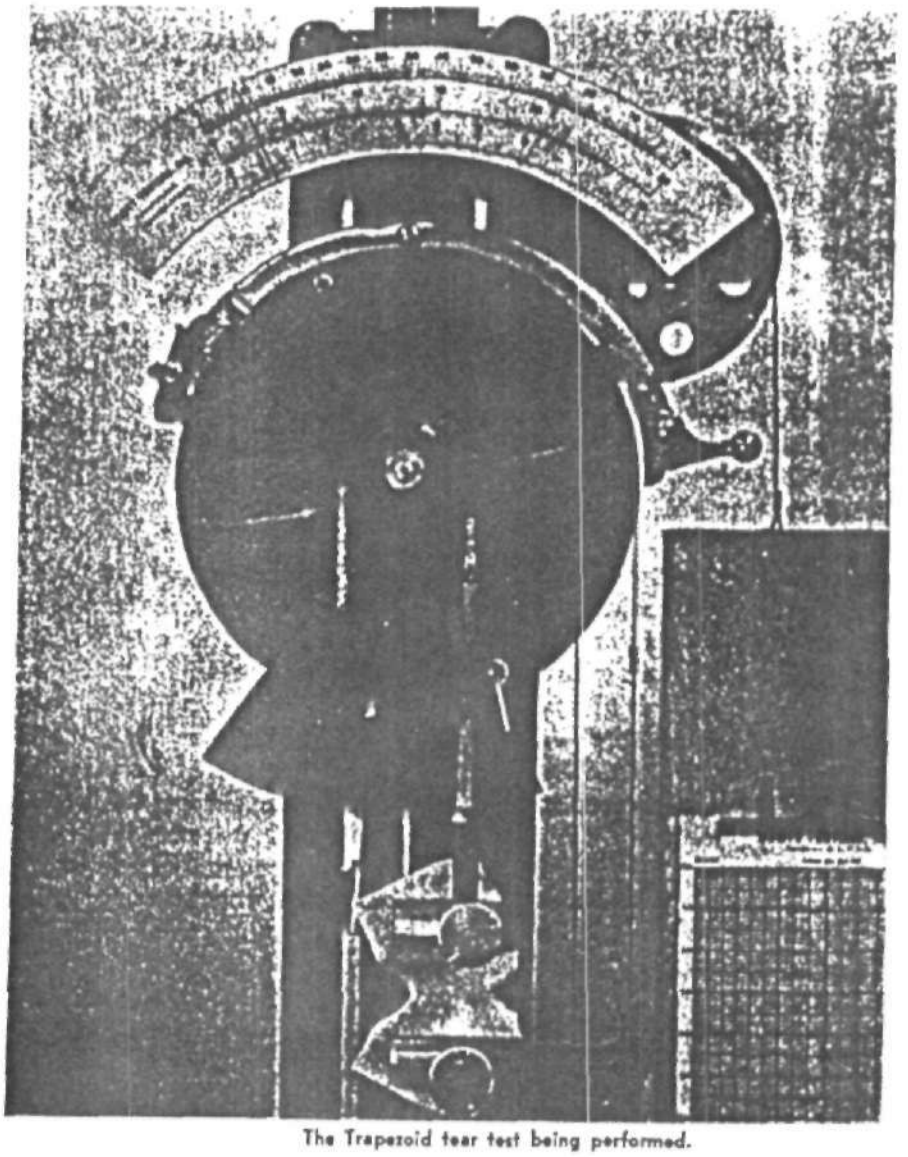
METHODS OF TEAR TESTING

There are many techniques that have been proposed for the measurement of tearing strength of textile fabrics, among which is the trapezoid method[5].

The test specimens are 3" wide and 6" long and an isosceles trapezoid with an altitude of 3" and bases 1" and 4" long is prepared from the specimen. A cut $^{1}/_{4}$ to $^{3}/_{8}$" in length is made in the centre of an perpendicular to the 1" base. The specimens are tested in a conventional pendulum-type testing machine, as shown in Figure 8, with the pawls disengaged from the rack. The specimen is clamped in the machine along the non-parallel sides of the trapezoid so that the cut is half way between the clamps, the short edge being tight and the longer edge lying in folds. The sample is torn across the narrow width and the average load recorded.

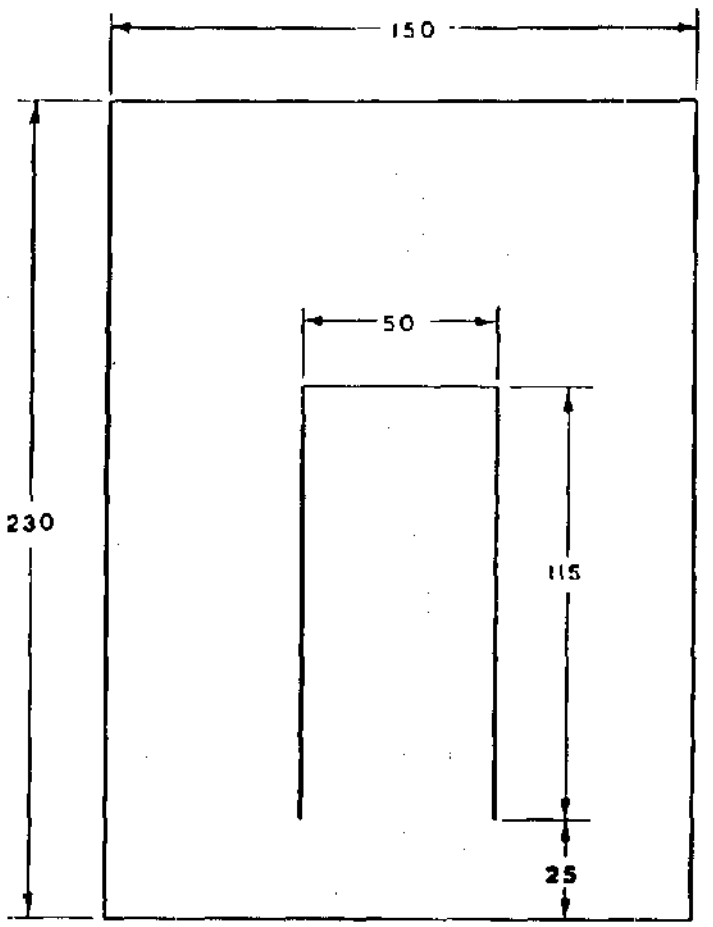
The tongue[6] (double rip) tear test is another method for determining the tear resistance of fabric samples. The test specification involves cutting specimens of dimensions 230 mm long and 150 mm wide with their sides parallel to the warp and weft threads. A tongue of dimensions 115 mm long and 50 mm wide is cut parallel to the threads in the centre of the specinen, terminating at a point so as to leave a 25 mm portion of cloth to be torn as shown in Figure 9.

The procedure involves placing the specimen in the testing machine with the end of the tongue secured evenly in the other pair of jaws. The machine is then operated to tear the specimen apart and the mean of five recorded values for tearing across the warp and weft threads is designated the tearing strength of the fabric.



The Trapezoid tear test being performed.

FIG. 8



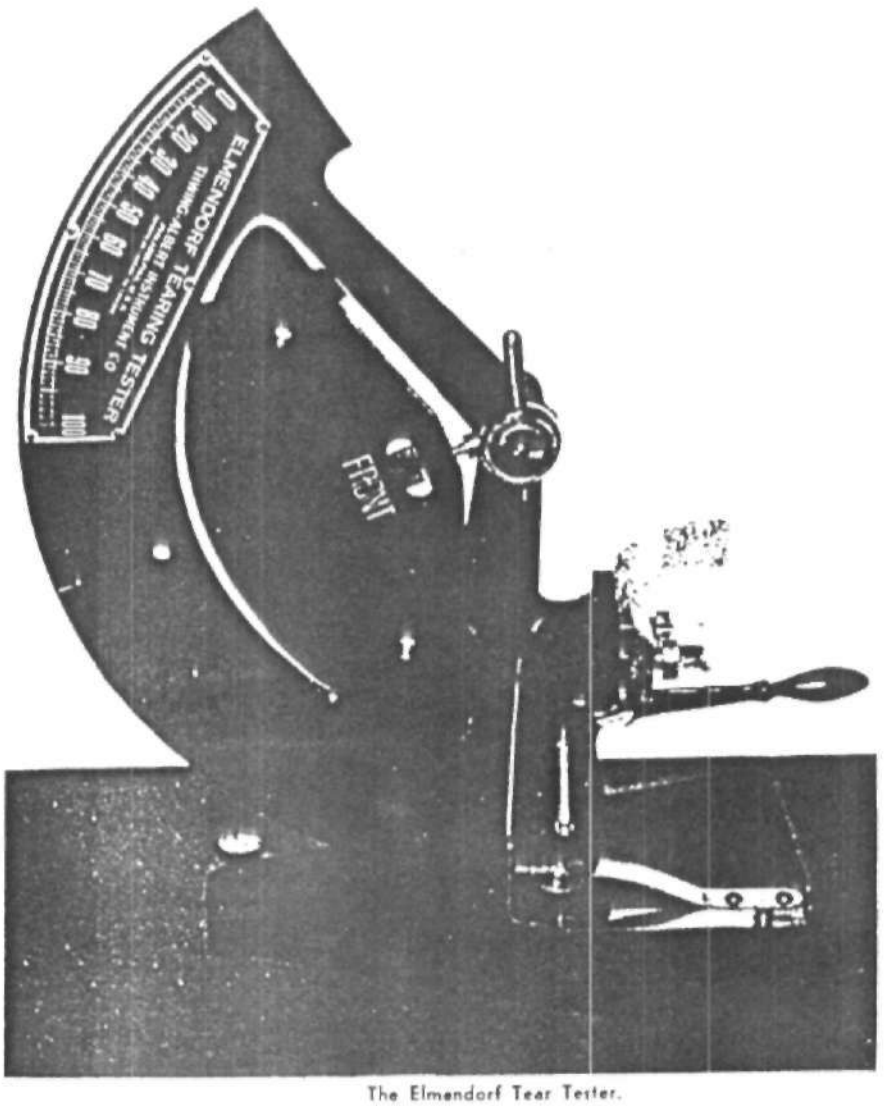
Dimensions in millimetres.

FIG. 9

The Elmendorf[7] is another method and the testing instrument is shown in Figure 10. Though designed for measuring the tearing strength of paper it is sometimes used to tear very light weight fabrics. The rectangular test specimens, of dimension 4" by 3", are placed in the jaws of a special tester. By the use of a swinging blade a slit is cut in the sample, starting at the bottom edge and ending about $1^3/_4$" from the top edge. During testing, the sector is allowed to fall, thus moving the pendulum jaw away from the fixed jaw and thereby tearing the specimen. The difference in height between the maximum free swing of the pendulum and the maximum height with the sample in place is indicative of the tear resistance of the fabric.

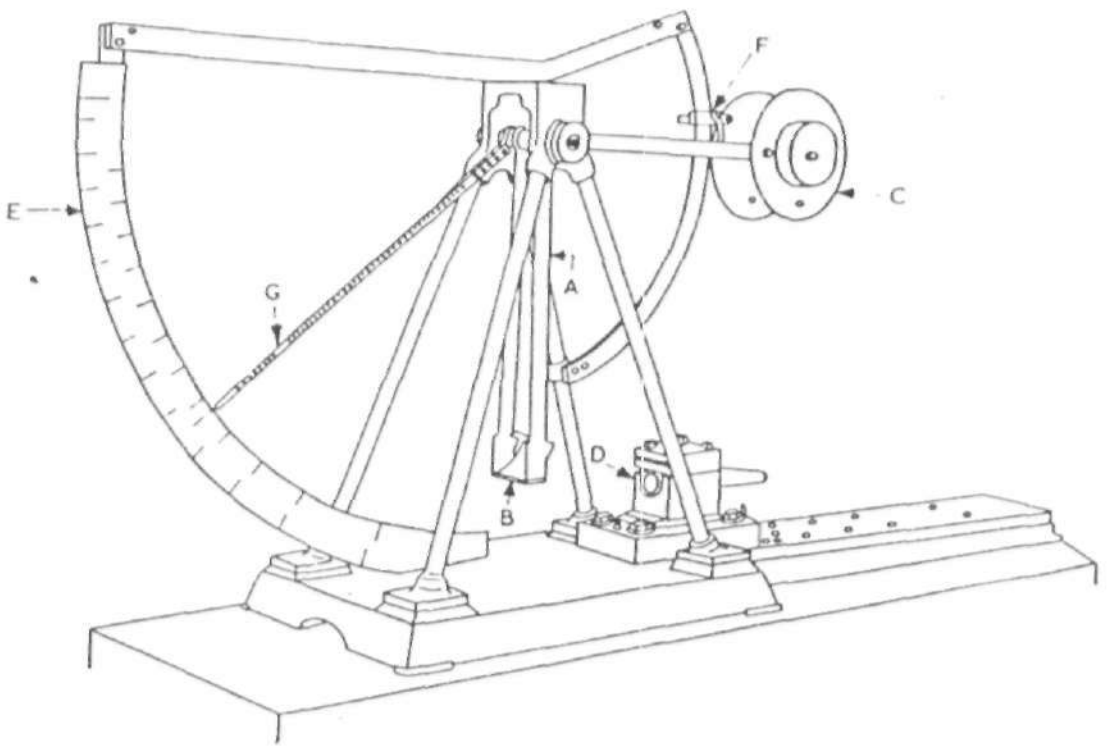
The ballistic[8] tear test is particularly suitable for testing material that is liable to be torn by sudden impacts, in which the extent of the damage is limited by the work done in tearing the cloth. Specimens are torn by a moving pendulum and the work done is determined from the difference between the height to which the pendulum rises after completing the tear and the height to which it rises in the absence of the specimen. A double pendulum ballistic tester as shown in Figure 11 is used and this consists of a light pendulum A, carrying a cloth grip B. A heavy pendulum C, which swings about the same axis as A, is provided with catches whereby A is secured to C on impact. A second cloth grip, D, is secured to the base of the instrument. A scale, E, calibrated in units of energy, is incorporated in the tester. The swing of the pendulum is indicated by a light pointer, G, which is set just below the final position of the pendulum and which the pendulum pushes forward and leaves in position.

Specimens 160 mm long by 50 mm wide are prepared and a central cut is made as shown diagrammatically in Figure 12. A line a b c is



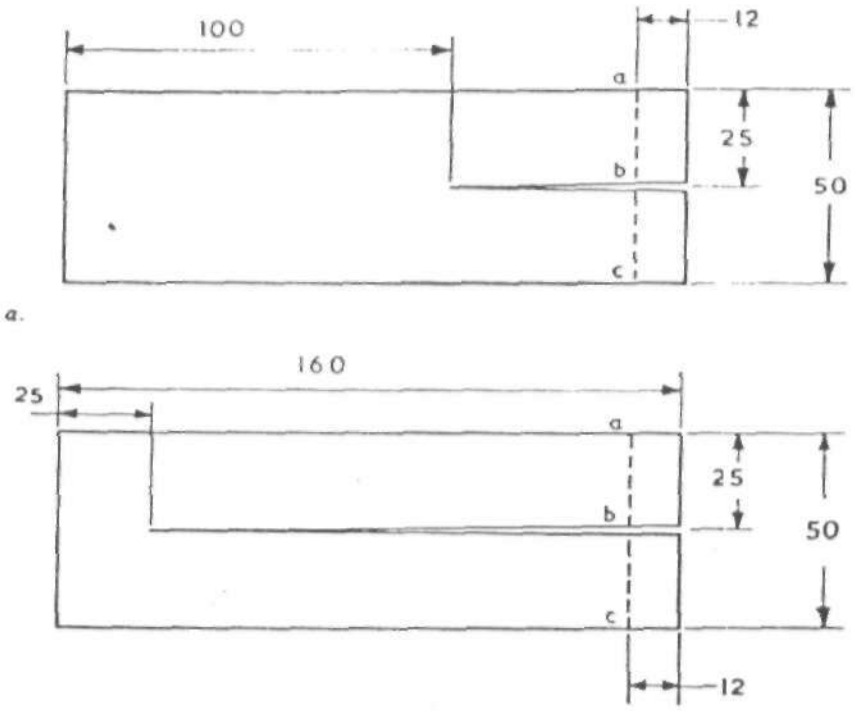
The Elmendorf Tear Tester.

FIG. 10



Double-pendulum ballistic tester

FIG. 11



Dimensions in millimetres.

Cutting of test specimens

FIG. 12

drawn on each face of the specimen at a distance of 12 mm from the cut end. The testing machine is adjusted such that the heavy pendulum is secured by means of a catch whilst the light pendulum hangs vertically at rest. The tester is then calibrated by setting the pointer to the zero reading on the scale. The specimen is mounted by securing one of its two tails in the fixed grip, D, at the line a b and the other in the grip, B, at the line b c. The heavy pendulum is then released to swing, thereby tearing the uncut portion of the specimen and the pointer, in the process of swinging pushes the pendulum forward along the scale, thus registering the work done necessary to tear the specimen.

CHAPTER 5

DESCRIPTION OF THE BASIC INSTRUMENT

The instrument used for this present experimental work is the Instron model 1026 which incorporates a highly sensitive electronic measuring system with load cells employing strain gauges to detect the load applied to the specimen under test. To outline the operation, the specimen is fastened between two grips, one attached to the load cell in the moving crosshead and the other attached to the fixed base of the tester. The moving crosshead is operated by two vertical lead screws. A synchronous motor drives the lead screws through a gearbox that provides a variety of crosshead speeds determined by change gears. The load applied to the specimen under test is recorded by the trace of a separate recorder connected to the Instron machine. The chart moves at a precise speed determined by change gears in either a time-drive or a proportional-drive mode. Figure 13 shows the Instron model 1026.

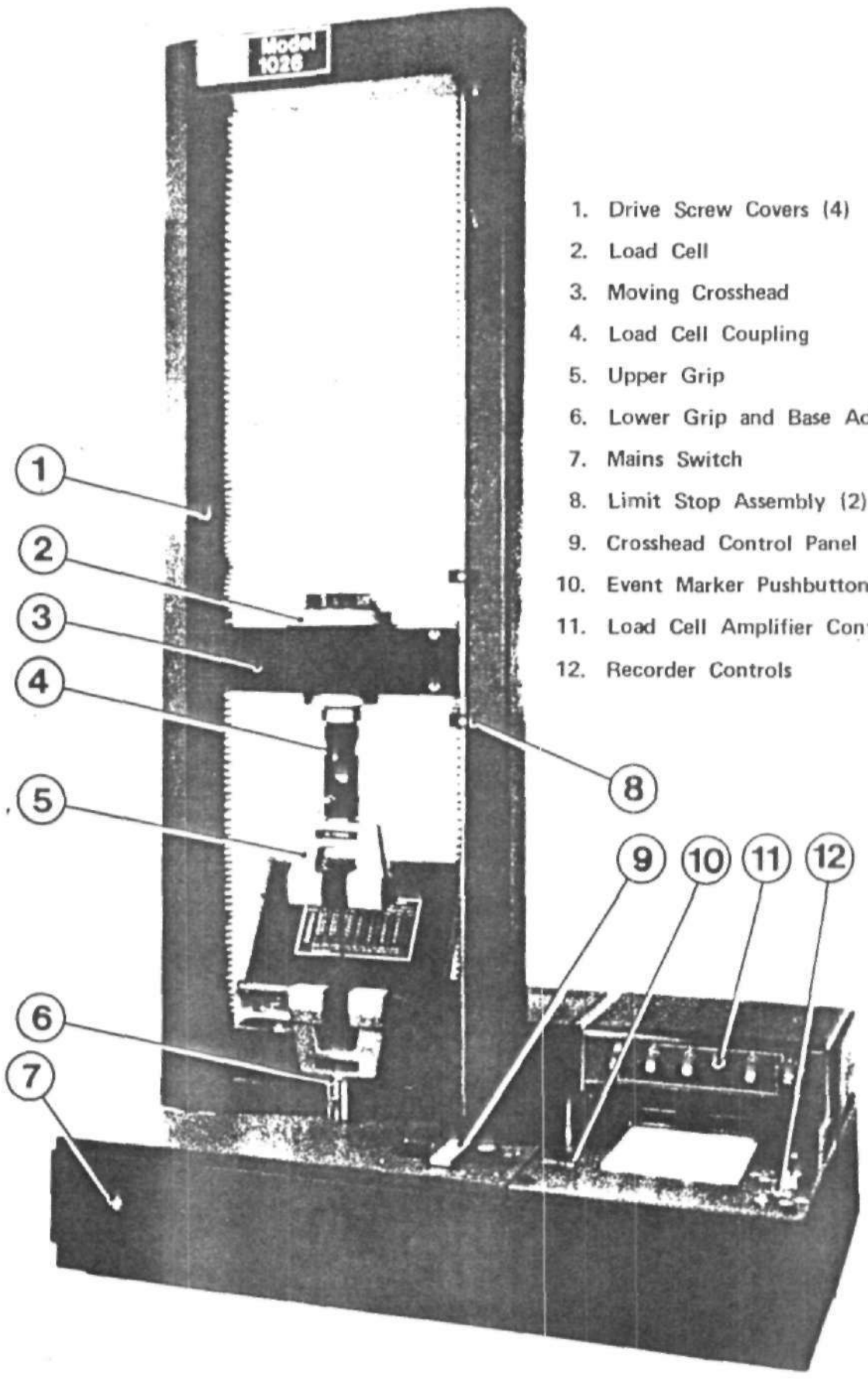
5.1 Principles of Operation

The instrument consists of two basic systems which are:

(a) the load weighing and recorder

(b) the crosshead control.

The load weighing system comprises of the load cell and the load cell amplifier. The load sensing devices in Instron load cells are bonded resistance strain gauges. The resistance of each strain gauge changes in proportion to the amount of deformation it receives. The change in strain gauge resistance caused by the applied load unbalances a bridge



1. Drive Screw Covers (4)
2. Load Cell
3. Moving Crosshead
4. Load Cell Coupling
5. Upper Grip
6. Lower Grip and Base Adaptor
7. Mains Switch
8. Limit Stop Assembly (2)
9. Crosshead Control Panel
10. Event Marker Pushbutton
11. Load Cell Amplifier Controls
12. Recorder Controls

FIG. 13

and results in a change in the output voltage. This is amplified to drive the pen of the strip chart recorder.

The load selector range switch changes the amplification of the load cell signal in steps of 5, 10, 20 and 50, enabling each load cell to provide a number of full scale ranges. The zero and calibration controls respectively permit the zero position of the recorder pen to be established and the load scale sensitivity to be accurately adjusted by the use of calibration weights.

5.2 Function of Controls

The load cell amplifier control panel located to the rear and above the recorder consists of five control knobs.

(1) Zero balance control

(2) Coarse balance control

(3) Fine balance control

(4) Calibration control

(5) Zero and range selector switch

5.2.1 The Zero Control

The use of the zero control enables the recorder pen to be adjusted about the zero graduation on the chart. This is carried out by simply turning the zero control switch until the pen is at the zero position, thus disconnecting any input signal from the load cell to the load cell amplifier.

5.2.2 Balance Controls

The coarse and fine balance controls are used to balance the resistance bridge in the load cell to compensate for any initial load applied to the load cell by the varying weights of grips and fixtures.

5.2.3 Calibration Control

This controls the adjustment of the load scale sensitivity and is used to set the recorder pen at full scale during the calibration procedure, when an accurate load signal is applied. Calibration is carried out using deadweight as shown in Figure 14.

5.3 Recorder Chart Controls

The chart recorder consists of two major assemblies, the pen and the chart drive mechanisms. The chart drive mechanism is powered by the synchronous motor that drives the crosshead. There are two modes of chart drive operation.

(a) Time Drive Mode

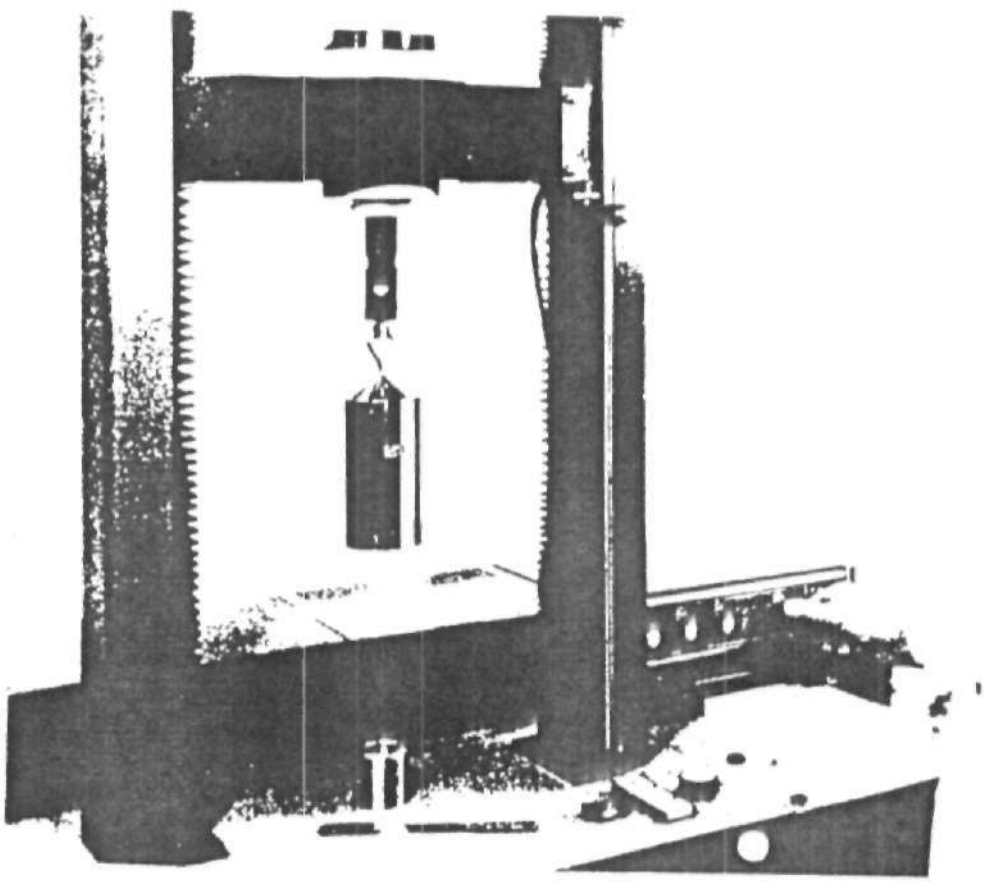
The chart moves forward at a range of speeds which may be pre-selected by the operator.

(b) Proportional Mode

The direction of chart movement follows the direction of crosshead motion and the chart speed may be selected as a direct ratio of the crosshead speed.

5.3.1 Chart Drive and Change Gears

The drive gearbox, as shown in Figure 15, is located to the rear of the loading frame and contains gearing for both the chart drive and



Calibrating using Deadweights

FIG. 14

Chart Drive and Change Gears

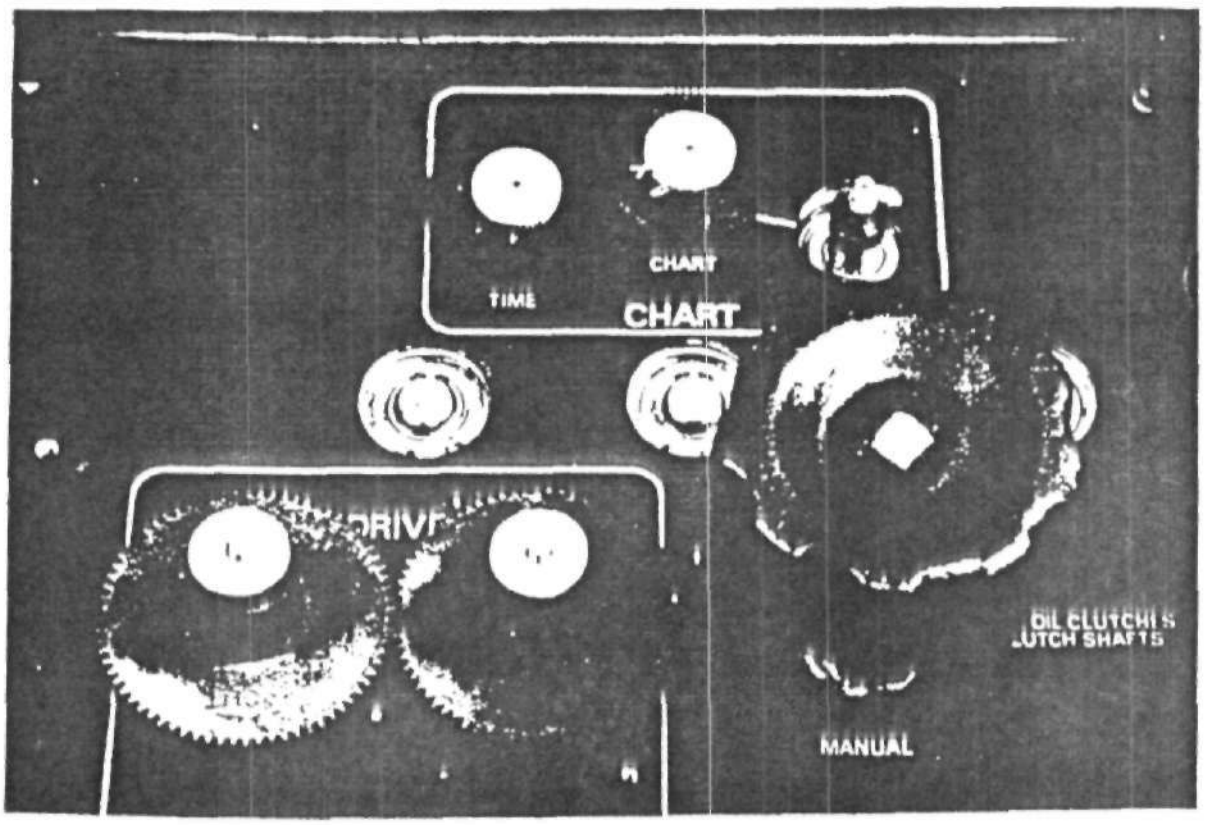


FIG. 15

the crosshead drive. Chart speeds and the operatives mode of the paper movement are selected by the fitting of change gears.

5.4 Crosshead Controls

The normal testing speeds obtained by merely depressing the UP and DOWN push buttons on the crosshead control panel, are determined by the choice of change gears. Two crosshead change gear shafts project from the gearbox. The right hand shaft, designated OUT, is mechanically connected to the crosshead headscrews and the left hand shaft, marked IN, is driven through gearing from the synchronous motor.

In fitting the gears for the crosshead drive the following procedures were followed:

1. The first change gear was placed on the right hand shaft, marked OUT, making sure that the square hole in the change gear engaged firmly over the square shank section of the shaft.

2. The second gear was fitted on the left hand shaft, marked IN, and then the gear was rotated until the square hole matched in position.

3. Finally the knurled nuts were tightened to lock the gears in position.

5.5 Operating Procedures

A minimum warm-up period of fifteen minutes is recommended to assure load cell stability. Before testing is carried out the recorder pen is set to the zero position on the chart. This was carried out by the following procedures:

(a) the pen switch was turned to the ON position with the range selector fully anti-clockwise.

(b) the necessary adjustments were made to set the pen at the zero position on the chart.

(c) The Range Selector was then turned clockwise to the first load range position, that is, 5.

(d) Finally, the coarse and fine controls were adjusted in the appropriate direction to keep the pen at the zero position.

5.5.1 Calibration

The calibration control was used to set the recorder pen at full scale while applying an accurate known load signal from the load cell. The procedure was carried out on a regular basis and most importantly whenever a load cell was changed.

To carry out the calibration procedure using calibration weights the following steps were followed.

1. The grip from the load cell coupling was removed and a calibration hanger appropriate to the load cell in use was installed.

2. The pen switch was turned on, then set at zero with the necessary adjustment.

3. The pen was then switched off and the required calibration weight attached to the hanger.

4. The Range Selector was turned to the position 5 and the pen switched on. The calibration control was then rotated until the

pen moved to the extreme right of the chart, which corresponds to the full scale setting.

5. Finally the pen switch was turned off and the calibration weight removed. If properly calibrated the pen automatically returns to its zero position.

CHAPTER 6

EXPERIMENTAL PROCEDURE

The fabrics from which the samples for this experiment were selected were woven on a Dobcross loom. the yarn structure prepared for warp and weft threads was spun from a blend of cotton and vincel fibres with a blend ratio of 50/50. The warp and weft threads are both $2/20^{s}$ cotton count yarns.

In the construction of the fabric, a reed width of $56^{1}/_{4}$" was used, with a set of 16/3 that is, 16 dents per inch on the reed and 3 threads per dent. The nine fabric samples used for this work were produced with constant warp fractional cover but varying the weft fractional cover. A problem encountered during weaving was the choice of appropriate pick wheel to produce the required number of picks per centimetre in the fully relaxed state of the fabric. Mostly the available pick wheels either have fewer or more teeth than the number needed to produce the required fabric sett. The actual relaxed warps and wefts per cm are indicated in Table 1.

Table 1

Fabric Number	A	B	C	D	E	F	G	H	I
Warp/cm	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Weft/cm	16.4	12.5	14.3	13.3	12.5	14.3	15.2	18.5	15.9
Warp α Weft Tex	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0

The fabrics were conditioned in accordance with method 2 recommended in the Canadian Standard Textile Test Methods.

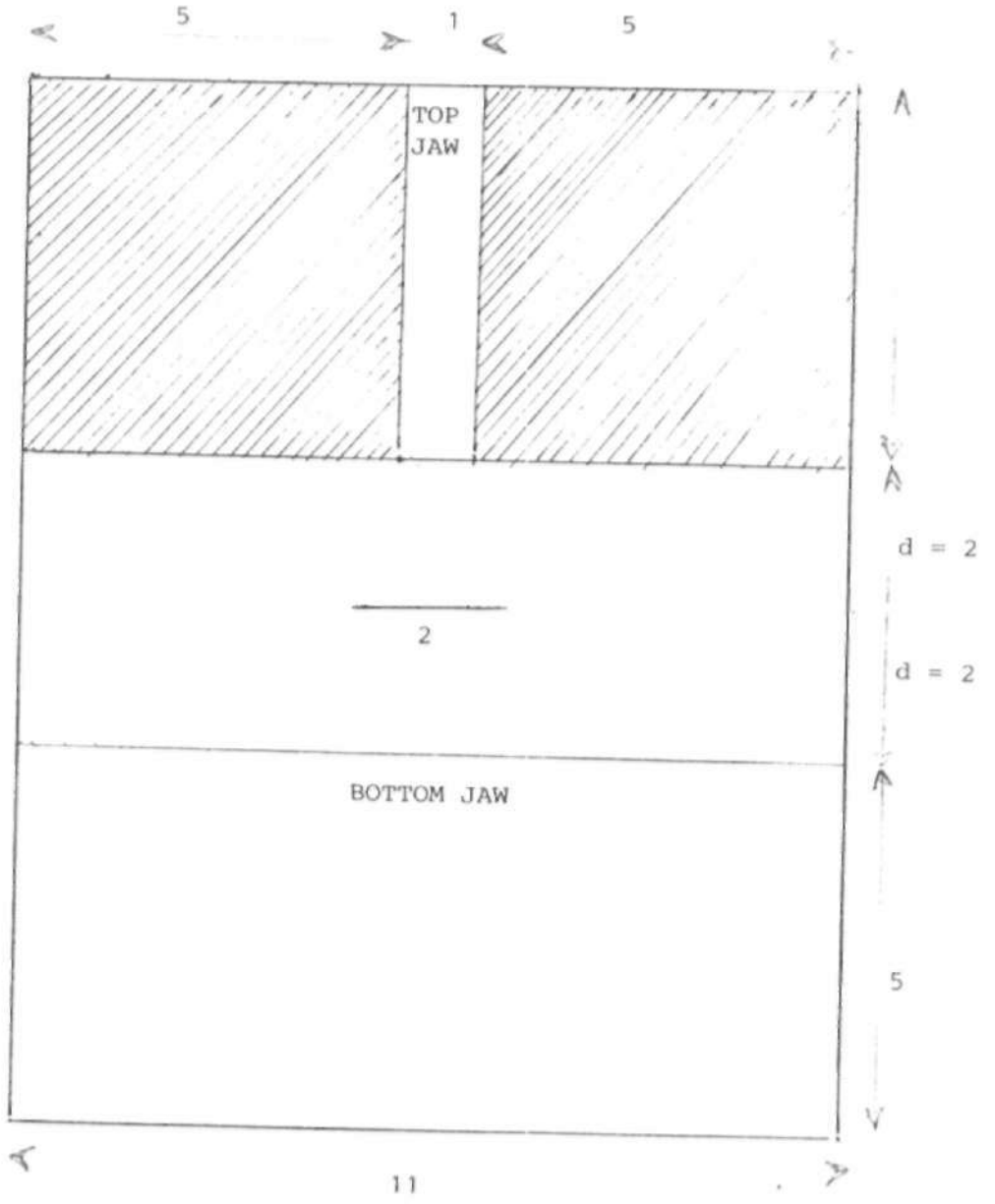
The object of the present experiments was to estimate the values of αP and β in the equation

$$fs = \frac{\alpha P\ (\beta^n - 1)}{\beta - 1}$$

Accordingly a series of experiments was carried out which consisted of measuring the force fs needed to pull out a yarn over n crossing threads. This test utilises a similar principle to that used by Taylor and is illustrated in Figure 6. The pre-conditioned sample selected from a grey plain woven fabric was prepared as shown schematically in Figure 16 for both warp and weft directions. The samples were of eleven centimetres width with variable length determined by the chosen values of 'd' which are 0.5, 1.0, 1.25 and 1.5, all measured in centimetres. These values represent the distance between a point on the specimen gripped at the upper jaw of the testing machine and the point of propagation of tear. A one centimetre width strip of length 5 cm was cut centrally as shown and at a distance of d below the base of the strip a horizontal cut of length 2 cm was made. This cut made below the strip was to enable the withdrawal of yarns from the strip of the fabric.

The experiment involves pulling out a group of yarns within the strip of fabric of width one centimetre and yarn length of value d. The changes in values of d alter the number of interlacing points and the effect of frictional forces on the test results.

Five specimens were prepared for each value of d in both warp and weft directions for the nine fabric samples ready to be tested on Instron model 1026.



All dimensions in centimetres

FIG. 16

The testing machine was adjusted to give the appropriate rate of crosshead movement by the use of the proportional drive mode. In this mode the change gears were installed between the CHART and PROPORTIONAL shafts to give the required speed ratio of 1 millimetre to 50 millimetres per minute was chosen.

The load cell of 50 kg maximum was selected and installed with its coupling component. The machine was switched on and allowed to warm up for at least fifteen minutes. Then the load weighing system was zeroed, balanced and calibrated. The calibration was carried out using a deadweight of 5 kg. The specimen grips were selected and fitted, and then readjusting the balance as necessary. The Range Selector was switched to the load range of 20 as the expected withdrawal force is less than 20 kg.

The specimen was inserted in the grips with the strip of fabric mounted in the top jaw and tightened whilst the lower part of the specimen was fitted in the lower grip and also tightened up to prevent the specimen from slipping out of the jaws. The specimen as set up on the machine is illustrated in Figure 17.

The test was started by pushing the UP button switch on the crosshead control panel with the pen and chart switches on simultaneously. The crosshead moved upward until some of the yarns were either broken or all withdrawn.

A typical yarn pull-out test load trace obtained during the test is shown in Figure 18. The trace shows force, measured in kilogrammes, recorded during the test for withdrawing a group of yarns within the one centimetre width strip of fabric. Taylor considers the relation of the force applied to a single thread in a cloth, to cause

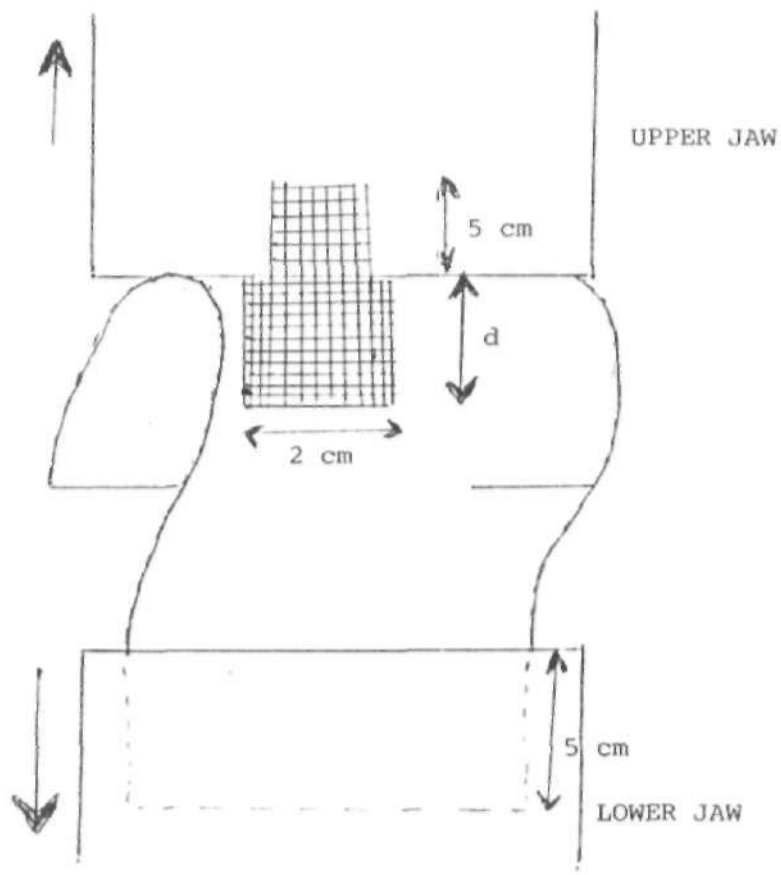


FIG. 17

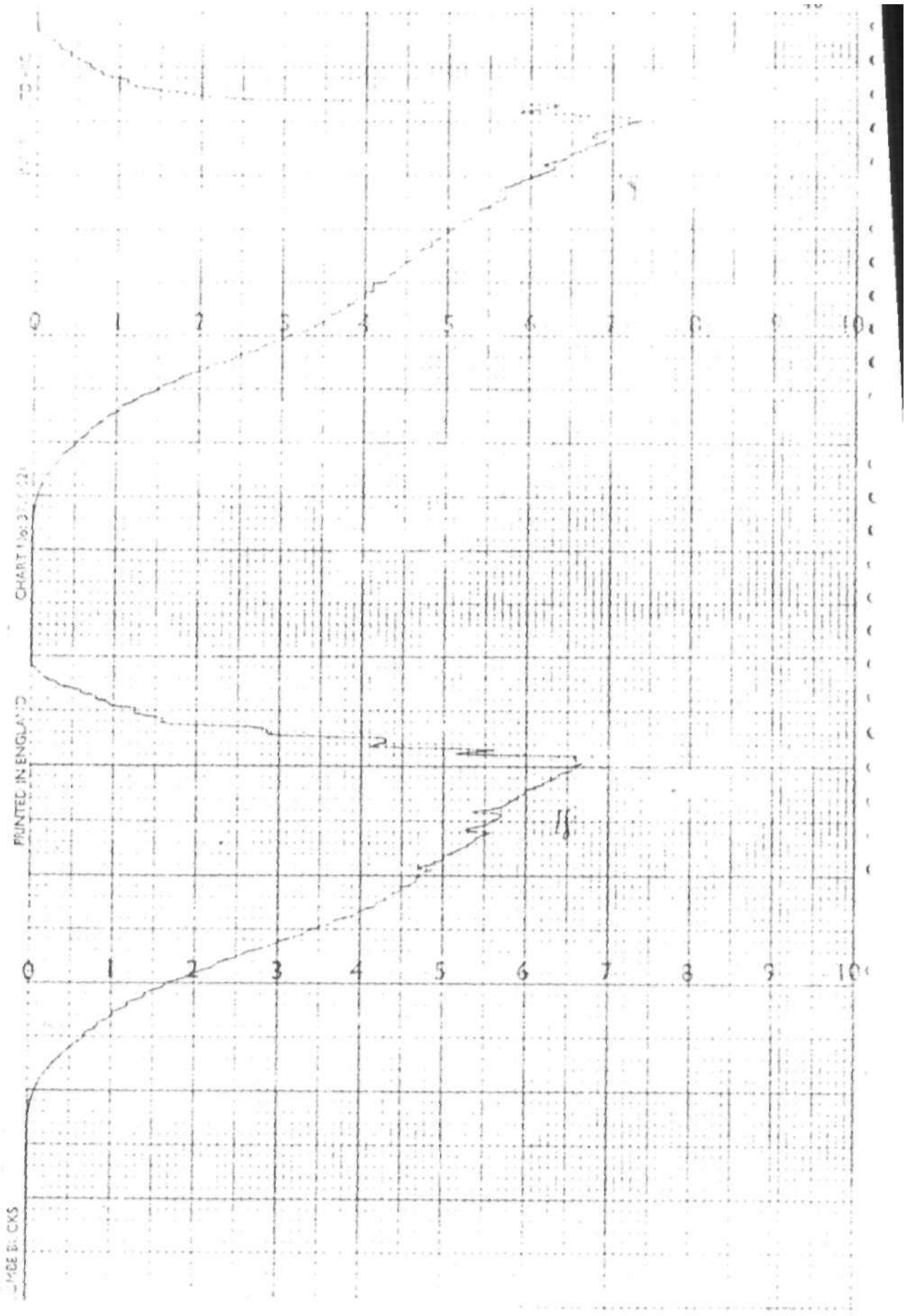


FIG. 18

slippage, and the tension along the thread. The above experimental procedure examines the effect of increasing the number of crossing points on the force required to withdraw a length of thread from the woven fabric sample. The withdrawal force per thread can be obtained by dividing the maximum load as recorded on the chart by the total number of threads within the one centimetre strip of fabric held in the upper jaw. The mean force in kilogrammes per thread was then calculated for the five tests. Table 2 shows the value of n obtained by multiplying the picks and ends per centimetre by each value of 'd' and fs (kg/thread) for the nine samples. The table shows the test results in withdrawing the yarns in warp direction whilst table 3 shows the results obtained in weft direction.

Table 2

A		B		C		D		E		F		G		H		I	
n	fs	n	fs	n	fs	n	fs	n	fs	n	fs	n	fs	n	fs	n	fs
8.2	0.09	6.25	0.05	7.15	0.03	6.65	0.02	6.25	0.01	7.15	0.03	7.6	0.02	9.25	0.04	7.95	0.04
12.3	0.24	9.38	0.10	10.73	0.15	9.98	0.05	9.38	0.06	10.73	0.09	11.4	0.04	13.88	0.17	11.93	0.18
16.4	0.61	12.5	0.37	14.30	0.38	13.3	0.15	12.5	0.25	14.3	0.19	15.2	0.29	18.5	0.43	15.90	0.26
20.5	0.91	15.63	0.50	17.88	0.59	16.63	0.48	15.63	0.50	17.88	0.62	19.0	0.72	23.13	0.57	19.88	0.75
24.6	0.95	18.75	0.69	21.45	0.84	19.95	0.89	18.75	0.61	21.45	0.90	22.8	0.83	27.75	0.73	23.85	0.76
		21.88	0.71	25.03	0.96			21.88	0.97								

Table 3

n	A fs	B fs	C fs	D fs	E fs	F fs	G fs	H fs	I fs
10.00	0.04	0.01	0.01	0.02	0.04	0.02	0.07	0.05	0.05
15.00	0.20	0.07	0.04	0.15	0.16	0.10	0.09	0.15	0.17
20.00	0.35	0.18	0.20	0.32	0.29	0.28	0.22	0.28	0.39
25.00	0.87	0.61	0.62	0.47	0.45	0.44	0.78	0.77	0.80
30.00	0.79	0.96	0.86	0.58	0.63	0.76	0.87	0.63	0.79

CHAPTER 7

RESULTS AND ANALYSIS

The concluding part of Chapter 6 shows in tabulated form the results obtained from the experimental work for each sample. The data are plotted in Figures 19 to 24 and we shall assume that the relation between fs and n can be represented by Taylor's theoretical equation

$$fs = \frac{\alpha P\ (\beta^n - 1)}{\beta - 1}$$

It remains to test whether this is a reasonable assumption and, if so, to estimate the values of αP and β for each sample. This estimation can be carried out by the method of least squares, in which the values of αP and β are chosen so that

$$S = \sum_{\text{all data}} \left[fs - \frac{\alpha P\ (\beta^n - 1)}{\beta - 1} \right]^2$$

is a minimum. A computer program, employing an iterative minimization routine was written to carry out this calculation. An initial guess at the appropriate values of αP and β is made and the program then automatically adjusts the values until the minimum value of S is reached, using the values of fs and n for each fabric as shown in tables 4-21.

A measure of the goodness of fit of Taylor's equation to the data is provided by the coefficient of determination R^2, which is defined by the equation

$$R^2 = 1 - \frac{SSE}{SSF}$$

INITIAL GUESS 1.070 0.019

N	FS	RESIDUALS	SE	PES	ERROR
8.20	0.0900	-0.1297D+00	0.1682D-01	0.22	144.09%
12.30	0.2400	-0.1192D+00	0.1422D-01	0.36	49.69%
16.40	0.6100	0.7619D-01	0.5805D-02	0.53	-12.49%
20.50	0.9500	0.1979D+00	0.3914D-01	0.75	-20.83%
24.60	0.9100	-0.1152D+00	0.1328D-01	1.03	12.66%

BETA 1.056096 AP 0.018894 SSE 0.8927D-01

ON EXIT, THE SUM OF SQUARES IS 0.0893
AT THE POINT B= 1.056096 AP= 0.018894

TABLE 4

INITIAL GUESS 1.200 0.007

N	FS	RESIDUALS	SE	PFS	ERROR
6.25	0.0500	-0.8623D-01	0.7436D-02	0.14	172.47%
9.38	0.1000	-0.1185D+00	0.1405D-01	0.22	118.55%
12.50	0.3700	0.5053D-01	0.2553D-02	0.32	-13.66%
15.63	0.5000	0.5599D-01	0.3135D-02	0.44	-11.20%
18.75	0.6900	0.9328D-01	0.8702D-02	0.60	-13.52%
21.88	0.7100	-0.7516D-01	0.5649D-02	0.79	10.59%

BETA 1.068508 AP 0.015133 SSE 0.4153D-01

ON EXIT, THE SUM OF SQUARES IS 0.0415
AT THE POINT B= 1.068508 AP= 0.015133

TABLE 5

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INITIAL GUESS 1.120 0.010

N	PS	RESIDUALS	SF	PFS	ERROR
7.15	0.0300	-0.1121D+00	0.1257D-01	0.14	373.66%
10.73	0.1500	-0.8823D-01	0.7784D-02	0.24	58.82%
14.30	0.3900	0.1609D-01	0.2585D-03	0.36	-4.23%
17.88	0.5900	0.6079D-01	0.3695D-02	0.53	-10.30%
21.45	0.8400	0.9465D-01	0.8959D-02	0.75	-11.27%
25.03	0.9600	-0.6956D-01	0.4839D-02	1.03	7.25%

BETA 1.078755 AP 0.013090 SSE 0.3810D-01

ON EXIT, THE SUM OF SQUARES IS 0.0381
AT THE POINT B= 1.078755 AP= 0.013090

TABLE 6

47

INITIAL GUESS 1.120 0.004

N	FS	RESIDUALS	SF	PFS	ERROR
4.45	0.0200	-0.1550D-01	0.2401D-03	0.04	77.48%
9.86	0.0500	-0.3484D-01	0.1214D-02	0.09	69.68%
17.30	0.1500	-0.4052D-01	0.1642D-02	0.19	27.02%
16.63	0.4800	0.6171D-01	0.3809D-02	0.42	-12.86%
10.95	0.8900	-0.1610D-01	0.2591D-03	0.91	1.81%

BEITA 1.258595 AP 0.001909 SSE 0.7163D-02

ON EXIT, THE SUM OF SQUARES IS 0.0072
AT THE POINT B= 1.258595 AP= 0.001909

TABLE 7

INITIAL GUESS 1.120 0.008

N	FS	RESIDUALS	SF	PFS	ERROR
4.25	0.0100	-0.6898D-01	0.4759D-02	0.08	689.82%
9.38	0.0600	-0.8515D-01	0.7251D-02	0.15	141.92%
12.50	0.2500	0.4443D-02	0.2156D-04	0.25	-1.86%
15.63	0.5000	0.1019D+00	0.1039D-01	0.40	-20.38%
18.75	0.6100	-0.1938D-01	0.3756D-03	0.63	3.18%
21.88	0.9700	-0.1192D-01	0.1420D-03	0.98	1.23%

BETA 1.147203 AP 0.006902 SSE 0.2293D-01

ON EXIT, THE SUM OF SQUARES IS 0.0229
AT THE POINT B= 1.143203 AP= 0.006902

TABLE 8

49

INITIAL GUESS 1.200 0.002

N	FS	RESIDUALS	SE	PFS	ERROR
7.15	0.0300	-0.3250D-01	0.1056D-02	0.06	108.34%
10.73	0.0900	-0.4264D-01	0.1191D-02	0.13	47.38%
14.30	0.1900	-0.7144D-01	0.5103D-02	0.26	37.60%
17.88	0.6200	0.1207D+00	0.1456D-01	0.50	-19.46%
21.45	0.9000	-0.3620D-01	0.1310D-02	0.94	4.02%

BETA 1.186279 AP 0.003851 SSE 0.2385D-01

ON EXIT, THE SUM OF SQUARES IS 0.0238
AT THE POINT B= 1.186279 AP= 0.003851

TABLE 9

INITIAL GUESS 1.200 0.003

N	FS	RESIDUALS	SE	PES	ERROR
7.60	0.0200	-0.6870D-01	0.4720D-02	0.09	343.51%
11.40	0.0400	-0.1326D+00	0.1759D-01	0.17	331.55%
15.20	0.2900	-0.1984D-01	0.3937D-03	0.31	6.84%
19.00	0.7200	0.1858D+00	0.3451D-01	0.53	-25.80%
22.80	0.8300	-0.7114D-01	0.5061D-02	0.90	8.57%

BETA 1.138158 AP 0.005998 SSE 0.6227D-01

ON EXIT, THE SUM OF SQUARES IS 0.0623
AT THE POINT B= 1.138158 AP= 0.005998

TABLE 10

INITIAL GUESS 1.150 0.005

N	FS	RESIDUALS	SE	PFS	ERROR
9.25	0.0400	-0.1288D+00	0.1660D-01	0.17	322.06%
13.88	0.1700	-0.7368D-01	0.5428D-02	0.24	43.34%
18.50	0.4300	0.1125D+00	0.1765D-01	0.32	-26.16%
23.13	0.5700	0.1794D+00	0.3217D-01	0.39	-31.47%
27.75	0.3200	-0.1428D+00	0.2039D-01	0.46	44.62%

BEITA 0.997500 AP 0.016662 SSE 0.8723D-01

ON EXIT, THE SUM OF SQUARES IS 0.0872
AT THE POINT B= 0.997500 AP= 0.016662

TABLE 11

INITIAL GUESS 1.150 0.004

N	FS	RESIDUALS	SE	PFS	ERROR
7.05	0.0400	0.1467D-01	0.2151D-03	0.03	-36.67%
11.03	0.1900	0.1179D+00	0.1389D-01	0.06	-65.48%
15.00	0.2600	0.1169D+00	0.1366D-01	0.14	-44.95%
19.98	0.1500	-0.1723D+00	0.2969D-01	0.32	114.88%
23.95	0.7600	0.4342D-01	0.1886D-02	0.72	-5.71%

BETA 1.220265 AP 0.001130 SSE 0.5934D-01

ON EXIT, THE SUM OF SQUARES IS 0.0593
AT THE POINT B= 1.220265 AP= 0.001130

TABLE 12

53

INITIAL GUESS 1.100 0.005

N	FS	RESIDUALS	SE	PFS	ERROR
10.00	0.0400	-0.1104D+00	0.1218D-01	0.15	275.94%
15.00	0.2000	-0.6101D-01	0.3723D-02	0.26	30.51%
20.00	0.3500	-0.6195D-01	0.3837D-02	0.41	17.70%
25.00	0.8700	0.2521D+00	0.6358D-01	0.62	-28.99%
30.00	0.7000	-0.1088D+00	0.1183D-01	0.90	13.77%

BETA 1.064 AP 0.01 SSE 0.9515D-01

ON EXIT, THE SUM OF SQUARES IS 0.0951
AT THE POINT B= 1.0641 AP= 0.0098

TABLE 13

```
     ap=f(fs(3),sn(3))

 INITIAL GUESS     1.150     0.002
      N        FS        RESIDUALS              SE       PFS      ERROR
     10.00     0.0100    -0.4236D-01     0.1794D-02      0.05    423.58%
     15.00     0.0700    -0.4762D-01     0.2268D-02      0.12     68.03%
     20.00     0.1800    -0.6581D-01     0.4331D-02      0.25     36.56%
     25.00     0.6100     0.1124D+00     0.1263D-01      0.50    -18.43%
     30.00     0.9600    -0.3218D-01     0.1036D-02      0.99      3.35%
 BETA   1.145 AP      0.00    SSE    0.2206D-01


ON EXIT, THE SUM OF SQUARES IS       0.0221
AT THE POINT B=      1.1446 AP=       0.0022

     ap=f(fs(5),sn(5))
 INITIAL GUESS     1.150     0.002
      N        FS        RESIDUALS              SE       PFS      ERROR
     10.00     0.0100    -0.4236D-01     0.1794D-02      0.05    423.58%
     15.00     0.0700    -0.4762D-01     0.2268D-02      0.12     68.03%
     20.00     0.1800    -0.6581D-01     0.4331D-02      0.25     36.56%
     25.00     0.6100     0.1124D+00     0.1263D-01      0.50    -18.43%
     30.00     0.9600    -0.3218D-01     0.1036D-02      0.99      3.35%
 BETA   1.145 AP      0.00    SSE    0.2206D-01


ON EXIT, THE SUM OF SQUARES IS       0.0221
AT THE POINT B=      1.1446 AP=       0.0022
```

TABLE 14

INITIAL GUESS 1.050 0.006

M	FS	RESIDUALS	SE	PFS	ERROR
10.00	0.0100	-0.4909D-01	0.2410D-02	0.06	490.87%
15.00	0.0400	-0.8655D-01	0.7492D-02	0.13	216.39%
20.00	0.2000	-0.5104D-01	0.2605D-02	0.25	25.52%
25.00	0.6200	0.1393D+00	0.1940D-01	0.48	-22.46%
30.00	0.8600	-0.4454D-01	0.1983D-02	0.90	5.18%

BETA 1.130 AP 0.00 SSE 0.3389D-01

ON EXIT, THE SUM OF SQUARES IS 0.0339
AT THE POINT B= 1.1303 AP= 0.0027

TABLE 15

311111

INITIAL GUESS 1.070 0.006

N	FS	RESIDUALS	SE	PFS	ERROR
10.00	0.0200	-0.8135D-01	0.6618D-02	0.10	406.75%
15.00	0.1500	-0.2634D-01	0.6936D-03	0.19	17.56%
20.00	0.3200	0.4098D-01	0.1680D-02	0.28	-12.81%
25.00	0.4700	0.5038D-01	0.2538D-02	0.42	-10.72%
30.00	0.5800	-0.3216D-01	0.1034D-02	0.61	5.54%

BETA 1.064883 AP 0.006597 SSE 0.1256D-01

ON EXIT, THE SUM OF SQUARES IS 0.0126
AT THE POINT B= 1.064983 AP= 0.006597

TABLE 16

INITIAL GUESS 1.070 0.007

N	FS	RESIDUALS	SE	PFS	ERROR
10.00	0.0400	-0.5217D-01	0.2721D-02	0.09	130.42%
15.00	0.1400	-0.5781D-02	0.3342D-04	0.17	3.61%
20.00	0.2900	0.1811D-01	0.3281D-03	0.27	-6.25%
25.00	0.4500	0.2517D-01	0.6337D-03	0.42	-5.59%
30.00	0.6300	-0.1527D-01	0.2331D-03	0.65	2.42%

BEITA 1.075859 AP 0.005661 SSE 0.3950D-02

ON EXIT, THE SUM OF SQUARES IS 0.0039
AT THE POINT B= 1.075859 AP= 0.005661

TABLE 17

58 FILE: F2 RESULT A LEEDS UNIVERSITY COMPUTING SERVICE VM/HPO 5.0 CMS PAGE 0000

INITIAL GUESS 1.070 0.004

N	FS	RESIDUALS	SE	PFS	ERROR
10.00	0.0200	-0.4338D-01	0.1862D-02	0.06	216.88%
15.00	0.1000	-0.2981D-01	0.8298D-03	0.13	28.81%
20.00	0.2800	0.3873D-01	0.1500D-02	0.24	-13.83%
25.00	0.4400	0.5424D-02	0.2942D-04	0.43	-1.23%
30.00	0.7600	-0.6836D-02	0.4673D-04	0.77	0.90%

BETA 1.114414 AP 0.003163 SSE 0.4287D-02

ON EXIT, THE SUM OF SQUARES IS 0.0043
AT THE POINT B= 1.114414 AP= 0.003163

TABLE 18

INITIAL GUESS 1.150 0.002

N	FS	RESIDUALS	SE	PFS	ERROR
10.00	0.0700	-0.2308D-01	0.5327D-03	0.09	32.97%
15.00	0.0900	-0.9186D-01	0.8437D-02	0.18	102.06%
20.00	0.2700	-0.1067D+00	0.1129D-01	0.33	48.31%
25.00	0.7900	0.2188D+00	0.4787D-01	0.56	-28.05%
30.00	0.8700	-0.7341D-01	0.5389D-02	0.94	8.44%

BEITA 1.102215 AP 0.004963 SSE 0.7352D-01

ON EXIT, THE SUM OF SQUARES IS 0.0735
AT THE POINT B= 1.102215 AP= 0.004963

TABLE 19

INITIAL GUESS 1.080 0.006

N	FS	RESIDUALS	SF	PFS	ERROR
10.00	0.0500	-0.8022D-01	0.6435D-02	0.13	160.44%
15.00	0.1500	-0.7340D-01	0.5387D-02	0.22	48.93%
20.00	0.2900	-0.6819D-01	0.4650D-02	0.35	24.35%
25.00	0.7700	0.2547D+00	0.6487D-01	0.52	-33.08%
30.00	0.6700	-0.1091D+00	0.1191D-01	0.74	17.32%

BEITA 1.060160 AP 0.008690 SSE 0.9325D-01

ON EXIT, THE SUM OF SQUARES IS 0.0932
AT THE POINT B= 1.060160 AP= 0.008690

TABLE 20

61

INITIAL GUESS 1.200 0.002

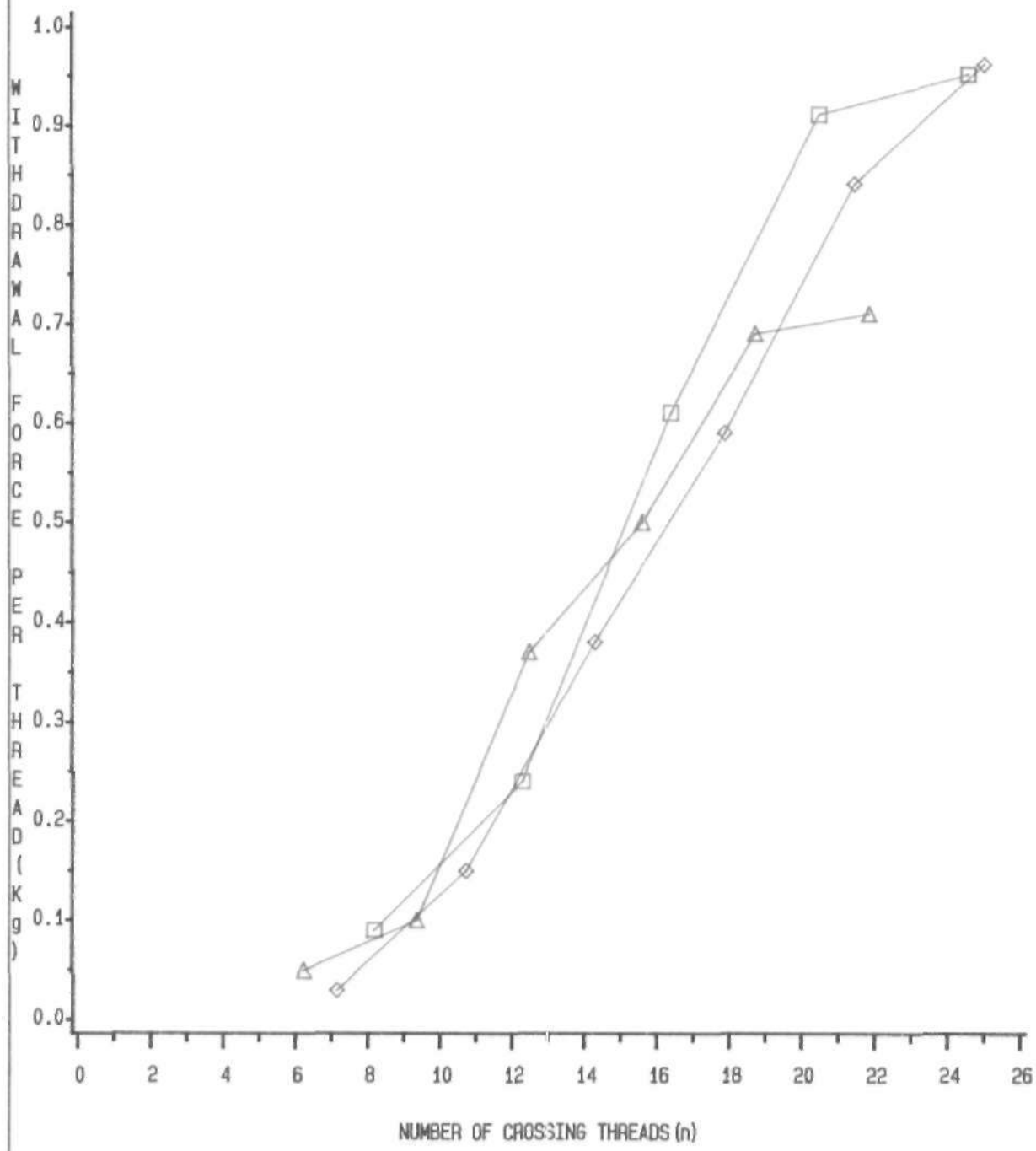
N	FS	RESIDUALS	SE	PFS	ERROR
10.00	0.0500	-0.9534D-01	0.9090D-02	0.15	190.69%
15.00	0.1700	-0.8305D-01	0.6897D-02	0.25	48.85%
20.00	0.3900	-0.1068D-01	0.1140D-03	0.40	2.74%
25.00	0.8000	0.1970D+00	0.3879D-01	0.60	-24.62%
30.00	0.7900	-0.9044D-01	0.8179D-02	0.88	11.45%

BEITA 1.065102 AP 0.009450 SSE 0.6307D-01

ON EXIT, THE SUM OF SQUARES IS 0.0631
AT THE POINT B= 1.065102 AP= 0.009450

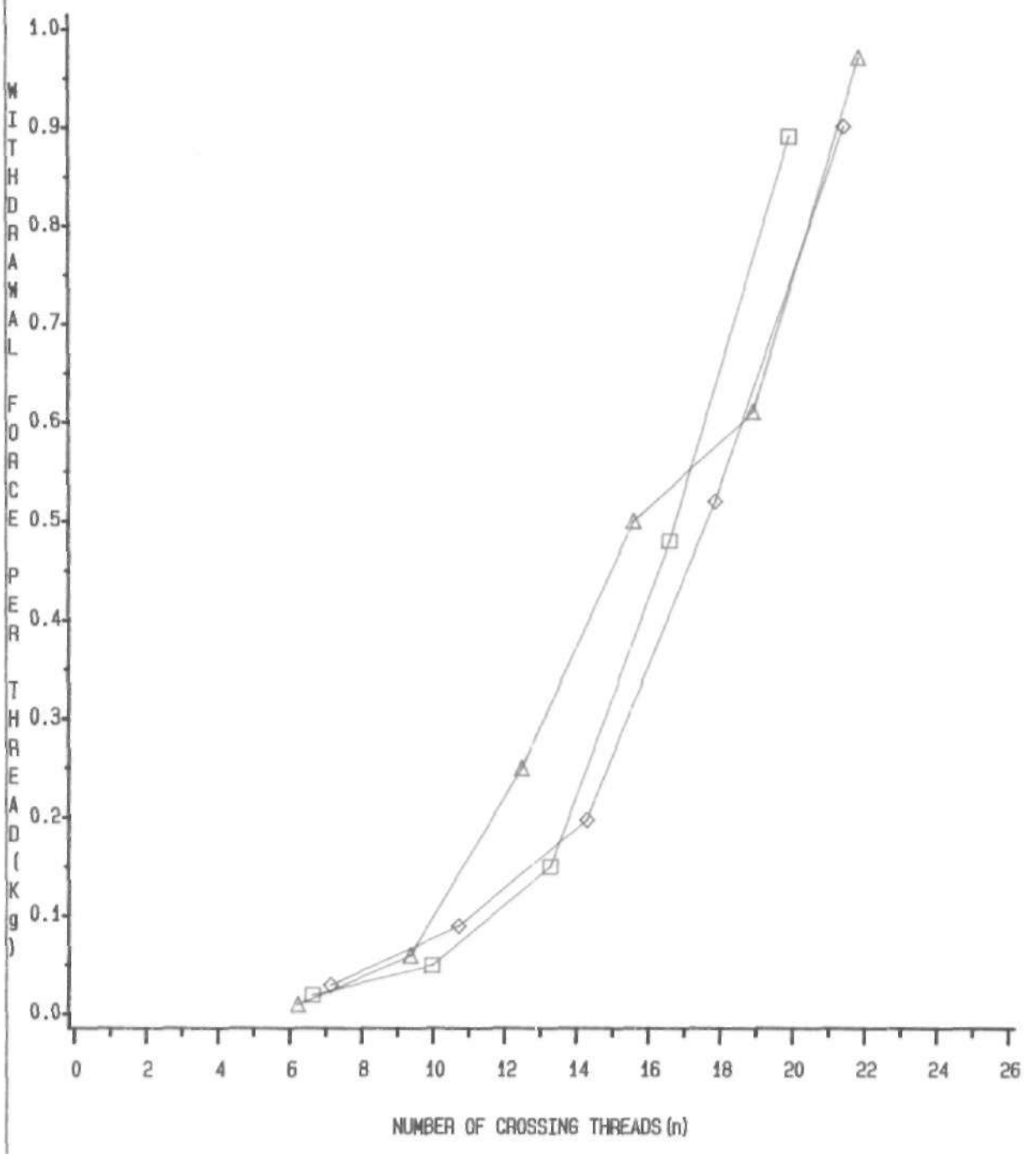
TABLE 21

FIGURE 19
EFFECT OF CROSSING THREADS ON
WITHDRAWAL FORCE IN WARP DIRECTION



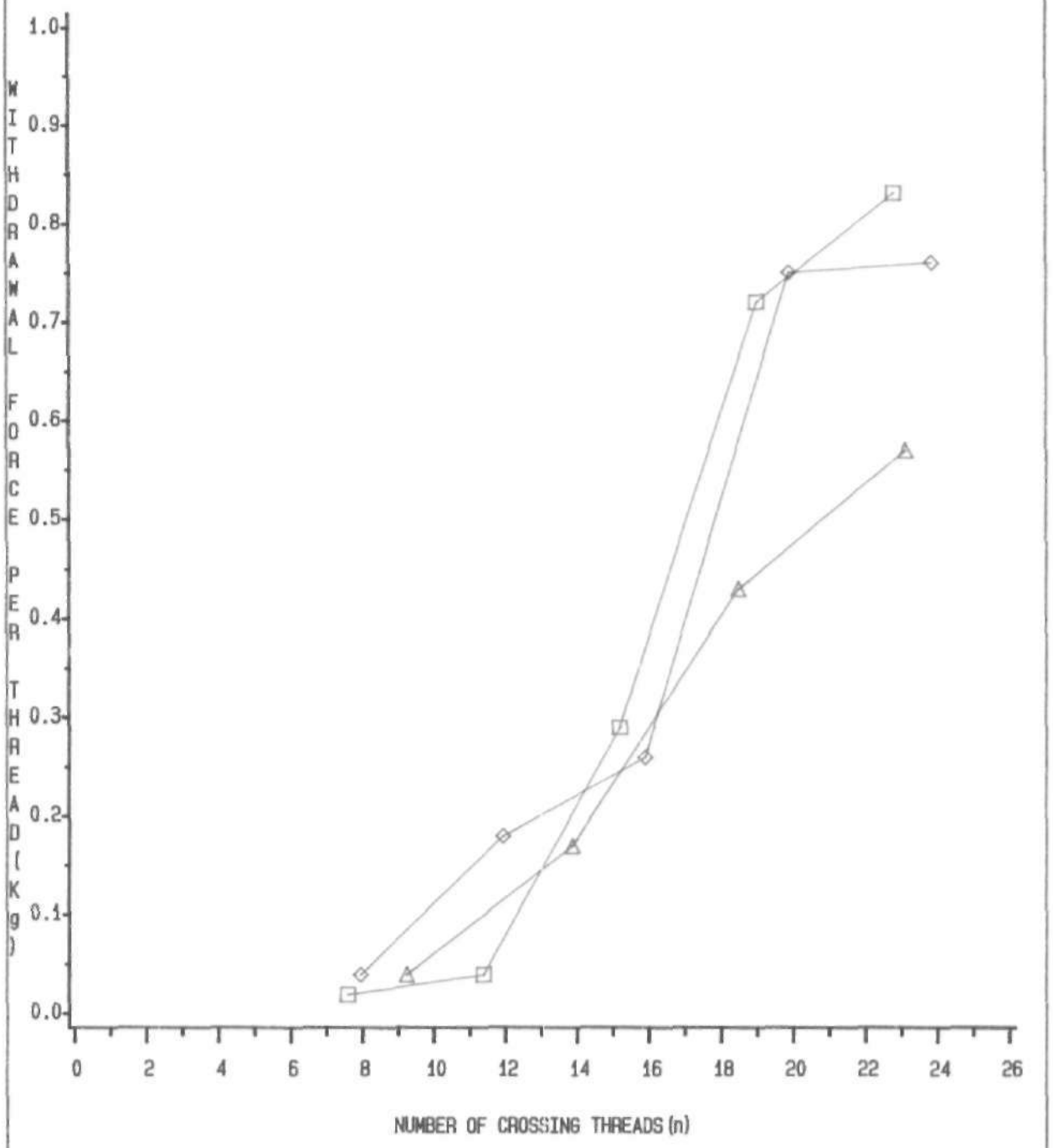
SQUARE PTS,RED=SAMPLE A
TRIANGULAR PTS,GREEN=SAMPLE B
DIAMOND PTS,BLUE=SAMPLE C

FIGURE 20
EFFECT OF CROSSING THREADS ON
WITHDRAWAL FORCE IN WARP DIRECTION



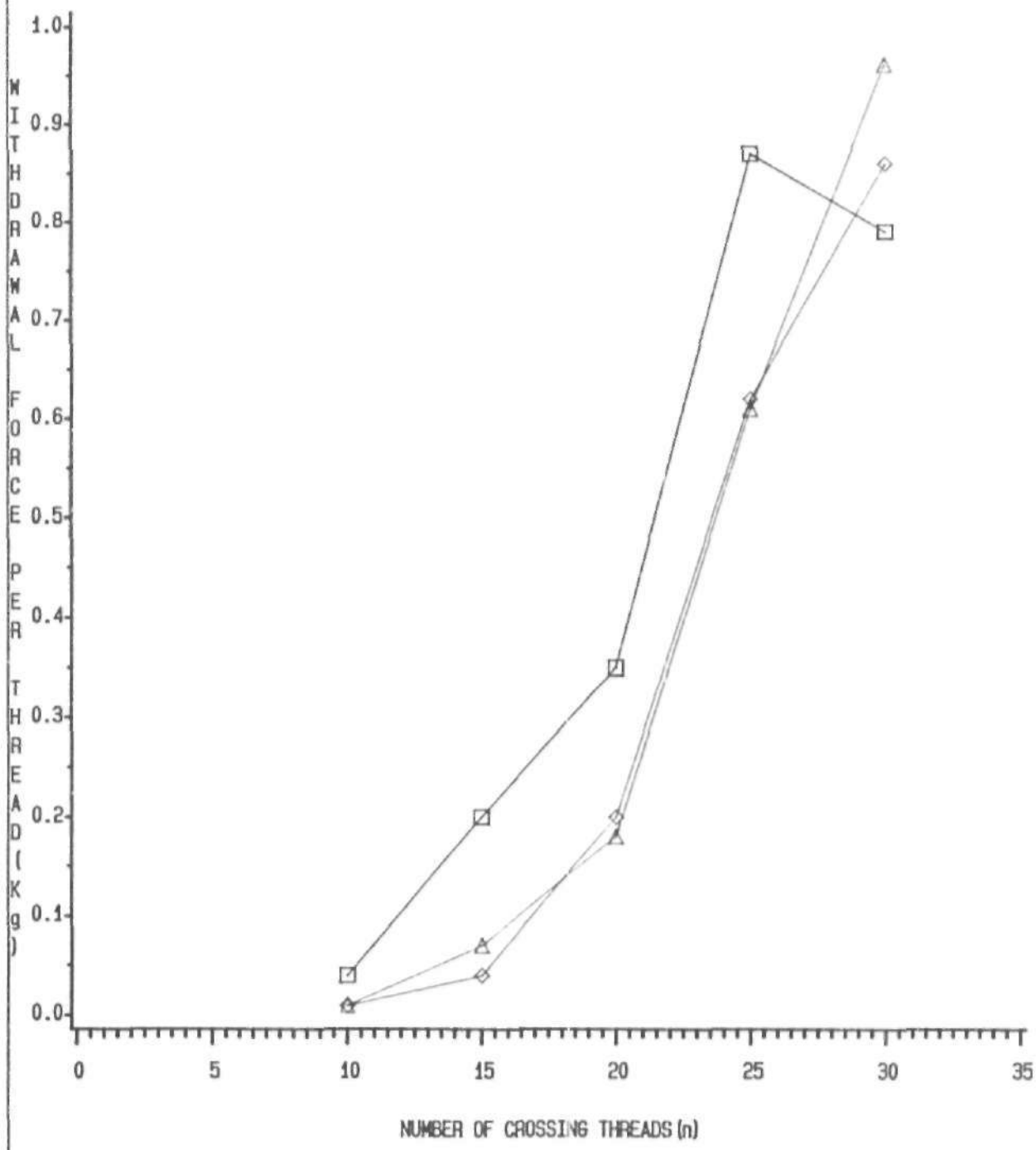
SQUARE PTS,RED=SAMPLE D
TRIANGULAR PTS,GREEN=SAMPLE E
DIAMOND PTS,BLUE=SAMPLE F

FIGURE 21
EFFECT OF CROSSING THREADS ON
WITHDRAWAL FORCE IN WARP DIRECTION



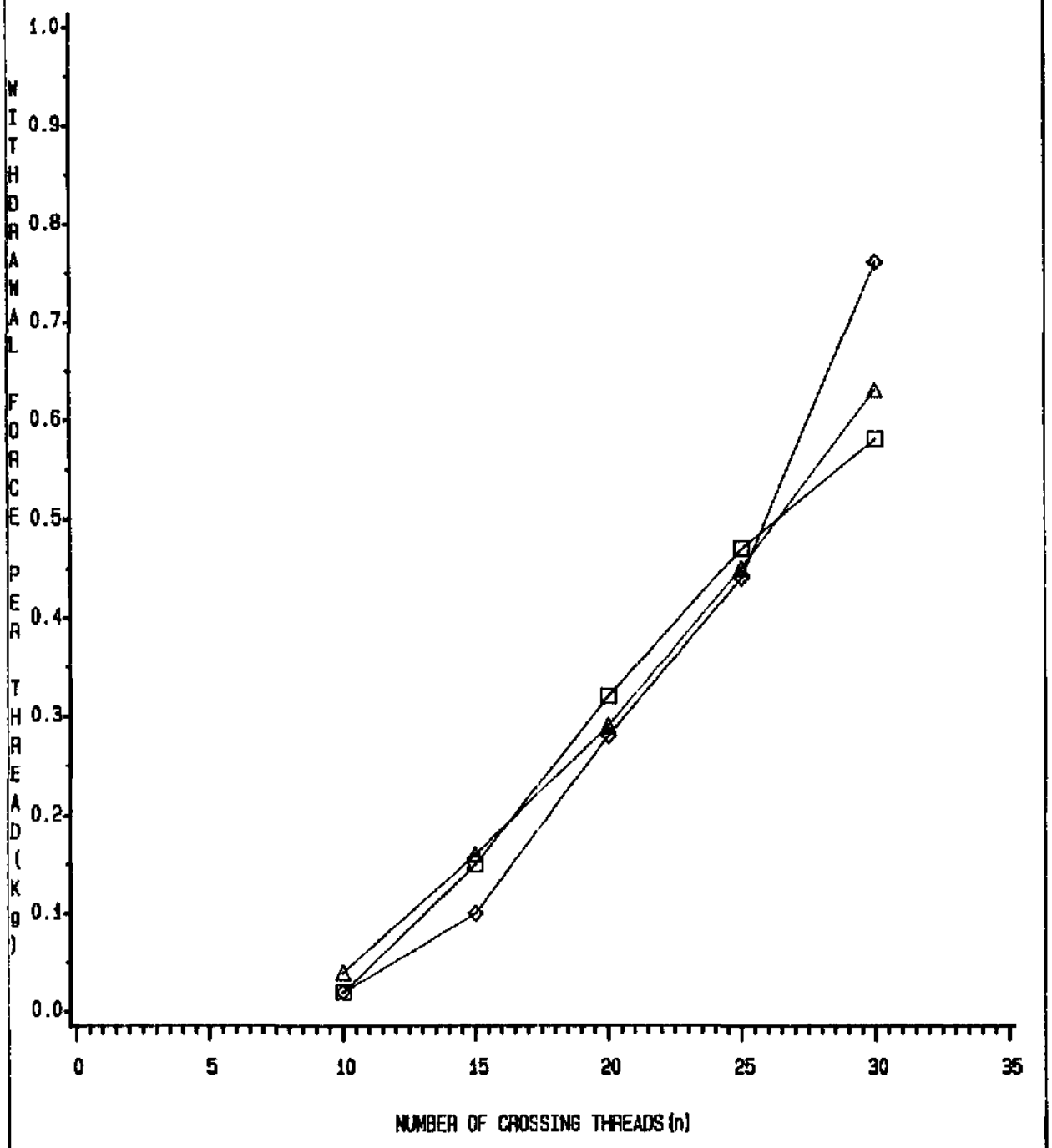
SQUARE PTS,RED=SAMPLE G
TRIANGULAR PTS,GREEN=SAMPLE H
DIAMOND PTS,BLUE=SAMPLE I

FIGURE 22
EFFECT OF CROSSING THREADS ON
WITHDRAWAL FORCE IN WEFT DIRECTION



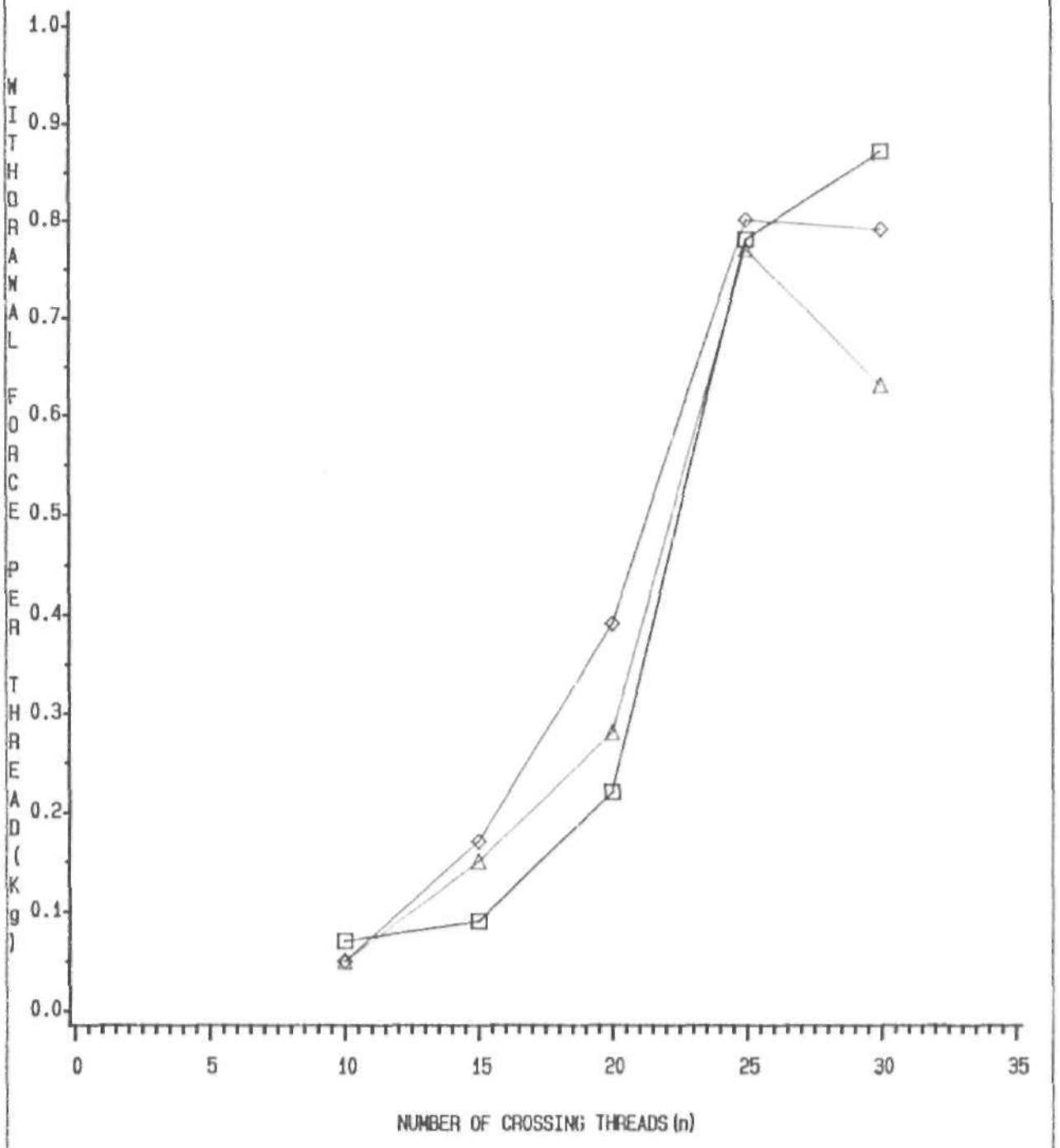
SQUARE PTS,RED=SAMPLE A
TRIANGULAR PTS,GREEN=SAMPLE B
DIAMOND PTS,BLUE=SAMPLE C

FIGURE 23
EFFECT OF CROSSING THREADS ON
WITHDRAWAL FORCE IN WEFT DIRECTION



SQUARE PTS,RED=SAMPLE D
TRIANGULAR PTS,GREEN=SAMPLE E
DIAMOND PTS,BLUE=SAMPLE F

FIGURE 24
EFFECT OF CROSSING THREADS ON
WITHDRAWAL FORCE IN WEFT DIRECTION



SQUARE PTS,RED=SAMPLE G
TRIANGULAR PTS,GREEN=SAMPLE H
DIAMOND PTS,BLUE=SAMPLE I

where SSE is the sum of squares of residuals, where a residual is the difference between the value of fs calculated from the fitted equation and the corresponding measured value, and SSF is the sum of squares of deviation of the measured fs values from their mean. A value of R^2 close to 1.0 indicates a good fit; a value close to zero indicates a poor fit.

The values of R^2, αP and β found by the computer program are shown in Tables 22-23.

Table 22

Results of the Calculations in Warp Direction

Sample	R^2	αP	β
A_1	0.85	0.0189	1.06
B_1	0.90	0.0151	1.07
C_1	0.95	0.0131	1.08
D_1	0.97	0.00191	1.26
E_1	0.97	0.00690	1.14
F_1	0.96	0.00385	1.19
G_1	0.89	0.00600	1.14
H_1	0.50	0.0167	0.998
I_1	0.80	0.00113	1.22

Table 23

Results of the Calculations in Weft Direction

Sample	R^2	αP	β
A_2	0.824	0.0098	1.06
B_2	0.97	0.0022	1.14
C_2	0.94	0.0027	1.13
D_2	0.94	0.0066	1.06
E_2	0.98	0.0057	1.08
F_2	0.99	0.0032	1.11
G_2	0.88	0.0050	1.10
H_2	0.76	0.0087	1.06
I_2	0.87	0.0095	1.07

It will be seen that all values of R^2 are greater than 0.8 with the exception of fabric H, for which R^2 = 0.5 in table 22 and with the same fabric having the lowest value of R^2 = 0.76 in Table 23. Apart from fabric H, therefore, Taylor's equation seems to fit the experimental data reasonably well and sometimes very well (e.g. fabrics D, E, F in table 22, where the value of R^2 = 0.97 and fabrics B, E, F in table 23 having values of R^2 equals 0.97, 0.98 and 0.99 respectively.

Analysis of αP and β

One would expect the values of αP and β to be associated with the fabric structure. αP, for example, is a force between the thread being pulled out and the crossing threads. β is associated with the change in tension in the pulled out thread as it passes over a cross thread and might therefore be related to $e^{2\mu\theta}$, where θ is the weave angle of the fabric and μ is the frictional coefficient between yarns. We examine these possibilities below.

αP

Pierce's rigid thread model[9] of a plain woven fabric is shown in Figure 25. The force between the two threads is distributed over the contact region but may be assumed to have a resultant perpendicular to the fabric plane of magnitude $2V_1$. Pierce shows that

$$V_1 = \frac{8\ \beta_1\ \sin\ \theta_1}{P_2{}^2}$$

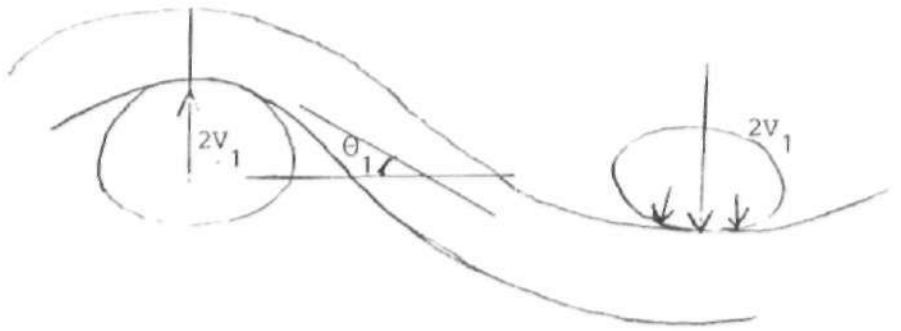


FIG. 25

where

β_1 is the warp flexural rigidity

θ_1 is the warp weave angle

P_2 is the weft thread spacing

If we put $n_2 = {}^1/P_2$ = the number of weft threads per unit length, this equation may be written

$$V_1 = (8 \beta_1 \sin \theta_1) n_2^2$$

If we assume that $\alpha P = K'V_1 = (8 K'\beta_1 \sin \theta_1) n_2^2 = Kn_2^2$ - (A) say, where K is approximately constant. The values of αP are plotted against those of n_2^2 as shown in Figure 26 and the values of n_2 are given in Table 1. While it can be seen that the relationship is not very good, there is a tendency for the points to trend upwards as would be expected from equation (A). Obviously more work is needed to confirm or deny this conclusion.

B

Figure 27 shows Pierce's flexible thread model of the plain woven fabric, from which it can be seen that the angle of wrap of the warp over the weft threads is equal to $2\theta_1$, where θ_1 is the warp weave angle. Hence, using the well-known Capstan equation

$$To = Ti\ e^{2\mu\theta_1}$$

where Ti is the input tension to the Capstain and To is true output tension. In his analysis Taylor assumes that

$$To = \beta\ Ti$$

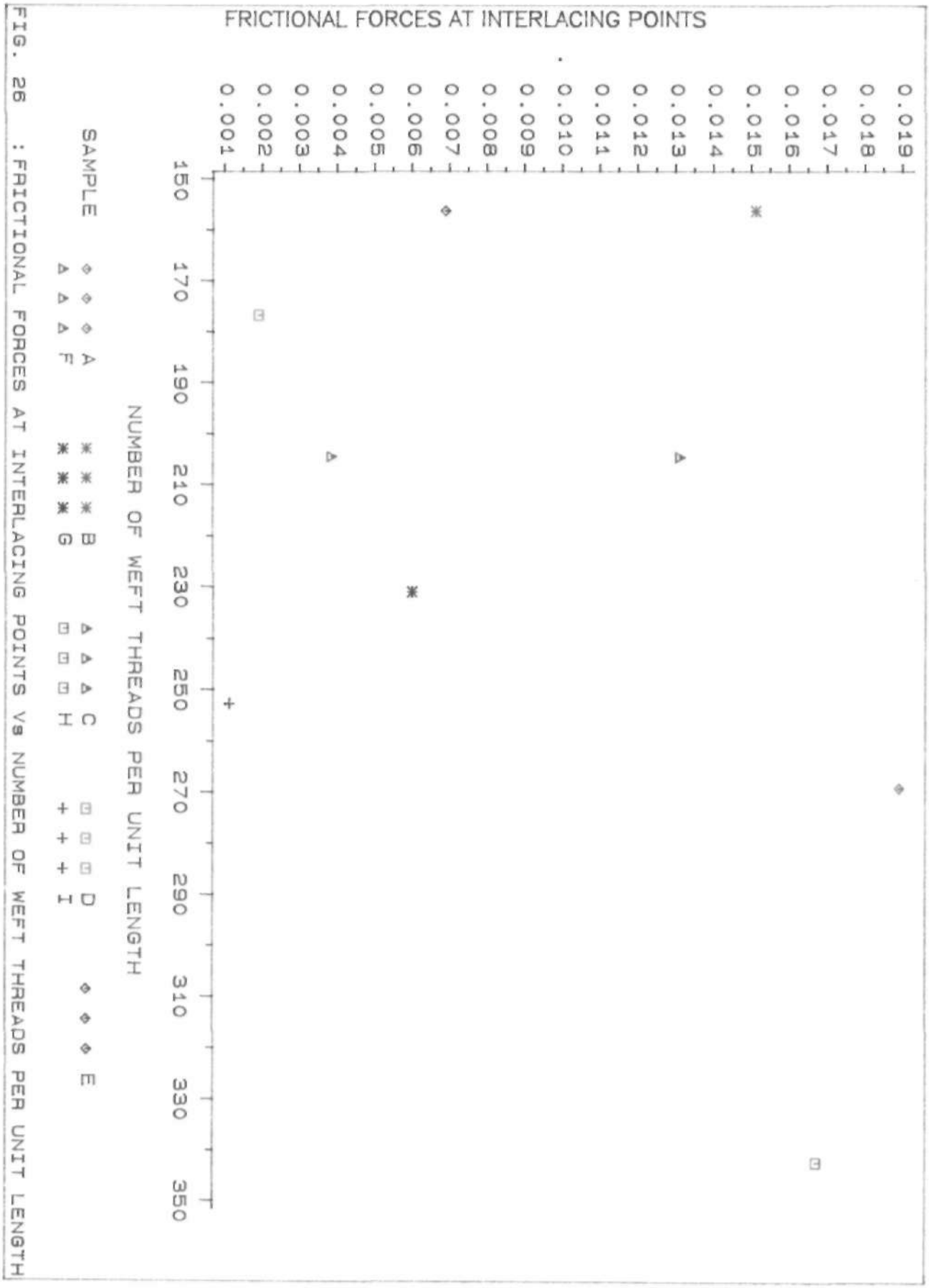


FIG. 26 : FRICTIONAL FORCES AT INTERLACING POINTS Vs NUMBER OF WEFT THREADS PER UNIT LENGTH

FIG. 27

so that β may be expected to be related to $e^{2\mu\theta}$. Suppose we assume

$$\beta = A\, e^{2\mu\theta_1}$$

so that

$$\ell n\, \beta = \ell n\, A + 2\mu\theta_1 \quad - \quad (B)$$

and thus a plot of $\ell n\, \beta$ against θ_1 would be expected to show a linear relationship between the two. Pierce shows that

$$\theta_1 \sim \sqrt{2C_1} = 1.41\sqrt{C_1}$$

where C = crimp of a yarn.

An experiment was carried out to measure the crimp in yarns taken from each woven fabric sample. The Shirley crimp tester was used for the experiment. This tester comprises of a ruler and two spring loaded clamps, one of which is mounted on a pivoted lever, by which the tension in the yarn may be adjusted.

The procedure involves laying the conditioned fabric samples flat, free from tension and creases. A rectangular strip of 50 cm by 2.5 cm along the direction of both warp and weft threads was marked and accurately cut for each of the fabric samples.

The tension device attached to one of the yarn clamps was set to the tension appropriate to the yarn linear density. Ideally, this tension would be one which removes all crimp without extending the thread, but this will rarely be possible. Consequently a table of tensions[10] has been provided as a guide with the aim of striking a balance between some inevitable extension and the incomplete removal of crimp.

By means of a dissecting needle, the threads were gently removed individually and held firmly to prevent any loss of twist. An end of the thread was inserted into one of the clamps of the tester so as to make the end flush with the mark on the perspex top. Next, the other end of the thread was carefully inserted without tension in the other clamp, again making the end flush with the datum line on the perspex. Then the moveable clamp was shifted away from the pivoted clamp. As the thread becomes taut, the lever will be pulled from its rest position. The clamp is slowly moved until the pointer on the pivot is exactly opposite the indicator line. The scale reading of the instrument at the line on the foot attached to the moveable clamp support was then recorded. This gives the straightened length of the yarn. This experimental procedure was repeated on ten (10) successive threads for warp and weft threads for all the fabric samples. The mean thread length was calculated with the initial length of 50 cm. The crimp was then calculated using the relationship

$$C_1 = {}^{\ell}/P_2 - 1$$

The results of the tests are shown in the following tables 24 and 25 for warp and weft respectively.

Table 24

	ℓ_1	P_2	C_1	θ_1	$\ell n\beta$
A	52.02	50.0	0.0404	0.28	0.058
B	51.53	50.0	0.0306	0.25	0.068
C	51.69	50.0	0.0338	0.26	0.077
D	51.28	50.0	0.0256	0.23	0.231
E	51.97	50.0	0.0394	0.28	0.131
F	52.46	50.0	0.0492	0.31	0.174
G	51.78	50.0	0.0356	0.27	0.131
H	52.68	50.0	0.0536	0.32	0.002
I	52.13	50.0	0.0426	0.29	0.199

Table 25

	ℓ_1	P_2	C_1	θ_1	$\ell n\beta$
A	51.09	50.0	0.0218	0.207	0.027
B	50.62	50.0	0.124	0.156	0.059
C	50.99	50.0	0.0198	0.197	0.053
D	50.72	50.0	0.0144	0.168	0.027
E	51.90	50.0	0.038	0.273	0.032
F	50.77	50.0	0.0154	0.174	0.047
G	50.79	50.0	0.0158	0.176	0.042
H	51.01	50.0	0.0202	0.199	0.025
I	50.80	50.0	0.016	0.177	0.027

The results are plotted on Figures 28 and 29. According to equation (B) a straight line with a positive slope (since $\mu > 0$) would be expected and if the points for fabrics H and D in Figure 28 are neglected this expectation is fulfilled, as indicated. Why fabrics H and D do not fall on this trend is difficult to explain. The agreement between expectation and what was observed in both Figures 28 and 29 is however sufficiently good to suggest that further, and perhaps more careful, work would be justified.

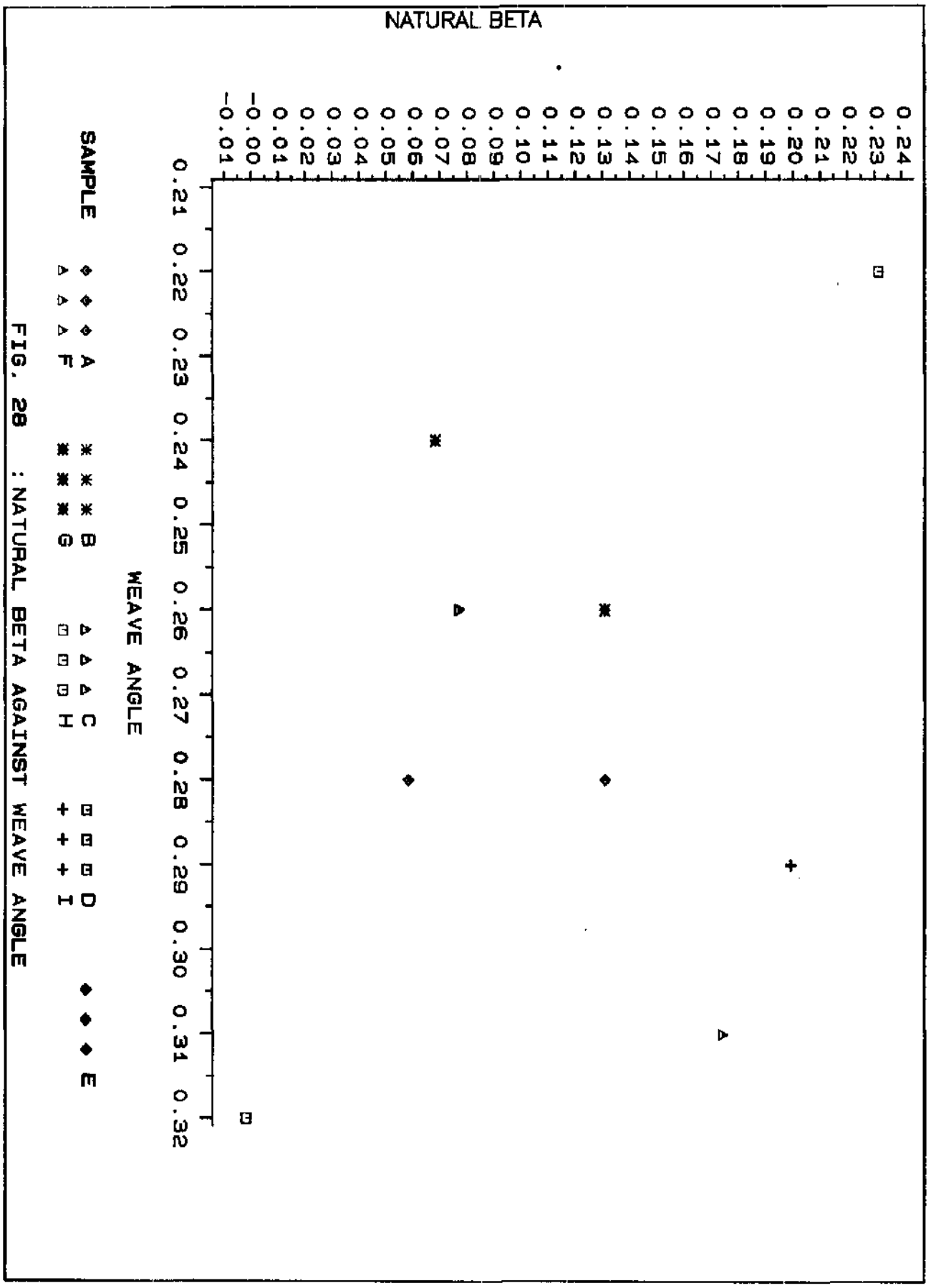


FIG. 28 : NATURAL BETA AGAINST WEAVE ANGLE

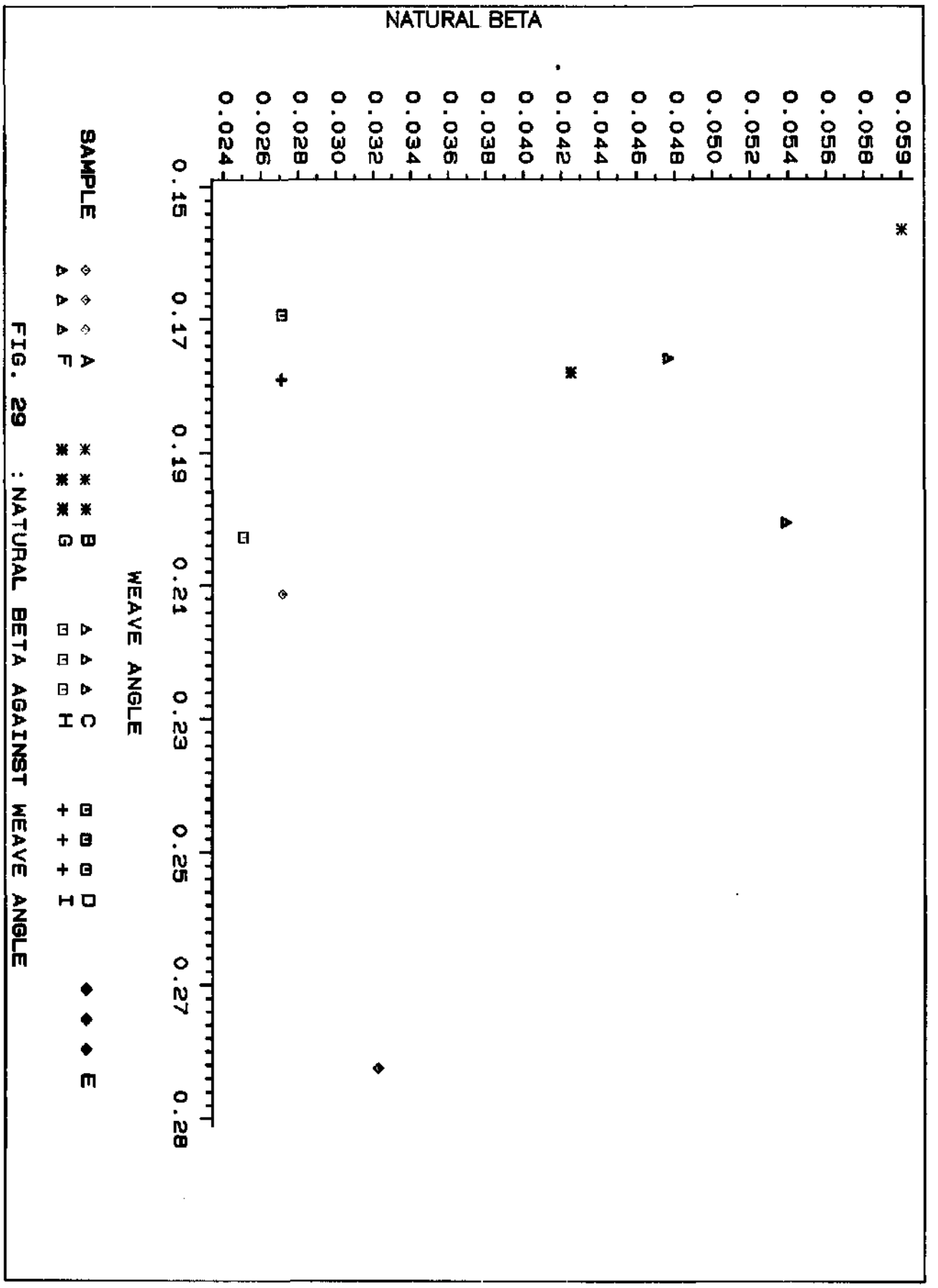


FIG. 29 : NATURAL BETA AGAINST WEAVE ANGLE

CHAPTER 8

CONCLUSION

In this dissertation Taylor's analysis of the tearing strength of fabrics is described. In his work the relationship

$$fs = \frac{\alpha P\ (\beta^n - 1)}{\beta - 1} \qquad - \quad (I)$$

is derived between the force fs needed to pull a thread out of a woven fabric, when n is the number of crossing threads the pull out thread has to negotiate, and αP and β are constants.

Several fabrics of ranging sett were woven and tests to measure fs and n were carried out on each. These data were used to test whether or not equation (I) can be used to fit such data, and a computer program was written to examine this question. It was found that, with one exception, the equation did fit the experimental data quite well, and estimates of the values of αP and β were found using the method of least squares.

The relationship between these values and the fabric structure was examined next, using Pierce's fabric models as a basis for the analysis. It was found that, with one or two anomalies, the parameters αP and β can be related to fabric structure and the tightness of weave.

In spite of the anomalies the results seem sufficiently good to suggest that further work along these lines may be justified.

REFERENCES

1. N.A. Teixeira, M.M. Platt and W.J. Hamburger, Textile Res. Journal, 1955, 25, 838-861.

2. C.M. Krook and K.R. Fox, Text. Res. J., 1945, 15, 389-396.

3. H.M. Taylor, Journal of Textile Institute, 1959, 50, T175-T187.

4. J. Skelton, "Tearing behaviour of woven fabrics" in "Mechanics of Flexible Fibre Assemblies", 243-249, ed. by John W.S. Hearle, John J. Thwaites and J. Amirbayata.

5. E.H. McAngus, W.W. Adams, "Physical Textile Testing", 47.

6. BS Handbook 11:1974, Methods of test for textiles 4/118

7. E.H. McAngus, W.W. Adams, "Physical Textile Testing" 48.

8. BS Handbook 11:1974, Methods of test for textiles 4/114.

9. Frederick Thomas Pierce, Journal of the Textile Institute, Vol. 28, 1937, T45-96.

10. BS Handbook 11:1974, Methods of test for textiles 4/96.