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A Review of the Relationship between Cotton Fibre Properties, Yarn Properties and Spinning Performance

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A REVIEW OF THE RELATIONSHIP BETWEEN COTTON FIBRE PROPERTIES, YARN PROPERTIES AND SPINNING PERFORMANCE

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INTRODUCTION

Technological advances in textile processing machinery have resulted in increases in production rates to levels which has not even been contemplated 30 years ago. Practical production rates of modern high-speed cards are six to seven times those of conventional cotton cards of twenty years ago. Drawframe delivery speeds have increased from a mere 100 metres per minute to speeds exceeding 400 metres per minute. The increases in flyer speed on the speedframe and spindle speed on the ringframe have not been as dramatic as those of the card or drawframe but are nevertheless significant.

Although the engineering standard of the modern high speed machines is extremely high, fibre characteristics play an increasingly important rôle in the efficient operation of these machines. Efficiency is one of the most important factors influencing the economics of any process.

The influence of fibre characteristics such as length, length variability, fineness, maturity, strength, elongation and grade, on yarn properties and spinning performance has been and still is the central theme of many studies all over the world. The interrelationship of fibre characteristics with yarn characteristics and processing efficiency is, however, a very complex one. Figure 1 illustrates this complexity.

The basic objectives of all these studies were to gain a fuller understanding of the spinning potential of existing cottons by:

(i) ranking fibre properties in their order of importance relative to yarn properties and spinning performance;
(ii) developing methods to predict yarn properties and spinning efficiency; and
(iii) providing guides so that the reduced contribution of one fibre property can be compensated for by another and still maintain particular yarn properties.

Cotton, being an agricultural product, is subject to environmental and varietal variation in its important fibre characteristics. Data on the influence of these variations in fibre characteristics on yarn characteristics and spinning efficiency are spread over a multitude of Journals, Bulletins, Reports, Proceedings of Conferences, etc. It is, therefore, a formidable task for someone in the cotton textile industry, but working outside the research field, to obtain all these data.

It is, therefore, the object of this survey to collect as many as possible of these data from the available literature. This paper reviews some of the results of twenty-five years' research on the effect of cotton fibre properties on yarn and fabric properties and on textile processing efficiency. It is hoped that the informa-

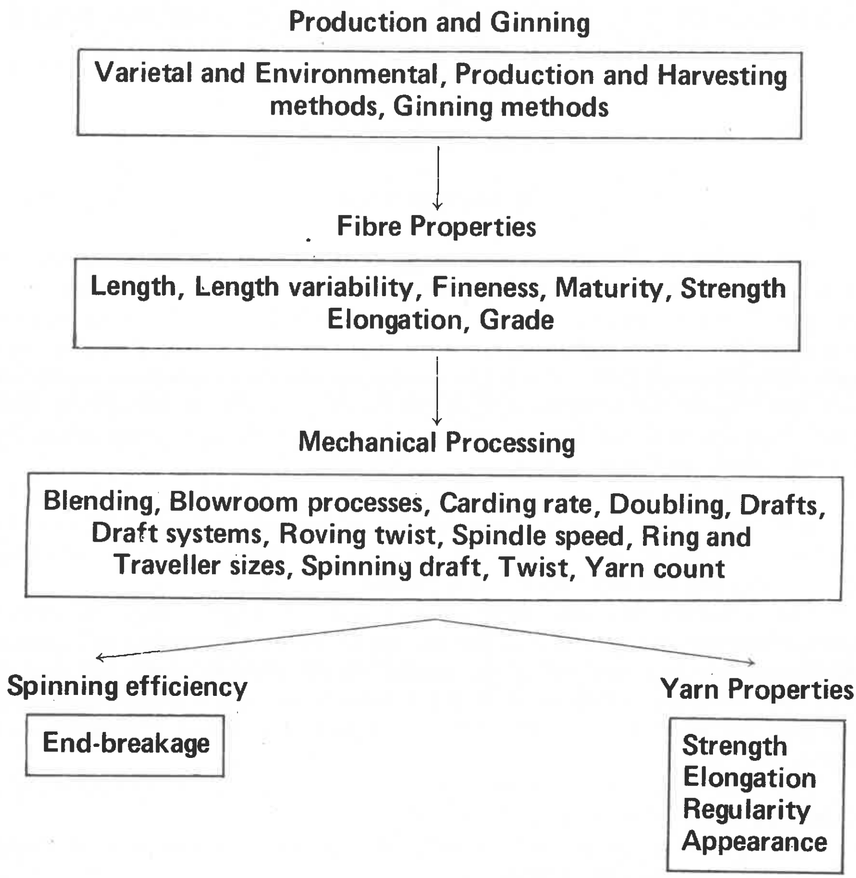

FIGURE I

A diagram illustrating the Complex Interrelationship between Fibre Properties, Yarn Properties and Processing Efficiency

tion contained in this paper will be of interest and benefit to cotton breeders as well as spinners. The fact that more than 75% of the 65 publications reviewed were of American origin does not mean that they were given any priority above publications from other origins. It was merely a case of research publications on cotton of American origin being more numerous compared with publications from other countries. Only English language publications were considered, but although this might have lead to the exclusion of some publications, these are considered to be relatively few.

FIBRE LENGTH CHARACTERISTICS

A single measure of length, known as the classer's length or staple length has long been regarded as the best criterion for evaluating a cotton's spinning potential. Other techniques, however, exist today which will give more information of the fibre length characteristics of a particular sample of cotton. Fibre length characteristics commonly quoted today are: mean length, 2,5% span length, effective length, uniformity ratio and percentage short fibres (by number and by mass). Fibre length has long been recognised as one of the major characteristics to be considered for the efficient utilisation of a particular cotton cultivar and is reported to be the principle determinant of yarn strength and of the finest count that can be spun from a cotton(1).

Data presented by Gangli(2) indicate an average increase of 0,9% in yarn strength for every one *per cent* increase in Balls staple fibre length (in the range 25 to 40 mm). Gangli also reported that in the case of staple length and yarn uniformity (U%) higher correlation coefficients were obtained when quadratic curves were fitted to the results. This means that the rate of decrease in yarn uniformity with increasing staple length was much less for longer cottons than for shorter cottons.

It is well-known that cottons having the same classer's length may have different fibre length *distributions*, since some cottons have significantly more short fibres than others. The effect of short fibre content on the quality of cotton yarns has been extensively investigated by various researchers(3—6).

By studying 43 cottons, Fiori *et al*(3) found that the percentage by mass of fibres less than 9 mm ($\frac{3}{8}$ inch) varied from 2,5% to 12,5% i.e. by as much as five times. It should, therefore, be noted that the short fibre content of commercial cottons may vary over a much wider range than any other important fibre property. Although the maximum of 12,5% was observed in cotton ginned prior to 1954, there is increasing evidence that new ginning practices necessitated by mechanical harvesting have led to increased fibre breakage and a consequent further increase in short fibre content(4). Although the short fibre content of the above cottons changed from 2,5% to 12,5%, the length coefficient of variation changed only from 22% to 37% i.e. by a factor of 1 to 1,7. Coefficient of variation is therefore relatively insensitive to variations in short fibre content.

Kohler(5) indicated that the "length of slippage" at the rupture point of a yarn is approximately 8 mm. By this he meant that fibres with a length of 8 mm or less are likely to slip rather than break when a yarn ruptures. Hence, these short fibres cannot contribute much to the strength of the yarn.

Wakeham(6) reported on four case histories demonstrating the inferior quality of cottons containing excessive quantities of short fibres. The results showed the effects of improper drying prior to ginning, overprocessing during cleaning and microbiological attack on fibres on yarn quality and processing performance. Not one of several cotton classers was able to distinguish between samples from cotton that was ginned at 6% and 3,7% moisture content. Very small differences in mean fibre length and uniformity ratio were detected for these two cottons but fibre length distribution studies showed a significant increase in short fibre content for the "dry" ginned (3,7% moisture) cotton. This was reflected in the higher waste production, less uniform rovings and yarns and 21% more ends-down in spinning for the "dry" ginned compared with the "wet" ginned cotton.

The importance of fibre length distribution has been delineated further by a series of investigations[7–10] in which the cotton was specially ginned, using the differential ginning technique, so as to produce cottons having different fibre length distributions and short fibre contents. All the experimental lots were produced from one lot of Acala 44 seed cotton having a staple length of approximately 27 mm ($1\frac{1}{16}$ inch) and the short fibre content [*per cent* by mass less than 9,5 mm ($\frac{3}{8}$ inch)] varied from 4% to 19% for the different lots. All the cottons were spun into 16, 27 and 42 tex yarns and where feasible over a range of twist constants* from 33,5 to 55,0 (3,50 to 5,75). Pilot scale spinning on standard commercial equipment corroborated and supported the findings of earlier work in this series when "miniature spinning techniques"[8] were used. The effect of increasing short fibre content on the characteristics of yarns can be summarised as follows: Increases in short fibre content resulted in decreased yarn strength (these decreases being in excess of 1% in tenacity for each 1% increase in short fibre content by mass), decreased yarn elongation at break, and deterioration in yarn appearance and decreased uniformity. These findings are supported by those of Waters and Phillips[11].

The simultaneous losses in yarn tenacity and elongation at break seem serious when the product of tenacity and elongation is considered[9] since this product is proportional to the toughness or energy required to rupture. The decrease in toughness amounted to almost 50% between yarns with lowest and highest short fibre content. It was speculated that this effect would be important in the utilisation of such yarns in fabrics to be treated with resin, since such a finishing treatment usually entails further strength and elongation losses.

The findings of Tallant *et al*[9, 10] on the relationship between short fibre content (for staple lengths 26 to 27 mm – $1\frac{1}{16}$ to $1\frac{3}{32}$ inches) and spinning efficiency showed the existence of an extremely complex pattern due to the strong interaction of certain processing variables such as spinning tension, spindle speed and yarn size. Twist constants played an important part in the number of end-breaks in spinning for a particular short fibre content. At a low twist constant [35,9 (3,75)] cottons with more than 10% (by mass) of fibres shorter than 9,5 mm ($\frac{3}{8}$ inch) produced an exceptionally high number of end-breaks in spinning,

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*Twist constants are defined throughout as:

Twist constant = t.p.cm × $(\text{tex})^{\frac{1}{2}}$

Twist factors based on English cotton count system are given in parenthesis.

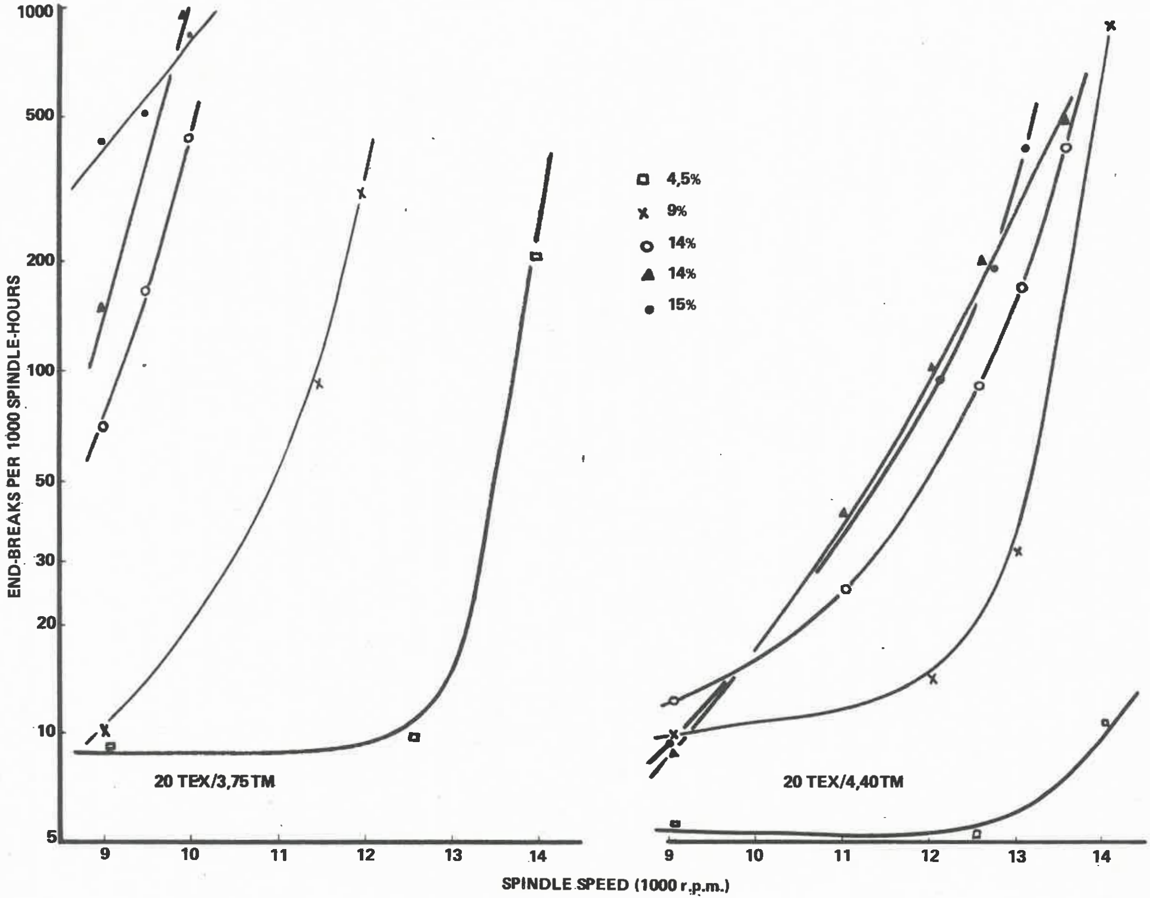

FIGURE 2

The effect of spindle speed on spinning efficiency for different levels of short fibre content

even at spindle speeds as low as 9 000 r.p.m. Using a twist constant of 42,1 (4,0), however, the difference in end-breaks for cottons having different short fibre contents became significantly smaller. Typical curves of end-breaks versus spindle speed for different levels of short fibre content are reproduced in Fig. 2. The following general conclusions could be drawn from these investigations:

(i) End-breaks decreased with increasing yarn twist and the decrease was more marked as the short fibre content increased.

(ii) End-breaks increased with decreasing yarn tex and it was more marked as the short fibre content increased.

(iii) End-breaks increased with increasing spindle speed and it was more marked with increasing short fibre content.

(iv) End-breaks increased with increasing spindle speed but showed a greater sensitivity to changes in spindle speed yarn count and twist when the short fibre content was high.

From the end-break data presented, Tallant concluded that short fibre content within the range 4,5% to 15% (by mass), is not critical for yarns of 20 tex or coarser having maximum strength twist and spun at spindle speeds of 11 000 r.p.m. or less. The deleterious effect of short fibre content on the end-breakage rate can, therefore be minimized by utilising cottons of high short fibre content to coarser yarns having higher twists. For fine yarns of low twist the use of cottons having a low short fibre content could be profitable since it would permit higher spinning speeds.

Data reported by Waters *et al*[12, 13] support those reported by Tallant[7–11] on the influence of short fibre content on spinning performance and yarn properties. From his results Waters[12] concluded that for a $1\frac{1}{16}$ inch-cotton, a short fibre content of approximately 15% by mass of fibres of 12 mm and shorter, which is approximately 10% for fibres of 9,5 mm and shorter, was the maximum that could be tolerated for practical purposes.

Bogdan[14] found that yarn strength decreased with increased mass of individual length groups in the short length groups, was not affected by the medium length groups, and increased with the long length groups. The mass of fibres in the length range 6 to 19 mm was found to be more important than that in the upper quartile length. Data presented by Louis and Fiori[15] support the established concept that elimination of short fibres either mechanically or genetically, would result in more efficient spinning and better yarn uniformity. Apparently the presence of shorter fibres in a cotton off-set the contribution of the longer fibres to improved spinning performance.

Tallant *et al*[8] reported that higher percentages of short fibres necessitate the use of higher twist values for rovings to maintain a constant roving hardness, but he also reported that, for the cottons studied, short fibre content appeared to have no influence on the twist required for maximum yarn strength[7, 8, 9].

Tallant[16] also investigated the effect of draft on the spinning performance of high short fibre content cottons. Reductions in spinning draft improved the spinning performance of all cottons investigated. For a given cotton and a constant spinning efficiency a reduction in spinning draft permitted increased spindle speeds. The increase in spindle speed was found to be approximately proportional to the square root of the ratio between the high and low drafts used. The result was that high short-fibre-content cottons spun at a low draft, performed better than did a medium short-fibre-content cotton spun at a high draft.

Navkal[17], apparently using length array data, has asserted that irregularity of fibre length appears to contribute very little towards the single thread strength. Navkal defined fibre length irregularity as "the percentage by weight of fibres shorter than $\frac{3}{4}$ of the mode". Tallant[9, 18] expressed concern over the use of a fluctuating upper limit for the definition of short fibre content, such as that used by Navkal[17] and that obtained from the Bear diagram. Tallant concluded that the fluctuating limit used for defining short fibre content was probably the reason for Navkal finding that single thread strength was so little influenced by short fibres.

Tallant *et al*[18] has put forward a hypothesis that a certain length of each fibre in the yarn cross-section may or may not contribute to the tenacity of the yarn. It was further theorized that a certain section at each end of each fibre must be unavailable for rupture and therefore incapable of contributing appreciably to yarn tenacity. The data on yarns (10 to 40 tex) spun from 41 different cottons supported the hypothesis and it was concluded that: cotton fibres contribute to single yarn tenacity as if, on the average, a 4,7 mm tip at each end of each fibre were incapable of rupture.

Reporting on the effect of short fibre content of cotton on fabric properties of a 80 x 80 (ends and picks per inch) print cloth, Tallant *et al*[19] concluded that:

(i) Increased short fibre content in either the constituent warp or filling yarns is detrimental to virtually all fabric properties.

(ii) The detrimental effects of increased short fibre content were significant at all stages of finishing, including resin treatment. The magnitude of the differences in the resin-treated state approximated those found in the grey state.

(iii) Subjective qualities such as appearance, smoothness and handle were also found to be degraded by an increased short fibre content.

In a recent publication, Ukidve and Sundaram[20] reported on the influence of some fibre length parameters on yarn irregularity. Thirty cottons, representing a fairly wide range of fibre length, were used, and the length parameters were measured using a Digital Fibrograph and a Balls Sorter. The results showed a positive, and generally significant, correlation between staple length and yarn irregularity. This is somewhat surprising, but a highly significant negative correlation was observed between the 2,5% Span Length and the length uniformity ratio (50% Span Length/2,5% Span Length). This showed that longer staple length cottons are associated with more variation in fibre length as was also observed by Ahmad and Navkal[21]. The positive correlation between staple length and yarn irregularity was, therefore, caused by the higher variation in fibre length for longer staple cottons. This was supported by the highly significant negative correlation found between length uniformity ratio and yarn irregularity. The short fibre content expressed merely as a percentage of fibres shorter than a particular value showed no appreciable influence on yarn irregularity. This latter result is, however, in contradiction with those reported by Tallant *et al*[7, 8, 10, 18], Wakeham[6] and Waters[12].

SUMMARY

The effects of fibre length parameters on yarn and fabric properties, and spinning performance can be summarised as follows:

(i) Increases in short fibre content cause the following: reduced yarn strength, elongation appearance and evenness; a necessity of increased roving twist for constant hardness; deterioration in fabric properties and reduced spinning performance especially for medium and fine yarns with low twists.

(ii) Short fibre content does not appear to affect the yarn twist required for maximum yarn strength.

(iii) Cottons of high short fibre content require lower spinning drafts to give spinning performance similar to that of normal cottons at high drafts.

(iv) Yarn twist and spindle speed have a greater effect on spinning performance than has short fibre content.

(v) Parameters denoting fibre length variation have a better correlation with yarn irregularity than those denoting fibre length alone.

FIBRE FINENESS

It is well-known that the Micronaire value is independently affected by both fibre maturity and intrinsic fibre fineness, i.e. a low Micronaire value is caused by a reduced maturity or fibre fineness or both. Of the three measured fibre properties (length, strength, and Micronaire value), Micronaire values are utilised most often. This is because mills have found by experience that the control of Micronaire value results in more uniform processing performance and quality from day to day with respect to nep formation, spinning performance, yarn appearance, strength and dye uptake. On the basis of available information on fibre fineness, manufacturers are now recognising Micronaire value as probably being one of the most important fibre properties to be considered in relation to quality and processing efficiency.

The formation of neps in cotton is the result of mechanical processing. It may originate in machine picking, ginning, opening and cleaning, but particularly in the carding operation. It is commonly known that improper setting of any of these machines or excessive beating tends to produce more neps.

Marth *et al*[22] reported that, within a given grade and staple length, fibre fineness, expressed as Micronaire value, was an excellent index of the number of neps to be expected in the card web and also the yarn appearance. Thin-walled,

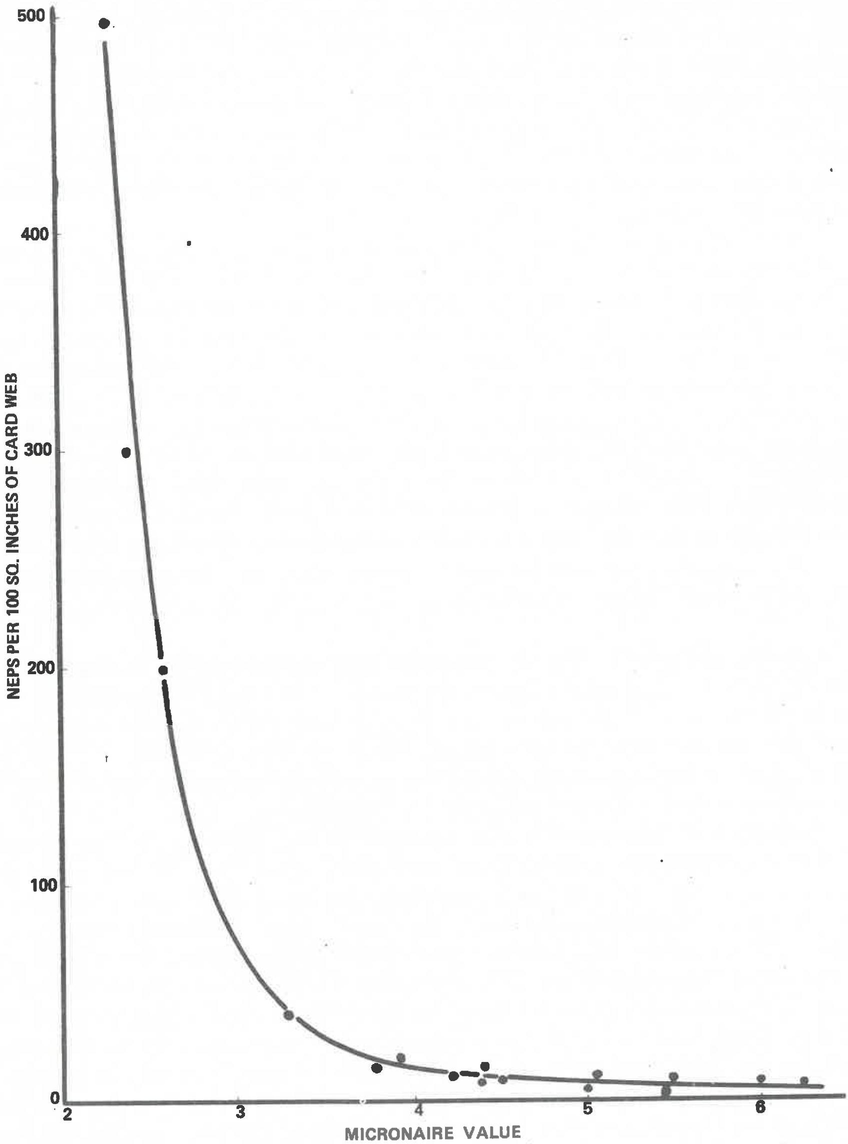

FIGURE 3
Neps per 100 sq. inches versus Micronaire value

immature cottons having Micronaire values below 3,0 tended to produce low grade yarns, whereas, blends of cottons with Micronaire values of 3,5 or higher produced high-grade yarns. Marth *et al* concluded that the dividing line between cottons that produce medium-to-high grade yarns and those that produce low-grade yarns is in the range of 3,0 to 3,5 Micronaire value. This depends, however, somewhat on the quality of mechanical processing. The increase in neps with decreasing Micronaire value is very gradual down to approximately 3,5 Micronaire value after which it increases extremely rapidly (see Figure 3).

Yarns, regardless of count, spun from coarse fibres lost strength more rapidly as the twist decreased from the point of maximum strength than did yarns spun from fine fibres[23]. Conversely, after the point of maximum strength was reached, yarns spun from fine fibres lost strength more rapidly than did yarns spun from coarse fibres. For medium to coarse yarns the twist constant for maximum yarn strength was independent of fibre fineness [approximately 43,0 (4,5)] while for fine yarns (24 tex and less) fine fibres required less twist than coarse fibres to attain maximum yarn strength. These results are supported by those of Leitgeb and Wakeham[24], and show that finer fibres become more easily overtwisted than coarser fibres. Mills changing to the use of finer cottons should take cognisance of these findings as they can benefit from this by using lower twist constants.

The study by Fiori and Brown[23] also revealed that although fibre fineness does not materially effect yarn elongation, it is a critical factor in optimum roving twist.

Several authors[24, 25, 11] presented data on the increase in yarn strength with decrease in Micronaire value of the cotton, but their findings differed with respect to the rate of increase in yarn strength with decreasing Micronaire value. From the available data the average increase in yarn strength is about 7–9% per unit decrease in Micronaire value, but there are strong indications that the percentage increase is more for finer yarns than for coarser yarns.

Leitgeb and Wakeham[24] also reported on the influence of fibre fineness on fabric performance. The cottons used were spun into 20 tex yarns and woven into a "66 x 68" (ends and picks per inch) print cloth construction. The strength difference between the fine (3,6 Micronaire value) and coarse (5,5 Micronaire value) cottons was smaller in the finished fabric form than in yarn form, dropping from a 23% superiority for the fine cotton in the yarn to about 10% in the finished fabric. Mercerization of both fabrics improved the flex abrasion, crease recovery (TBL method) and fabric elasticity. Prior to resin treatment the fine fibre fabric was superior to all other fabrics from coarser cottons in resistance to flex abrasion and elasticity, but had an inferior crease recovery compared with the coarse fibre fabric. Resin finishing, however, levelled out these differences among the fine and coarse fibre fabrics, and also decreased the tear strength by approximately 40% and the flex abrasion (cycles to tupture) by 85%. The resin used was of the dimethylol ethylene urea type, with a final resin take-up of approximately 3%. The results also showed that a 50/50 blend of a fine and a coarse cotton producing a blend with a medium Micronaire value (4,3) gave very much the same performance as an unblended cotton of a similar Micronaire value.

Apart from the well-known relationship between Micronaire value and nep formation Waters *et al*[25] reported that Micronaire value affects spinning performance only slightly in warp twist yarns [43,0 (4,50) twist constant] and significantly in low twist [35,9 (3,75) twist constant] medium and particularly for fine count yarns. This is most probably due to the greater effect of twist compared with the effect of Micronaire value on the cohesive properties of the fibres in the yarns. Leitgeb and Wakeham[24] reported an increase of 183% in end-breaks (18,5 to 52,3 per 1 000 spindle hours) for an increase in Micronaire value from 3,6 to 5,5 when spinning a 20 tex yarn with a twist constant of 43,0 (4,50). This increase was found despite the fact that the finer cotton possessed a poorer fibre length distribution.

Like Fiori *et al*[23], Leitgeb *et al*[24] and Waters *et al*[25], Newton *et al*[26] also reported that an increase in Micronaire value decreased yarn strength and improved yarn appearance. For finer yarns these effects increased in magnitude.

Newton *et al*[26] investigated how fibre fineness (and length uniformity) affect spinning performance, with and without the use of card crush rollers. *When card crush rollers* were used Micronaire value (and length uniformity) significantly affected end-breaks for a 15 tex (35,4 twist constant) and a 20 tex (40,2 twist constant) yarn – increasing with increasing Micronaire value. In the case of the finer yarn (15 tex), fibre fineness was more important than fibre length uniformity, while in the case of the coarser yarn (20 tex) the opposite was found. *Without* the use of *card crush rollers* the only significant correlation which was found was that between end-breaks and Micronaire value for the finer (15 tex) yarn. Since the crush rollers are designed to reduce trash content, it seemed as though trash overshadowed the effects of length uniformity in the 15 tex yarn, and overshadowed Micronaire value and length uniformity in the 20 tex yarn. This is supported by the fact that a significant correlation between Uster Imperfection count ("nep-like" fragments) and end-breaks was found. Consistent trends between Micronaire value and spinning performance were, therefore, not present in all the cases investigated and, generally the results indicated that spinning variables have a greater effect upon spinning performance than did changes in Micronaire value within the range investigated. This was also the case for changes in short fibre content or length uniformity[9, 10]. In general, however, it is possible to state that, other factors being constant, end-breaks increase with increasing Micronaire value and the effect becomes larger for finer count yarns.

It is interesting to note that Newton *et al*[26] reported as follows on the use of card crush rollers:–

The use of card crush rollers

(i) caused a 30 to 35% reduction in end-breaks for a 20 and 15 tex yarn.

(ii) caused an improvement in yarn appearance by about one-third of a grade for both a 20 and 15 tex yarn

(iii) had no effect on yarn strength.

Textile manufacturers have been accustomed, due largely to circumstances, from the very beginning of the industry to blend fibres differing in quality. Fineness values of the constituent components used in a blend, however, usually have been limited to a small range around an average fineness. Micronaire values in the range of approximately 3,2 to 5,0 for individual components are usually used in blends. This practice makes the fine (below 3,0) and the coarse (above 5,0) cottons difficult to market. It has already been shown that when processed alone fine cottons adversely affect yarn appearance while coarse cottons adversely affect yarn strength and spinning performance(22–26).

Jennings and Lewis(27) recommended that the harmonic mean of the Micronaire values of the blend components be used in calculating the average Micronaire value of the blend. If the difference between the finest and coarsest component is, however, less than 1,0 Micronaire unit, an arithmetic mean will usually be satisfactory for routine testing.

It was observed(28, 29) that there is a relationship between the Micronaire value and the percentage picker and card waste for cottons of a given grade and staple length. Picker and card waste decreased with increasing Micronaire value. This increase in waste with increasing fibre fineness can be attributed to the tendency of fine fibres to stick to trash particles and thus thrown out in cleaning, and also to the fact that fine fibres are weaker and are more easily broken in cleaning and carding than are coarse fibres.

It is also considered(28) that blending cottons with a gradation of fibre fineness is more successful than when blending two cottons differing greatly in fibre fineness. In the latter case the action of the dominant number of fine fibres makes it necessary to take special care when blending such cottons.

The blending of extremely fine and coarse cottons was also investigated by Fiori *et al*(30, 31) as a possible way of economically using these "difficult-to-market" cottons in the blended form. The processing behaviour of a 60/40 blend of a fine (3,0 Micronaire value) and a coarse (6,0 Micronaire value) cotton, giving an average Micronaire value of 4,0, was compared with that of an unblended control cotton also having a Micronaire value of 4,0. The other fibre properties of the control and blended cottons were very much the same. Yarns of 42 tex, 28 tex and 16 tex with varying twist constants from 35,4 (3,7) to 54,6 (5,7) were spun from these cottons. A "type 128" (total of ends and picks per inch) sheeting fabric woven with 28 tex [43,0 (4,5) twist constant] warp and 26 tex [34,5 (3,6) twist constant] filling yarn was tested for various fabric properties. The results obtained on the spinning performance and the properties of the yarns and fabrics produced from the control and blended cottons can be summarised as follows:

(i) Picking and carding waste was the same for both cottons.

(ii) For all practical purposes the control and blended cottons produced equal numbers of neps in carding. It appears therefore that when a coarse cotton of low nepping potential is blended with a fine cotton of high nepping potential a nep content value between those of the fine and coarse cottons can be expected.

(iii) The same roving twist was required for both cottons. The average fibre fineness is, therefore, the determining factor for proper roving twist.

(iv) The twist strength curves for all yarns spun from the blended and control cottons were similar in all respects.

(v) Generally the uniformity of yarns spun from both cottons was the same for the 42 tex and 28 tex yarns at all twists. For the finer (16 tex) yarn the control cotton resulted in more uniform yarns at all twists. This tendency may be partially explained by the presence of coarse fibres in the blended cotton, which caused it to approach the spinning limit more rapidly than the control cotton.

(vi) Grades for all yarns spun from the blended and the control cotton were about equal.

(vii) No significant difference in end-breaks in spinning was observed between the control and blended cotton.

(viii) The Grab breaking strength and elongation properties, and the Elmendorf tearing strength properties generally showed no significant differences between the control and blended cottons.

(ix) The fabrics produced from the control and blended cottons showed no differences in resistance to abrasion in the grey or finished states.

(x) Colour evaluations showed very little differences between the two fabrics and it was felt that only small modifications in the dyeing procedure should be required.

(xi) The results showed that extremely fine and coarse fibres could in most instances be tolerated in bleached materials and to a limited extent in dyed materials. The major objection to the dyed fabrics from the blended cotton was excessive neppiness rather than streakiness. This indicated that the fine and coarse fibres were blended randomly enough not to cause weft bars and streaks. (The objections to the neppiness of the dyed fabric from the blended cotton, limited the percentage extremely fine cotton that can be included in the blend).

Simpson *et al*[32] also reported that blends having the same average Micronaire value, but containing different percentages high and low Micronaire value cottons showed no significant differences in yarn strength, uniformity and elongation.

Recently Louis and Fiori[33–36] investigated the utilisation of medium staple discount cottons in sheeting fabrics, denim fabrics, printcloth, and twill fabrics. Five lots of cotton of the same variety with a classer's length of $1\frac{1}{16}$ inch and having Micronaire values of 2,8 3,1 4,4 5,1 and 5,5 were blended in various percentages into eight blends all with an average Micronaire value of 4,3. The maximum percentage of a particular component in any one of the eight blends was 30% of 2,8 Micronaire value, or 35% of 3,1 Micronaire value or 70% of 5,5 Micro-

TABLE I

YARN AND FABRIC SPECIFICATIONS (33, 34, 35, 36)

Specification \ Fabric	Sheeting	Denim	Print Cloth	Twill
Yarn (tex)				
Warp	32	63	19	42
Filling	26	90	17	38
Twist Constant				
Warp	41,5 (4,34)	41,8 (4,37)	40,7 (4,25)	43,7 (4,57)
Filling	34,7 (3,63)	36,4 (3,80)	36,1 (3,77)	38,8 (4,05)
Fabric Construction (ends x picks per inch)	64x 64	68 x 44	80 x 72	107 x 54
Fabric Mass/Unit Area				
g/m^2 (oz/yd^2)	163 (4,8)	390 (11,5)	125 (3,7)	299 (8,8)

naire value. The performance of these eight blends were compared with an unblended control cotton of the same staple length and with a Micronaire value of 4,4. The yarn and fabric specifications are given in Table 1.

The nep content of the blended cottons after carding were generally slightly higher than that of the control cotton, but there were also cases where it was lower. The differences noted were, however, not considered to be of practical significance, because they were not reflected in the yarn grades. Spinning efficiency was not affected materially and it was considered that the presence of components differing widely in Micronaire value in the blends did not adversely affect the spinning efficiency. Yarn evenness was less for the yarns spun from the blended cottons compared with those spun from the control cotton, but was still lower than the Uster yarn variability "standards" for the particular tex values.

In general, the effect of the high and low Micronaire value components in the blends on yarn and fabric properties was in line with the results of a previous investigation by Fiori *et al*[30, 31]. The complaint about neppiness of the dyed fabric when 60% fine cotton was included in the blend was not encountered in the latter investigation where a maximum of 35% fine cotton was included in a blend[33]. From their investigations into the utilization of discount cottons Louis and Fiori[33–36] came to the overall conclusion that sheeting, denim, printcloth and twill fabrics of marketable quality can be produced by blending cottons having extremely high and low Micronaire values.

According to a study by La Ferney and Perkins[37], the blending of discount cottons with cottons in the medium range of Micronaire values appeared to be economically feasible, although there was a tendency for the price discount to the manufacturer to be offset by lower processing performance. They concluded, however, that the inclusion of more than 5% cotton with very low Micronaire values (as low as 3,2) would probably produce both processing and quality problems, including dyeing problems. Cotton with a 5,2 Micronaire value, however, could constitute up to 33% of the blend without serious processing and quality problems. Under normal conditions of dyeing time and temperature, the lower Micronaire cottons require more dye and the higher Micronaire cottons less dye to match the shade of a cotton with a natural Micronaire value of 4,2.

FIBRE STRENGTH PROPERTIES

In certain processes such as spinning, yarn strength may be of prime concern, while in others such as knitting, yarn elongation may be of importance, and yet others may be influenced by yarn stiffness or toughness or both. It is possible, therefore, to postulate that for a fibre to spin and for a yarn to process efficiently, minimum strength and elongation are required. The value and validity of the use of yarn break elongation as an evaluating criterion of processing efficiency may, however, be significantly influenced by yarn spinning tension and other processing variables[38].

The usual assumption that a high strength yarn should process more efficiently than a weaker one, if yarn strength is used as the only criterion, may be misleading. A lower modulus or higher elongation properties or both of a weaker yarn may more than compensate for the reduced strength.

High strength cottons are utilized principally in fine yarns, which normally have a lower elongation at break than coarser yarns. If high strength fibres, with reduced elastic properties, are used in these fine yarns there is the possibility of approaching a dangerously low level of yarn elasticity which may lead to bad processing performance. Breeders should, therefore, recognise these possibilities in planning breeding programmes.

In cases of a simple correlation analysis[63, 64] bundle strength tests at a gauge of 3,2 mm ($\frac{1}{8}$ inch) showed better correlation with yarn strength than tests at zero gauge length. When, however, other fibre properties are used in addition to fibre strength as independent variables in a multiple correlation analysis the 3,2 mm gauge strength apparently has no advantage over the O-gauge strength in relation to yarn strength or end-breaks. Furthermore, as fibres in a textile structure assume an increasingly regular arrangement, and as applied stresses tend to become concentrated at points rather than over finite lengths, the influence of O-gauge strength becomes increasingly important, as for example in folded fine combed yarns[65]. Time and economy usually limit fibre bundle strength measurement to the use of one gauge length. Cotton fibres characteristically have weak places which occur erratically in both magnitude and distribution along their length. Tests using a finite gauge length, such as 3,2 mm, therefore, give bundle breaking strengths much lower than do those at zero gauge. Not only structural weak places, but also mild microbiological damage that starts as localised fibre weakening, are detected more easily by use of a finite gauge length.

It is well-known that fibre strength has a significant influence on yarn strength. This also presupposes an effect upon spinning performance, but Fiori *et al*[39, 40] reported that fibre strength has little, or no effect, on processing performance through spinning. High strength cottons, however, produced stronger single and two-fold yarns than did low strength cottons for any given yarn count or twist. Gangli[2] also reported highly significant correlations between fibre strength and yarn strength, but found that better correlation coefficients were obtained when quadratic curves were fitted to the results. This means that Gangli's results indicate that the effect of fibre strength on yarn strength becomes less for stronger cottons. The amount of twist required for maximum yarn strength and elongation was also found to be unaffected by fibre strength[39]. For a balanced ply twist construction the ply twist constant was found to be approximately 0,7 times the single yarn twist constant. It is interesting to note that the data presented by Fiori *et al*[40] showed that maximum strength values, for either the balanced or equivalent twist constructions, are obtained at lower twist constants in the case of skein tests than in the case of single strand tests. Brown *et al*[41] reported a similar observation for single yarns spun from six different cottons.

From an analysis of the yarns spun from 43 cottons, varying extensively in fibre properties, Fiori *et al*[38] found yarn strength and yarn elongation to be directly related for commercially grown short and medium staple cottons. Long staple varieties (Pima and Karnak) and some experimental high strength cottons, however, showed an inverse relationship between yarn strength and elongation. This seems to indicate that when yarn strength is plotted as a function of yarn elongation the cottons are grouped according to genetic characteristics. The data on yarn break elongation also indicated that there are definite lower and upper limits to this yarn property that can be obtained from fibre property combinations. The limits indicated were 5,5% and 7,5% respectively for a single 20 tex and 6,5% and 8,5% respectively for a single 40 tex yarn.

At twist levels for maximum single yarn strength, Fiori *et al*[38] reported a simple correlation coefficient of 0,715 between yarn and fibre break elongation. An increase in fibre break elongation from 6% to 10%, however, resulted in an increase of only 1% (6,2% to 7,2%) in yarn break elongation. These findings were confirmed by Louis *et al*[42] working with blends of a high and low elongation cotton. This may indicate the need for drastic differences in fibre break elongation if significant differences in yarn break elongation are to be realized. The grouping effect previously observed in the relationship between yarn strength and yarn break elongation was not observed in the relationship between fibre and yarn break elongation. Nevertheless, since small changes in yarn elongation were associated with relatively large changes in yarn strength, the importance of fibre elongation as a secondary contributor to yarn strength becomes obvious.

A positive correlation (coefficient 0,854) was found to exist between fibre resistance to deformation (gf/tex per *per cent* elongation) and yarn resistance to deformation[38]. This relationship together with those of yarn elongation and strength, and fibre elongation and strength indicate that breeders should consider not only fibre strength but strength as related to elongation.

Brown *et al*[41] investigated the yarn properties of a high-strength experimental cotton and compared it with that of a Karnak and Wilds 13 variety. The important properties of these 3 cottons are given in Table 2. The experimental cotton although significantly shorter and somewhat coarser than the Karnak (see Table 2) produced yarns (8,16 and 33 tex) of higher strength except those at the lowest twist constants [below 33,5 (3,5) for the 8 tex yarn]. Furthermore, when the experimental cotton was compared with the Wilds 13 variety, it produced yarns which were about 35% stronger for the twist constant range from 28,7 (3,00) to 55,0 (5,75). This may indicate the possibility of substituting fibre strength for fibre length without the necessity of using a high twist constant. It can also be concluded from these results that fibre strength is an exceedingly important fibre property for maintaining yarn strength for a range of medium yarn counts. In the case of finer yarns, however, fibre strength must be complemented by fibre fineness and length to maintain yarn strength.

It is known that fibres which differ widely in elastic properties are not always compatible in blends. The tenacity of yarns spun from such blends is basically dependent on the tenacity of the fibres with the lowest elongation. Louis *et al*[42, 43] investigated the effect of blending two cottons, with elongations at break of 7,2% and 12,3%, on yarn and cloth properties. Other fibre properties of the two cottons were similar. Increased fibre bundle break elongation resulted in a limited but significant increase in yarn strength, but had no effect on the twist constant necessary for maximum yarn strength. It is interesting to note that the

TABLE 2

FIBRE PROPERTIES[41]

FIBRE PROPERTY	VARIETY		
	Karnak	Wilds 13	Experimental
Length			
Classer (mm)	36,5 ($1\frac{7}{16}$)*	31,8 ($1\frac{1}{4}$)*	26,2 ($1\frac{1}{32}$)*
Fibrograph mean (mm)	26,7 (1,05)*	23,1 (0,91)*	21,8 (0,86)*
U.R.% (Mean length/ UHML)	81	76	82
Fineness : µg/cm	1,26	1,50	1,42
µg/inch	3,2	3,8	3,6
Micronaire	3,8	3,6	3,6
Maturity			
NaOH Method (%)	93	86	82
Immaturity ratio	1,70	1,84	1,91
Strength			
Pressley Index: O-gauge (lb/mg)	9,6	8,4	11,5
Gram/tex	51,5	45,0	61,6
Elongation			
Stelometer (at 3,2 mm) (%)	8,7	7,7	7,5

*inches

data presented by Louis *et al*[42] showed an inverse relationship between fibre stiffness (gf/tex per *per cent* elongation) and number of neps in the card web. Fibres with similar tenacities but higher elongations at break were less stiff and tended to form more neps.

The two cottons which had significant differences in fibre break elongation showed that, in general, the high elongation cotton produced fabric of superior breaking and tearing strength and elongation[43]. The influence of fibre elongation also gradually became less evident during successive finishing processes. The properties of fabrics produced from blends of the high and low elongation cottons were in general unpredictable by a simple ratio based on the proportions of the components in the blend. The fabric breaking strength (warp direction) was for example lower for the blends compared with either of the fabrics produced from 100% low of 100% high elongation fibre. It is, therefore, possible to conclude that there is no apparent advantage, from the point of view of quality, in blending low and high elongation fibres.

In a progress report Waters *et al*[44] presented results of a series of spinning tests statistically designed to show the effect of fibre strength and spinning variables upon spinning performance and yarn properties. The following conclusions were drawn from their results:

(i) Confirmation of previous findings that fibre strength has no significant effect upon processing performance up to spinning.

(ii) Fibre strength did not appear to have a large effect on spinning performance at spindle speeds of up to 12 000 r.p.m., except for low twist medium yarns [15 tex, 35,9 (3,75) twist constant]. For coarse high twist yarns [30 tex, 43,1 (4,50) twist constant] fibre strength was important only at very high spindle speeds (14 000 r.p.m. and more).

(iii) Generally, fibre strength contributed more to spinning performance at low twists than at high twists irrespective of yarn count.

(iv) Spindle speed and twist had a greater effect on spinning efficiencies than fibre strength.

(v) Fibre strength had no appreciable effect on yarn evenness and grade, but increasing fibre strength resulted in yarns of increased strength.

GINNING, COLOUR AND GRADE

Excessive drying of seed cotton before ginning is considered one of the most important conditions which could lead to an increase in the number of short fibres. Studies[4] of undried, moderately gin dried and excessively (185°C) gin dried cottons of average characteristics have shown that excessive drying prior to ginning and cleaning can decrease mean fibre length by as much as 5% and at the same time increase short fibres by 8% to 10%. Classers' staple length can be decreased by as much as 1,6 mm under certain conditions of drying and ginning. The reason for excessive drying before ginning causing a reduction in fibre length is probably due to the fact that hot, dry fibres can experience a temporary reduction in strength[45] of up to 20% compared with that of unheated fibres. When the fibre strength is temporarily reduced the number of fibres which will break will obviously increase. Tests also showed that over-heating of seed cotton does not cause permanent changes in inherent fibre properties. The change in length distribution was the only permanent effect of increased fibre breakage as the result of a temporary reduction in fibre strength.

Results reported by Burley[46] indicate that elaborate equipment at the gin (it is assumed that this means seed cotton cleaning equipment) significantly decreased the spinning performance of a cotton. Similarly each additional lint cleaning stage in ginning reduced the spinning performance of the cotton investigated. These results were confirmed by Newton *et al*[47, 48] who reported that a decrease in trash content (non-lint content) through increased cleaning in ginning was associated with a decrease in fibre length of the lint cotton.

On the world market the grade of cotton lint, determined on the basis of trash content and lint colour, is as important as (perhaps even slightly more important than) as staple characteristics. The question of how trash content affect processing performance, therefore, immediately arises. It is generally accepted that current grade standards do not accurately reflect the true "use value" of cotton lint to the user of cotton. This is because one of the factors determining grade, namely trash content, can be suppressed by overcleaning to produce cotton of an artificially inflated rating. This has developed to such a stage that the opinion is often expressed that machine-picked cotton *has to be over-ginned* to produce a grading of Middling or better[49].

Improved classer's leaf grade (reduced trash content) significantly reduced manufacturing waste and end-breakage during spinning when *card crush rollers* were not used[47]. However, when *card crush rollers were used* the relationship of leaf grade and end-breakage was statistically insignificant. The use of card crush rollers, on the other hand caused a much greater reduction in end-breakage than did an improvement in leaf grade from Strict Good Ordinary to Middling.

Newton *et al*[47] concluded that trash removal during ginning will cause improvements in the spinning performance of a cotton if *no noticeable fibre damage occurred during ginning.* Furthermore, when card crush rollers are used the trash content of cotton becomes a manufacturing waste factor and not a quality factor. It was therefore suggested that leaf grade and colour grade should be considered separately in a marketing system, so that the proper weight can be given to each factor. When this is the case producers would not be encouraged or forced to "upgrade" cotton by increased lint cleaning but at the same time decrease the inherent fibre quality.

In a discussion of some of the economic implications of trash removal, Ross and La Ferney[50] showed that on the basis of "conservative" estimates and with the marketing system existing at the time, a grower stood to lose by stressing trash removal in ginning. The textile manufacturer will also experience economic gains by removing less trash in the gin but have more efficient removal of trash in the mill under better controlled conditions. It is also felt that the increased use of crush rollers will place increased emphasis on this.

In a study to determine the relationship between colour and other fibre properties, spinning performance and to yarn quality Shanklin *et al*[51] showed that lint colour usually ranked last or next to last in importance and usually did not explain a significant amount of variation in the dependent variables when other fibre qualities were included in the analysis. The only exception was colour grade of the yarn which was closely related to lint colour. The relationship between lint colour and processing performance, when considered alone, is primarily due to the correlation between lint colour and other lint properties. Shanklin and his co-workers concluded that their findings had strongly indicated a need for changes in the pricing system and the classification of cotton and recommended amongst other the following changes "with a plea for prompt action":

(i) The emphasis on colour should be greatly reduced as a pricing factor. The measurement of colour in the presence of varying amounts of trash can be completely misleading.

(ii) The perfecting of an automated practical system for grading cotton, which includes the measurement of the other important fibre properties.

When grade, staple length and Micronaire value were correlated with manufacturing waste, yarn strength, yarn irregularity and production rate, each of the latter four measures of "use value" was significantly influenced by the three lint properties[52]. When price alone was correlated with these four measures of "use value", only manufacturing waste was significantly influenced and only 31% of the variation in manufacturing waste could be explained by price variations. It was, therefore, concluded that with the existing market system in America price was highly inadequate in reflecting use value for cotton lint. The opinion was expressed that if grade, staple length and Micronaire value are weighted properly, then price can reflect about two-thirds of the variation in use value of a cotton.

RELATIVE IMPORTANCE OF FIBRE PROPERTIES

The problem of utilizing fibre properties more efficiently in terms of end-breaks becomes more complicated when one realizes that the combination of fibre properties which result in maximum yarn strength is not necessarily the combination which yields minimum end-breaks in spinning. It becomes necessary, therefore, to provide guides so that one fibre property can be substituted for another in terms of specific yarn properties and end-breakage. To do this it is necessary to develop means to predict yarn properties and end-breaks. In the past several formulae were developed to predict yarn strength from the measured fibre properties. Four of these formulae are quoted below –

(a) Estimated skein strength[53]

= Upper half mean length (inches) x 123,78
\+ Fibre strength (1 000 p.s.i.) x 0,73
– Fineness (Micronaire value) x 1,73
– 82,27

(b) Yarn strength[54]

= Cotton grade x 0,384
\+ Upper half mean length (inches) x 51,55

+ UR (Mean length/Upper half mean) x 0,204
– Micronaire value x 4,776
+ Percentage mature fibres x 0,035
+ Fibre strength (1 000 p.s.i.) x 0,452
– 64,70

(c) Skein count strength product[55]
= 50% span length (inches) x 5 676,81
– Micronaire value x 86, 98
+ Tenacity O-gauge (gf/tex) x 51,73
+ Bundle elongation (%) x 22,62
+ Trash content (%) x 98,65
– 2 884,06

(d) Single thread strength (Egyptian Cotton)[56]

$$G_p = \frac{H}{Tt} = 2{,}83\ (\overline{FR}_p + \log t) - 13{,}07$$

where $\overline{FR}_p = 2(\log l_a + \log i)$

H = single thread strength (gf)
t = yarn linear density (tex)
T = twist (turns/cm)
l_a = mean fibre length (cm)
i = fibre bundle strength (gf/tex) at O-gauge

It must be borne in mind that spinning variables, such as twist, speed and draft, yarn count and preparation techniques leading up to spinning are not always taken into account in the above formulae for predicting yarn strength. The type of cotton on which the particular formula is based may also limit its application. The formula (d) was obtained from results on Egyptian cottons only in which case a correlation coefficient of + 0,98 was found between the combined fibre length – strength characteristic and single thread strength. Du Bois[57] tested this formula for American-type cottons and found a maximum correlation coefficient of + 0,85 which, although it was highly significant, limited the accuracy of the predicted strength to such an extent that its value is doubtful.

Bogdan[58] developed a set of tables of yarn strengths that assign a quality index to a particular cotton blend when the yarn count, twist and skein breaking strength of only one yarn are known. This quality index is then used to obtain a good estimate of the skein breaking strength of any other yarn spun from the same cotton.

The skein strength of any count for a spinnable cotton yarn may be predicted by measuring the fibre fineness and then spinning one count (preferably a coarse

TABLE 3

PERCENTAGE VARIATION[a] IN SPINNING QUALITY EXPLAINED BY FIBRE PROPERTIES [60]

SPINNING QUALITY	PRODUCTION LINE TEST METHODS		Classer's grade, staple, Micronaire
	Trash Index, Colorimeter Colour, Fibre length, strength, Micronaire	Trash Index, Colorimeter Colour, 2,5 % Span Length, Uniformity Ratio, Micronaire, Strength	
Yarn Appearance	33	36	30
Production Rate[b]	49	48	22[c]
Total Picker and Card Waste	55	57	39
Yarn Break Factor	54	58	10[c]
Yarn Evenness	38	42	10[c]

(a) Average coefficient of multiple determination, significant at 95%-level.
(b) Production rate for a nominal 40 end-breaks per 1 000 spindle hours.
(c) Some of the individual coefficients were not significant at 95%-level.

count) under optimum conditions. The skein strength of a specified count can then be calculated using the formula of Ewald and Landstreet[59], given below –

Predicted strength of specified count C_2

$$= S_1 + \frac{500}{A} \times \frac{C_1}{C_2} - \frac{500}{A}$$

where S_1 = Observed skein strength
C_1 = Observed count
A = Fibre fineness (mm^2/mm^3) measured on the Arealometer.

At the 1971 Cotton Quality and Processing Conference held at Pinehurst N.C., Shanklin *et al*[60] reported on an investigation of the feasibility of high-speed

TABLE 4

THE RELATIVE CONTRIBUTION OF FIBRE PROPERTIES TO YARN STRENGTH AND APPEARANCE

FIBRE PROPERTIES	PERCENTAGE RELATIVE CONTRIBUTION TO:–							
	YARN STRENGTH					YARN APPEARANCE		
	42 Tex*	27 Tex*	27 Tex**	16 Tex*	12 Tex*	12 Tex**	27 Tex**	12 Tex**
Upper half mean length	33	30	–	36	40	–	–	–
Fibre strength	24	29	34	23	17	19	1	1
Fibre fineness	10	11	24	13	17	36	1	12
Grade Index	4	4	2	4	2	3	14	6
Length uniformity ratio	4	3	–	2	3	–	–	–
Percentage mature fibres	1	1	3	1	2	2	6	6
Length + Length variation	–	–	31	–	–	35	42	44
Mechanical	24	22	6	21	19	5	36	31

* Webb[61] – to nearest integer.
** Wright[62]

production-line cotton quality measurements to explain variation in spinning quality between cottons. The experimental production-line testing system used in this study included a Fibronaire, Model 270 Fibrograph, Length Analyzer, Strength Analyzer, Colorimeter and a Trashmeter. The cottons used were 55 bales from the 1967 crop and 30 bales from the 1968 American crop. A summary of the results obtained are given in Table 3 where the values of the coefficients for the two crop years from two test centres are averaged. In all cases, the fibre properties measured by the production lines were more closely associated with spinning quality than the classer's quality measurements. The general level of correlation coefficients obtained by both the classer and production lines are low compared with routine laboratory measurements which gave more accurate results. The important result is, however, that instrument measurements are better (see Table 3) than classers' measurements in determining the spinning quality of a cotton. Shanklin concluded that this result indicates that considerable thought should be given to how instruments can be used to improve the classification of cotton for the benefit of producer and manufacturer.

The results of Webb[61] on the influence of yarn size on the relative contributions of six cotton fibre properties (American Upland types) to the strength of carded yarns are summarised in Table 4 for the 3 crop years 1948–50. On the basis of the averages obtained for the 3 respective crop years, it is evident that the relative contribution of fibre fineness (μg/cm) to yarn strength progressively increased in importance with decrease in yarn tex. Fibre strength decreased in importance to yarn strength from 27 to 12 tex, but this trend was reversed from 42 to 27 tex. Upper half mean length increased in importance to yarn strength from 27 to 12 tex but showed a reversal of this trend from 42 to 27 tex. There was no variation or trend in the relative contribution of grade, length uniformity ratio or percentage mature fibres to yarn strength of various tex values. These latter contributions were, however, very small. The relative contributions of a slightly different combination of fibre properties to yarn strength and appearance as obtained by Wright[62] are also given in Table 4. In a study of the relationships among fibre properties and yarn properties, Louis *et al*[64] reported a multiple correlation coefficient of 0,92 when fibre strength (3,2 mm gauge), fibre fineness (μg/cm), 50% span length and bundle elongation were correlated with yarn skein strength. The relative ranking in importance of these fibre properties to yarn strength was as given above. For end-breaks the relative ranking was: 50% span length (rather than 2,5% span length), fineness, strength and elongation.

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