SAWTRI TECHNICAL REPORT

NO 177

A Study of the Forces Involved in the Withdrawal Action during Rectilinear Combing

by

De V. Aldrich and P. J. Kruger

SOUTH AFRICAN
WOOL AND TEXTILE RESEARCH
INSTITUTE OF THE CSIR

P. O. BOX 1124
PORT ELIZABETH
REPUBLIC OF SOUTH AFRICA

ISBN 0 7988 0224 3

A STUDY OF THE FORCES INVOLVED IN THE WITHDRAWAL ACTION DURING RECTILINEAR COMBING*

by DE V. ALDRICH and P. J. KRUGER

ABSTRACT

An apparatus is described which simulates the withdrawal action of a rectilinear comb, allowing the measurement of the force necessary to withdraw a tuft of fibres from a pin bed at high speed. Several factors influencing the withdrawal force were investigated, namely, withdrawal speed, pin density, number of gillings, distances between the pin rows and sliver linear density. The average withdrawal force per fibre was found, in all cases, to be well below the breaking strength of the fibres. The contribution of the withdrawal action to the fibre breakage encountered in rectilinear combing should, therefore, be small.

KEY WORDS

Rectilinear comb – withdrawal action – withdrawal force – apparatus – withdrawal speed – pin density – gillings – sliver – linear density – force per fibre – fibre breaking strength.

INTRODUCTION

The measurement of forces involved in the withdrawal of either single fibres or tufts of fibres from pinned beds or other types of fibre assemblies has attracted the attention of several authors. The basic purpose of all these investigations has been to establish the magnitude of these forces, their influence on the mechanical process concerned and the factors which influence them.

Taylor(1, 2) developed a technique of measuring drafting forces and he studied the relation between the forces and inter-fibre friction and the relation between the degree of fibre control and inter-fibre friction during drafting.

Kruger *et al*(3) investigated the force required to dab fibres into the pinned circles of the Noble comb, as well as the factors which influence it.

Borhani(4) investigated the forces exerted on the various rows of pins in the comb circle of the Noble comb during the withdrawal process. The withdrawal speeds used were, however, lower than the actual speeds used in practice. The author reported that the withdrawal force decreased with increasing temperature of the pins, withdrawal distance, number of gillings, pin density and draft at first gilling, while it increased with increasing depth of dabbing, withdrawal speed and

---

* Part of a Ph.D. Thesis submitted by De V. Aldrich at the University of Port Elizabeth

regain of the slivers. All these variables did not influence the actual pattern of the distribution of the forces on the various pin rows but only shifted the curve vertically in relation to the force axis. The form of the distribution curve of the forces on the pins of the comb circle was determined by the spaces between the rows of pins, i.e. a larger space resulted in a higher force on the row nearest the withdrawal mechanism and a smaller space produced the opposite effect. Borhani also explained the effect of the distance between the rows on the force distribution on the various rows in terms of the floating fibres behind each row. During withdrawal the moving fibres carry with them some of the floating fibres which are present between and behind each row of pins. These floating fibres are drawn forward until some are being blocked by the front row, thus increasing the force exerted on that particular row by the fibres during withdrawal.

Dyson and El-Bayoumi(5) reported on an experimental study of the factors which affect the withdrawal force of fibres from pinned beds under conditions which simulate those which occur during commercial Noble combing. The authors concluded that the forces required to withdraw a tuft from the pinned segment, were independent of the speed of withdrawal but decreased with increasing temperature of the pins, number of gillings, amount of oil up to a certain value and the viscosity of the oil. The withdrawal force was found to increase with increasing pin density, linear density of the input slivers, depth of dabbing and angle of withdrawal.

Kruger described a technique(6) to measure the force required to withdraw a tuft of fibres at a low speed from a sliver embedded in pins. Using this technique the influence of the number of gillings, draft during gilling and direction of feed on the degree of fibre parallelization during the preparation of sliver was investigated(7). It was also shown that a direct relationship between withdrawal force and percentage noil in rectilinear combing exists. Further investigations(8) showed that increasing pin densities produced significant increases in the withdrawal force, but in all cases the average withdrawal forces per fibre were well below the breaking strength of the weakest fibres in the tuft. Although the withdrawal speeds used were very low (20 cm per min), the low withdrawal forces per fibre may well indicate that fibre breakage during withdrawal in actual combing is very small.

In the work reported on in this paper, an experimental study was made of the forces encountered by fibres during withdrawal through pins under conditions which simulate those encountered during the withdrawal action in rectilinear combing. The object of this investigation was to establish the magnitude of the forces encountered by individual fibres in the tuft during withdrawal and the influence of factors like pin density, distance between the top comb and front row of the feed-gill and speed of withdrawal on the withdrawal forces.

APPARATUS AND EXPERIMENTAL PROCEDURE

Because of mechanical shocks and irregular vibrations caused by the rectilinear comb, it is difficult to measure the actual forces on the comb itself. It was, there-

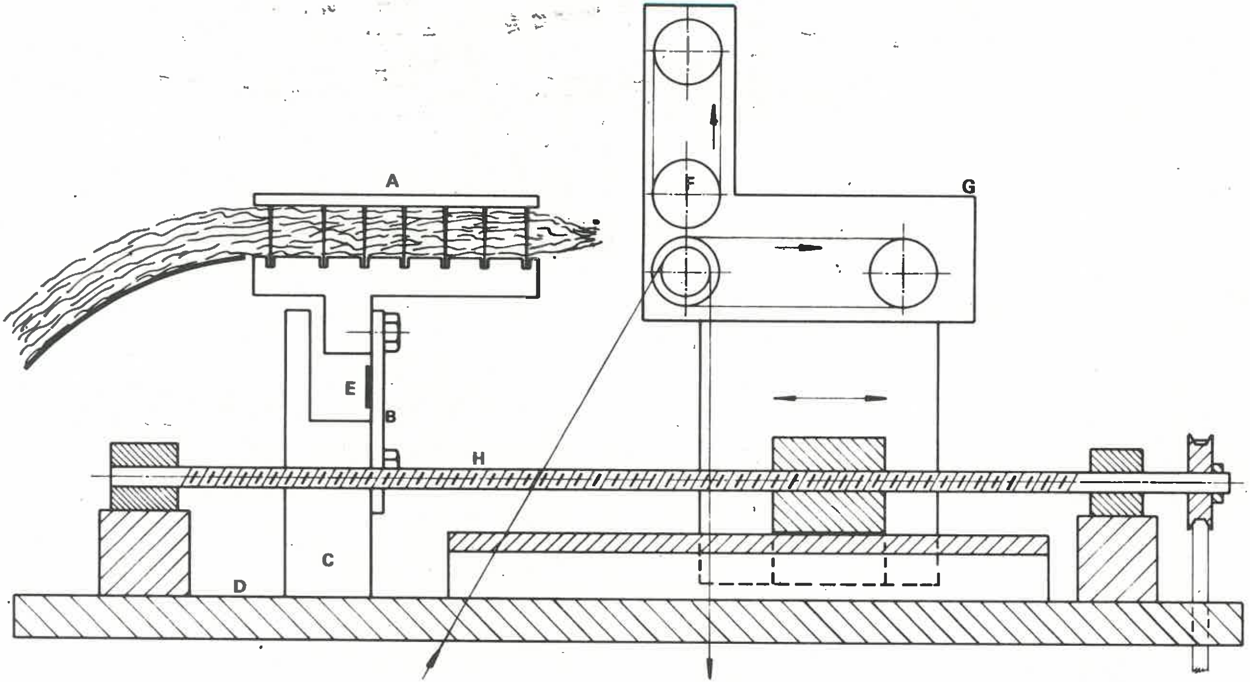


FIGURE 1

Cross-sectional Diagram of the Instrument used to measure Withdrawal Forces at High Speeds

TABLE 1

DETAILS OF THE PINNED BED (SEE FIG. 1,A)

Row No.	Pins per cm	Distance from preceding row (mm)	DIMENSIONS OF PINS (mm)	
			Thickness	Width
1 (front)	18	–	0,390	0,750
	25	–	0,326	0,735
	28	–	0,307	0,738
	30	–	0,305	0,746
2	15	9	0,410	1,020
3	15	9	0,410	1,020
4	13	9	0,460	0,910
5	13	10	0,460	0,910
6	13	12	0,460	0,910
7	10	12	0,710	(round)
8	8	12	0,910	(round)
9	8	13	0,910	(round)

fore, decided to carry out the investigations on a special apparatus built to simulate the withdrawal action of the comb. The well-known strain gauge technique of measuring forces was applied in this apparatus.

A cross-sectional diagram of the apparatus is shown in Fig. 1. The pinned bed A, which represents the feed-gill and top comb arrangement of the rectilinear comb, was mounted on two high quality steel plates, B, measuring 3 mm x 25 mm x 100 mm. These plates were, in turn, attached to two rigid pillars, C, mounted on the base, D. The pinned bed, A, containing nine rows of pins, was 120 mm wide, 90 mm long and 7 mm deep. Details of the pin rows are given in Table 1.

One strain gauge, E, was fixed to each of the two plates, B, to act as two arms of a Wheatstone bridge. The out-of-balance signal of the Wheatstone bridge, which was a measure of the applied force on the plates, B, was registered on a strain indicator and recorder. The system was calibrated by applying known forces in a horizontal direction towards the withdrawal rollers, F.

The withdrawal rollers were mounted in a carriage, G, and were driven by an electric motor (not shown). Through a suitable choice of the combination of gears driving the withdrawal rollers, the circumferential speed of these rollers could be varied in seven steps (approximately equally spaced) from 29,2 to 112,1 cm per sec. To prevent any slippage of fibres in the nip of the withdrawal rollers during withdrawal, an apron arrangement was used as shown in Fig. 1. The withdrawn tuft was collected on the horizontal apron.

The carriage, G, containing the withdrawal rollers could move horizontally to simulate the carriage of the comb. This movement was effected by a lead-screw, H, driven by an electric motor (not shown). Through a suitable arrangement of micro-switches the direction of rotation of the motor driving the lead-screw could be reversed instantaneously once the carriage had reached a predetermined point. The carriage, therefore, moved forward towards the pinned bed, reversed and stopped at a predetermined position. This reversal point was such that the nip of the withdrawal rollers was approximately 7 mm from the first row of pins. The tolerance for the position of the carriage, G, at the point of reversal of its direction was within ±0,3 mm for successive reversals.

The value of the horizontal speed of the carriage, G, quoted in this work, was the average speed over the last 6 mm of the forward movement of the carriage, G, before it reached the reversal point.

After each withdrawal of a tuft of fibres, the protruding fringe (beard) was clamped over its entire width with a suitable external clamp before the pinned bed was lifted out of the slivers. The slivers were then gently pulled forward by moving the clamp a fixed distance (6 mm) away from the pinned bed. This means that with each withdrawal, 6 mm of the protruding fringe was removed by the withdrawal rollers. This operation simulated a gill-feed of 6 mm on the rectilinear comb.

The total withdrawal force was expressed as the maximum force encountered during withdrawal per unit mass of fibres withdrawn (kilogram force per gram of

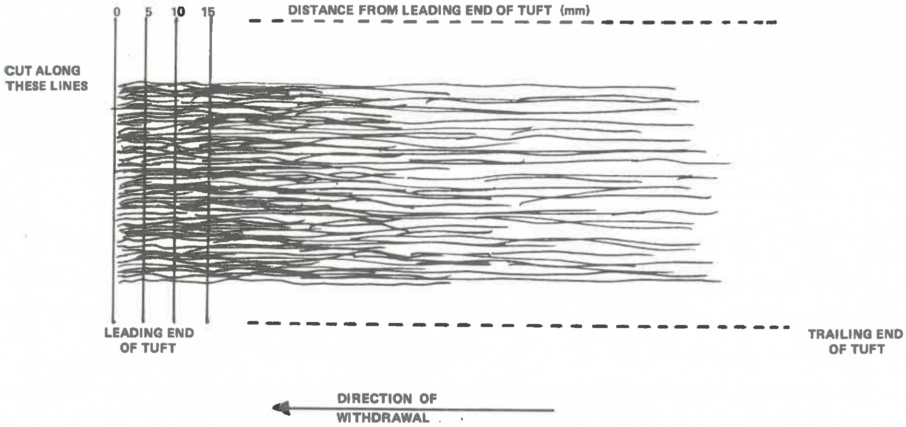


FIGURE 2

The Shape of the Tuft Illustrating the Way in which it was cut to determine the Number of Fibres in different Cross-sections

fibres withdrawn – (kgf/g)). This was done to compare the withdrawal force obtained with the present method with that of the method described by Kruger(6). In both cases the average of five measurements was taken as the withdrawal force for a particular set of conditions.

The tuft of fibres as it was delivered by the withdrawal rollers is illustrated in Fig. 2. The tufts were carefully removed from the horizontal apron and kept between layers of paper to prevent any movement of the fibres relative to each other. To determine the average withdrawal force per fibre, the tufts were cut into sections 5 mm long starting from the leading end as shown in Fig. 2. The mass of each section was accurately determined and the number of fibres in the section calculated using the formula –

$$n = 971\,547 \frac{m}{\mu^2(1 + V^2)\,L}$$

where n = number of fibres in the section
μ = mean fibre diameter in microns
m = mass of the section in mg
L = length of section (5 mm)
V = fractional coefficient of variation of fibre diameter.

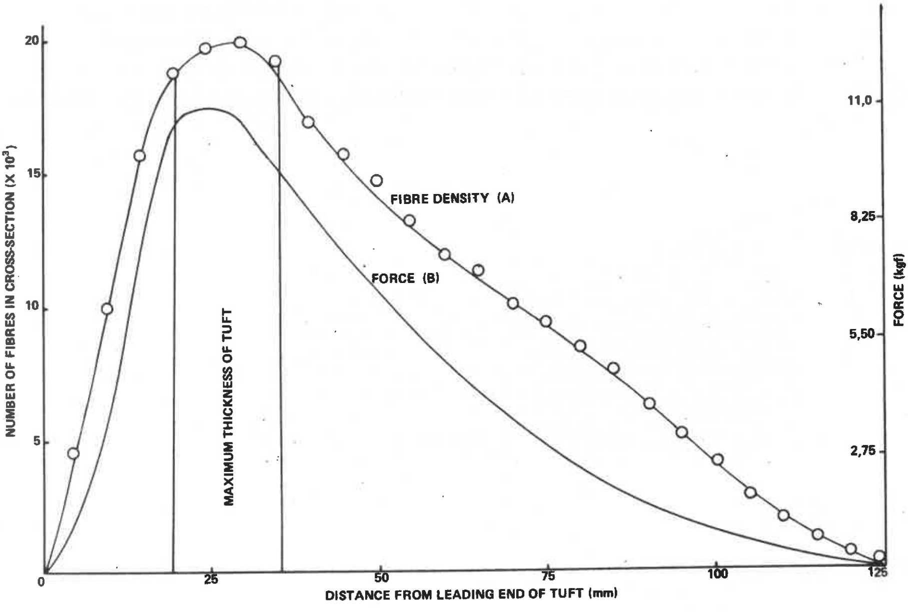
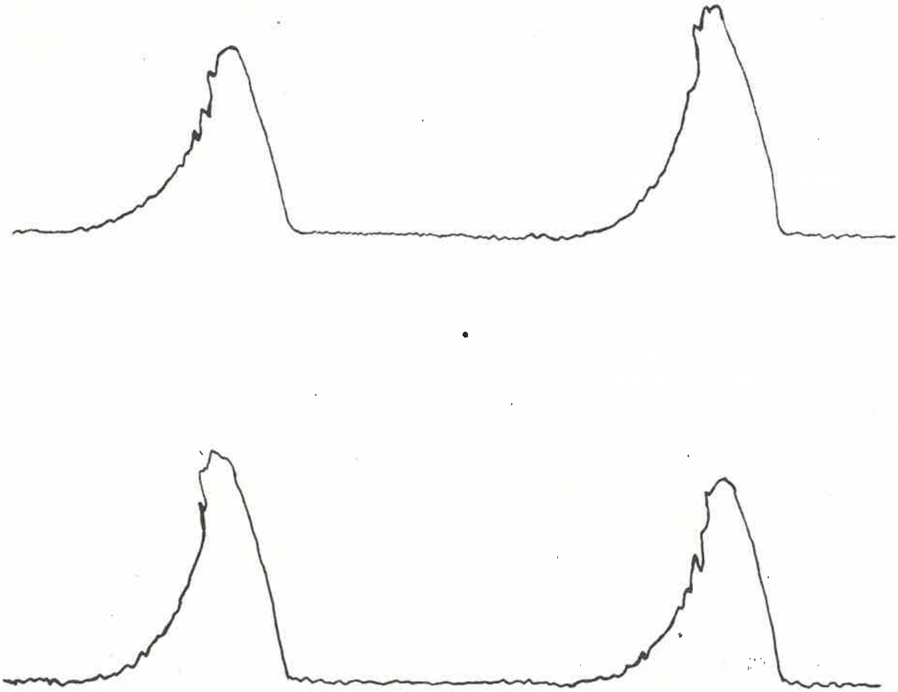


FIGURE 3

Profile of the Fibre Density in a Withdrawn Tuft and the corresponding Withdrawal Force Trace



(PAPER SPEED = 125 mm/sec)

FIGURE 4

Typical Withdrawal Force Traces as produced by a High Speed Recorder

A typical distribution of the number of fibres in the tuft is shown in Fig. 3 (curve A) while typical withdrawal force traces as produced by a high speed recorder, are shown in Fig. 4. These withdrawals were carried out at a withdrawal roller speed of 65,4 cm per sec, a carriage speed of 12,8 cm per sec, and a recorder paper speed of 125 mm per sec. The curve B in Fig. 3 was obtained when the recorder trace was enlarged to such an extent that its starting and ending points (left and right in the graph) coincided with those of curve A in Fig. 3. The short irregularities in the trace, due to background noise (mechanical vibrations), were averaged by a smooth line in curve B. It is clear from these two curves that the maximum withdrawal force is associated with that cross-section of the tuft which has the maximum number of fibres. The average withdrawal force per fibre was taken as the ratio between the maximum withdrawal force and the average number of fibres in the four 5 mm-sections containing the highest number of fibres, (sections a, b, c and d in Fig. 3).

The wool used for these investigations was a 64's quality with a mean fibre diameter of 21,3 microns and a mean fibre length of 60,5 mm in the card sliver. The dichloromethane extractable matter content was 0,8% after carding, with 1% Eutectal (0,33% dichloromethane extractable material) being added before carding.

The card slivers were gilled on an autoleveller intersecting gillbox, their direction being reversed after each process except at the first gillbox where they were fed into the gillbox in the same direction as that in which they had left the card. The trailing-end of the card sliver leaving the card was designated as the "T-end" and the leading-end as the "L-end". Normal drafts were used and the doublings were arranged to produce a sliver of 24 grams per meter after each gilling.

Four slivers were fed into the pinned bed for withdrawal force measurements, giving the same load as on the rectilinear comb, which is in the range of 7 to 9 grams per meter per cm width of the feed-gill. The direction of withdrawal is designated as T or L (Table 2) indicating that the T-end or L-end of the sliver was placed in the pinned bed respectively, and the fibres withdrawn from the same end.

TABLE 2

THE WITHDRAWAL FORCES IN DIFFERENT DIRECTIONS

Direction of Withdrawal	Number of Gillings applied	Withdrawal force (kgf/g)	Average Withdrawal force (kgf/g)	Withdrawal force* (kgf/g)	Average Withdrawal force* (kgf/g)
T	1	26,3		21,22	
L		22,1	24,2	8,70	14,96
T	2	17,7		6,51	
L		19,3	18,5	7,69	7,10
T	3	17,0		6,18	
L		16,0	16,5	6,05	6,12
T	4	15,3		5,05	
L		15,7	15,5	5,00	5,03
T	5	15,3		4,79	
L		15,1	15,2	4,70	4,74

*Withdrawal force as determined by the method of Kruger(6)

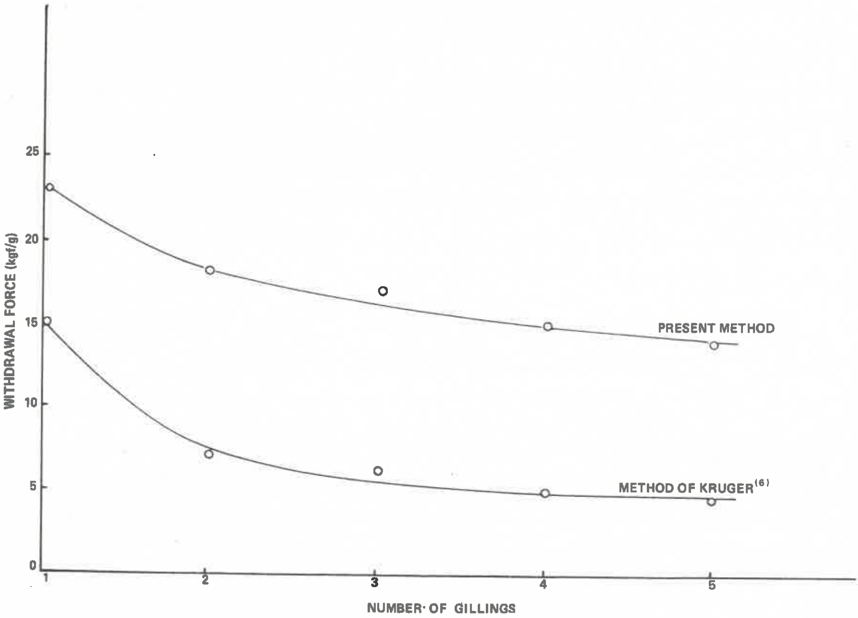


FIGURE 5

Maximum Withdrawal Force versus Number of Gillings

RESULTS AND DISCUSSION

The results on the influence of the number of gillings on the total withdrawal force as determined by the present method (given in Fig. 5) show the same tendency as do those obtained by the method of Kruger(6) (also given in Fig. 5). These results also reflect the same tendency as previous results of Kruger(7) for the case where the card slivers were fed with the L-end leading into the first gillbox and subsequent reversals after each gilling. The forces obtained with the present method were generally higher than those obtained with the method of Kruger(7). This might have been due to the higher withdrawal speed and higher pin density of the pinned bed being used.

The directional effect was only significant in the first three gillings while the effect after three gillings was almost negligible (see Table 2). This indicates that once both ends of the fibres were pulled through the pins of the fallers in the gillbox (i.e. after two gillings) the directional effect was almost destroyed and successive gillings only improved the overall alignment of the fibres.

The pin density of only the front row of pins was varied and the results at different withdrawal roller speeds are illustrated in Fig. 6. These measurements were

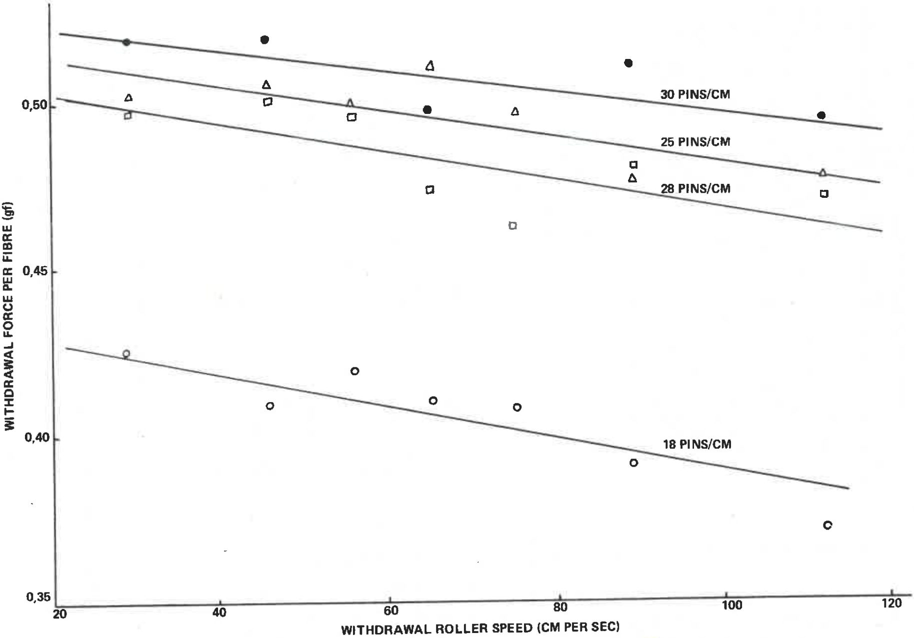


FIGURE 6

Average Withdrawal Force per Fibre versus withdrawal Roller Speed for different Pin Densities of the front Pin Row

carried out at a carriage speed of 12,8 cm per sec and with a 27 mm gap between the front and second rows of pins.

An increase in the withdrawal roller speed resulted in a decrease in the maximum number of fibres in the cross-section of the tuft. This decrease was due to the increased draft during withdrawal. The average withdrawal force per fibre, however, also decreased with increasing withdrawal roller speed. For an increase in pin density from 18 to 30 pins per cm in the front row, the average force per fibre increased by approximately 18%. The withdrawal forces obtained with pin densities of 25, 28 and 30 pins per cm did not differ much, although those for 30 pins per cm were slightly higher than those for the other two. It is, however, expected that at still higher pin densities a value will be reached from where the withdrawal force will be critically influenced by pin density. This, in fact, was indicated by Kruger(8) in his studies on withdrawal forces at low speeds. For some unknown reason 25 pins per cm resulted in a slightly higher withdrawal force than did 28 pins per cm. The scatter of the points is, however, large with the result that it is difficult to draw definite conclusions.

Using the full complement of 9 rows of pins in the pin bed the distance between the front two rows was 9 mm. On removing the second and third rows a gap of 27 mm between the front and the succeeding row was obtained. Similarly, by removing all the rows from the second to the seventh, a gap of 61 mm was obtained. The results on the influence of these three gaps on the withdrawal force per fibre are illustrated in Fig. 7. The pin density of the front row was 28 pins per cm throughout and the carriage speed 15,4 cm per sec.

Decreasing the distance between the front and second rows, increased the average withdrawal force per fibre. This increase can be attributed to the fact that with the consecutive addition of rows to the pinned bed the overall packing density of the fibres and the pressure between fibres in the spaces between the pins increased and, therefore, the total fibre-pin and fibre-fibre frictional forces also increased, which resulted in higher withdrawal forces. It can be expected that with increasing distance between the front and second rows the number of floating fibres between the two rows will increase, and this will increase the number of floating fibres to be blocked by the front row. This could have led to an increase in the force on the front row, but it was more than counteracted by the decrease in the total fibre-pin and fibre-fibre friction.

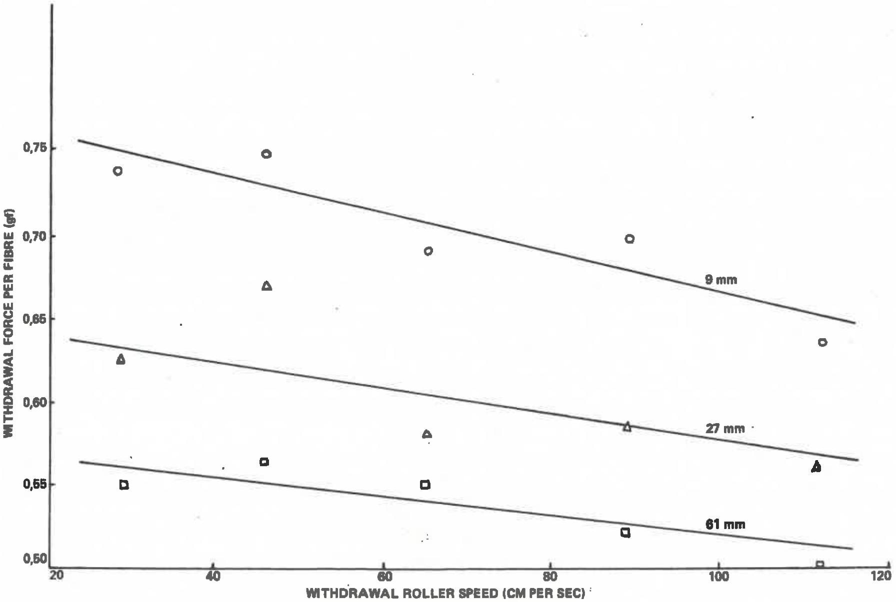


FIGURE 7

Average Withdrawal Force per Fibre versus Withdrawal Roller Speed for different Distances between front two Pin Rows

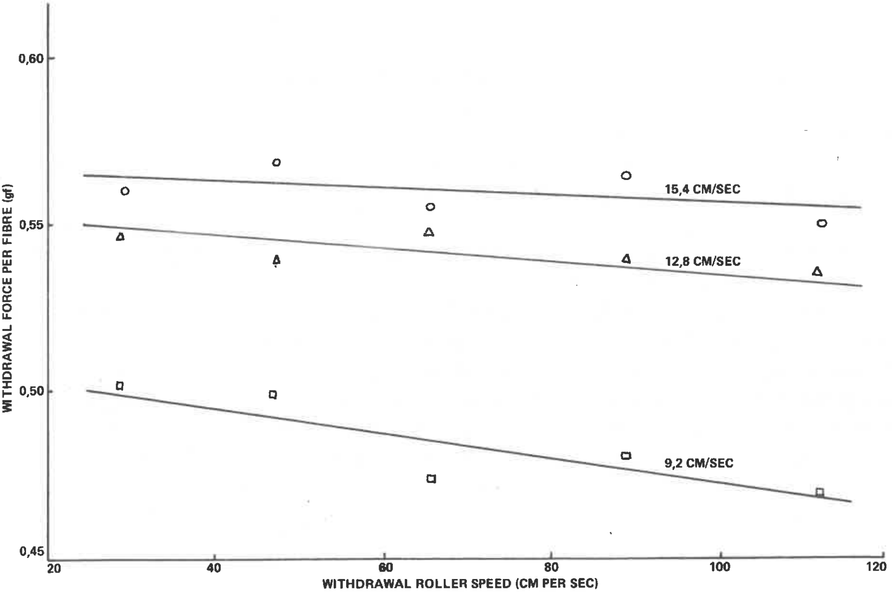


FIGURE 8

Average Withdrawal Force per Fibre versus Withdrawal Roller Speed for different Carriage Speeds

The effect of carriage speed on the withdrawal force is illustrated in Fig. 8. For these measurements the pin density of the front row was 28 pins per cm and the gap between the front and second rows 27 mm. Increasing the carriage speed caused the withdrawal rollers to "eat" into the fringe at a higher speed and to complete the withdrawal action in a shorter time. The overall effect was, therefore, that with increasing carriage speed (other factors being constant) the total number of positively moving fibres, at any moment during the withdrawal period, increased. The increase in the average withdrawal force per fibre is probably the result of increased frictional forces when a large number of fibres are withdrawn simultaneously. Floating fibres between the pin rows might have contributed to the increase in frictional forces.

The influence of total sliver mass per unit length on the withdrawal force was investigated by producing slivers of 20, 24 and 28 grams per meter during the third gilling. The total draft during the three gilling processes was kept constant, while the doublings at the third gilling were changed to produce the three different slivers. For withdrawal force measurements the front row of the pinned bed contained 28 pins per cm, the distance between the first and second row was 27 mm and the carriage speed was 12,8 cm/sec. The graphs of average withdrawal force per fibre versus withdrawal roller speed for the three slivers are given in Fig. 9. These

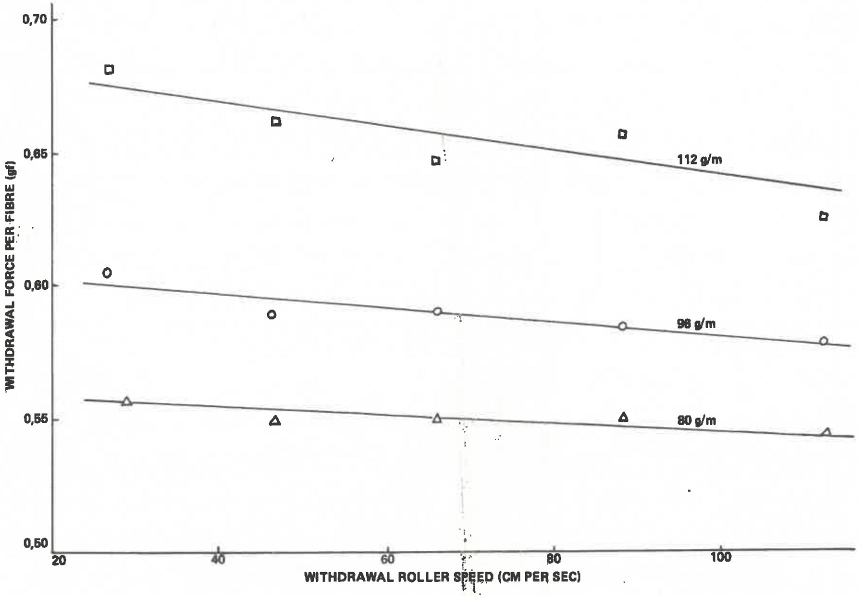


FIGURE 9

Average Withdrawal Force per Fibre versus Withdrawal Roller Speed for different total Input Sliver Masses per Unit Length

results are in agreement with those reported by Borhani(4), Dyson(5) and Kruger(7), who also found that withdrawal force increases with increasing sliver mass per unit length in their respective investigations. This increase in the average withdrawal force per fibre with increasing sliver mass per unit length can be attributed to the fact that with the resultant increase in packing density of the fibres the inter-fibre pressure and the fibre-pin pressure increase with a concomitant increase in the frictional forces.

The final, and the most important, conclusion drawn from all the results given here, is that the average withdrawal force per fibre was of the order of 0,4 to 0,7 gf. The breaking strength of the wool fibres used in this investigation was measured on an Instron Tensile Tester at a gauge length of 2 cm and an extension rate of 2 cm per min. A histogram of the breaking strength measurements is given in Fig. 10. These results indicate that only approximately 3% of the fibres tested had a breaking strength of between 2,0 and 2,5 gf, and no fibres had a breaking strength of less than 2,0 gf. The average withdrawal force per fibre of between 0,4 and 0,7 gf is, therefore, very small, when compared with the breaking strength of the weakest fibres. It is, therefore, highly improbable that any significant number of fibres will be subjected to tensile forces exceeding their breaking strength during withdrawal. On this evidence alone, hardly any fibre breakage should be en-

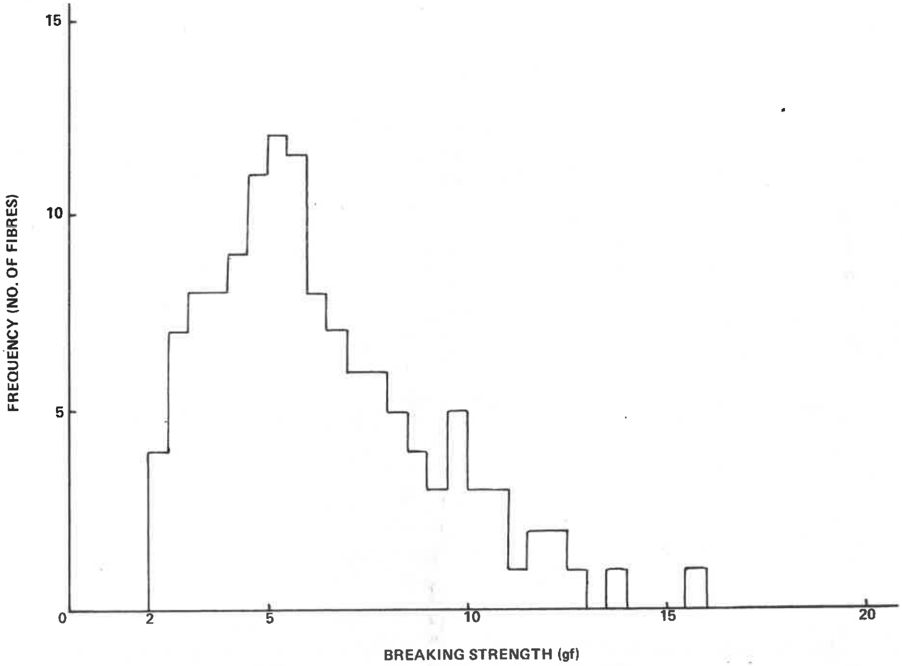


FIGURE 10

Fibre Breaking Strength Distribution for the Wool used in the Withdrawal Force Measurements

countered during the withdrawal action in rectilinear combing. The contribution of the withdrawal action to the total amount of fibre breakage in the comb, which can be as high as 40% under unfavourable conditions, should, therefore, be very small. To explain the high percentage fibre breakage in rectilinear combing, it is, therefore, necessary to consider the action of the comb cylinder, which is the only other combing action where fibre breakage can occur. This should be done in conjunction with the movement of fibres behind and through the top comb during withdrawal(9).

SUMMARY

An experimental study has been made of the forces encountered by fibres during the withdrawal action in rectilinear combing. An apparatus was built by means of which could be measured the forces necessary to withdraw at high speed a tuft of fibres from a sliver embedded in pins. The pin-bed resembled the feed-gill

and top comb arrangement of a rectilinear comb. The withdrawal force was registered on a pen-recorder by means of strain gauges, which were arranged in a bridge circuit.

It was found that the average withdrawal force per fibre increased with:

(i) decreasing number of preparatory gillings;
(ii) decreasing withdrawal roller speed, i.e. a decreasing draft between the pin bed and the withdrawal rollers;
(iii) increasing speed of the carriage, i.e. decreasing the time in which the withdrawal action is completed;
(iv) increasing pin density;
(v) decreasing distance between the first and the consecutive pin rows, which increase the packing density of the fibres and consequently the frictional forces;
(vi) increasing linear density of the slivers.

The results on the influence of number of preparatory gillings, pin density and linear density of the slivers on the withdrawal force, show the same tendencies as do those found by Borhani(4), Dyson *et al*(5) and Kruger(7), for their respective methods.

For the range of variables studied, the average withdrawal force per fibre was found to fluctuate between a maximum and a minimum value of 0,7 and 0,4 gf respectively. Comparing this force with the breaking strength of single fibres, the average withdrawal forces per fibre were much smaller than the fibre breaking strength. Considering these results, only, it is concluded that hardly any fibre breakage should occur during the withdrawal action in rectilinear combing.

ACKNOWLEDGEMENTS

The authors wish to record their thanks to Misses L. Oosthuizen and Y. A. Mannell for the excellent manner in which they have carried out the measurements. Thanks are also due to the Divisions of Carding and Combing, and Statistics for their assistance in preparing the samples and analysing the results. Finally the authors wish to thank the S.A. Wool Board for permission to publish the results of this investigation.

THE USE OF PROPRIETARY NAMES

The fact that chemicals with proprietary names have been mentioned in this report, does not in any way imply that SAWTRI recommends them or that there are not substitutes which may be of equal value or even better.

REFERENCES

1. Taylor, D. S., The Measurement of Fibre Friction and its Application to Drafting Force and Fibre Control Applications, *J. Text. Inst.* **46**, P59, (1955).
2. Taylor, D. S., Drafting Force and its Relation to Fibre-Fibre Friction, *J. Text. Inst.* **48**, T466 (1957).
3. Kruger, P. J., Onions, W. J. and Townend, P. P., Factors Influencing Dabbing of Fibres into Pins, *J. Text. Inst.* **55**, T192, (1964).
4. Borhani, M., A Study of the Forces Generated during the Drawing-off Action in the Combing of Fibres, Ph.D. Thesis, Leeds University (1968).
5. Dyson, E. and El-Bayoumi, A. E.-A., A study of the Forces between Fibres and Pins during Relative Motion, Proc. Fourth Int. Wool Text. Res. Conf. – Part II, 1255, (1971).
6. Kruger, P. J., Withdrawal Forces in the Processing of Wool Slivers Part I; The Determination of the Withdrawal Forces, *J. Text. Inst.* 58, 463, (1967).
7. Kruger, P. J., Withdrawal Forces in the Processing of Wool Slivers Part II: The Influence of Variations of Gilling on the Withdrawal Force, *J. Text. Inst.* **58**, 472, (1967).
8. Kruger, P. J., Withdrawal Forces in the Processing of Wool Slivers Part III: The Influence of Pin Density Variations, *J. Text. Inst.* **58**, 478, (1967).
9. Kruger, P. J. and Aldrich, De V., Fibre Breakage in Rectilinear Combing, Proc. Fourth Int. Text. Res. Conf. – Part II, 1375, (1971).

Published by
The South African Wool and Textile Research Institute
P.O. Box 1124, Port Elizabeth, South Africa,
and printed in the Republic of South Africa
by Nasionale Koerante Beperk, P.O. Box 525, Port Elizabeth.