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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

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QUALITY CONTROL OF FIBRE RAW MATERIALS [1]

by

J.D. Collins
University of New South Wales
Australia

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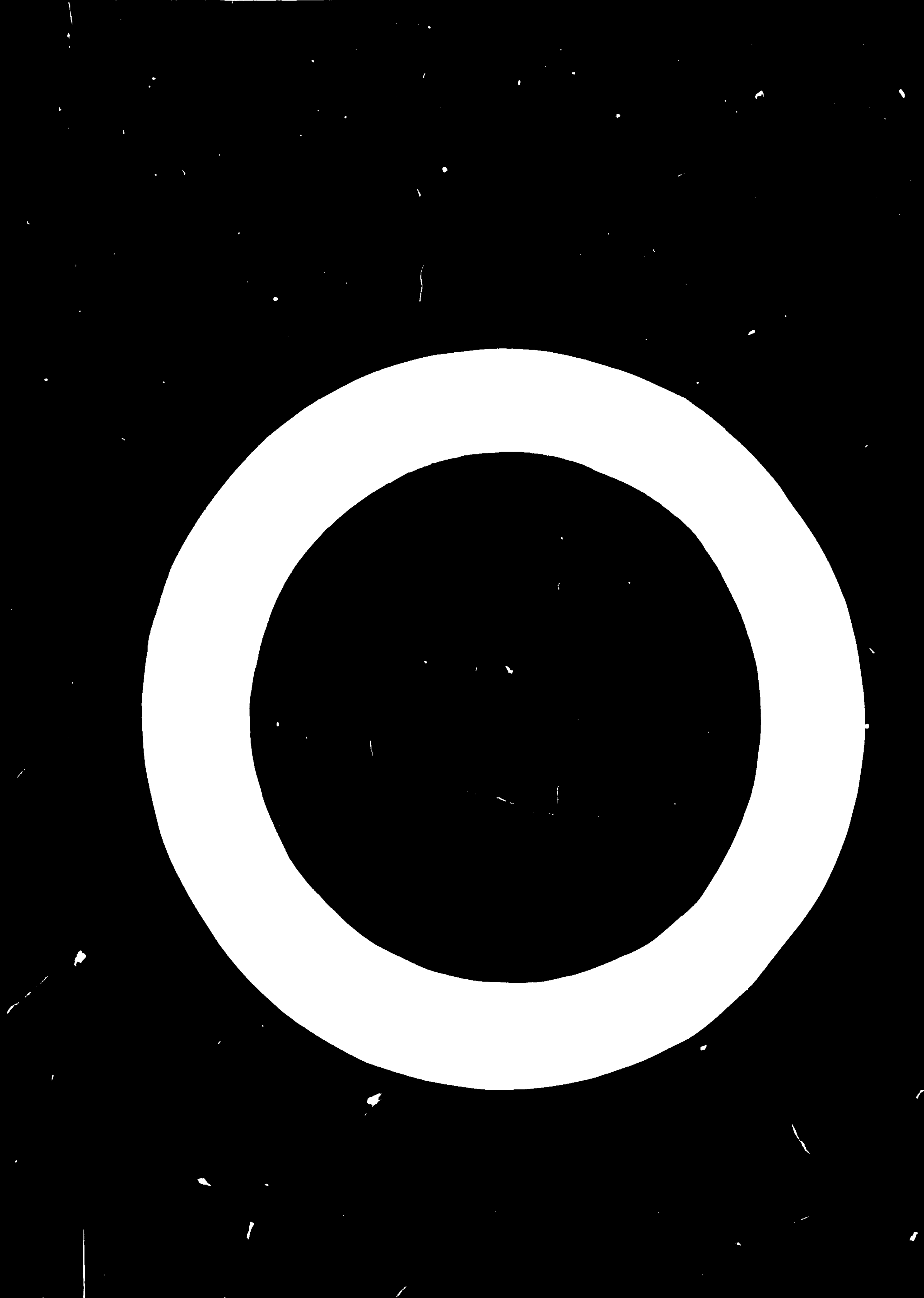

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1. Introduction

The textile industry is required to process fibre raw materials to produce finished fibre assemblies which meet the standards (both objective and subjective) specified by the user and the main problem is to carry out this operation at minimum total cost. The minimising of costs is necessary to enable a firm to meet the increasing competition within the industry and to maximise profits. The fibre raw material used in a particular application can significantly affect the overall production costs so that the control of fibre raw materials is an essential part of any quality control scheme.

In the choice of fibre raw materials it is necessary to decide on the minimum fibre property requirements which are necessary for the particular end product. If the fibre raw material properties are inadequate then financial loss may result due to processing difficulties (e.g. more waste, more ends down in spinning, more yarn breakages in winding, warping and weaving, etc.) and to the production of yarns and fabric which do not meet the specifications. Even when the fibre properties are satisfactory for a particular application it is necessary to adapt the processing conditions to suit the chosen fibres since the use of non-optimum conditions may lead to processing difficulties resulting in more waste and inferior yarns and fabrics.

It is also necessary to minimise the cost of raw material so that it is important to purchase the cheapest fibres with the required properties. The price of a fibre raw material depends to a large extent on the fibre properties so that where the price varies widely with different values of a particular property it is economically desireable to ascertain upper quality limits as well as lower quality limits. A high premium is charged for longer staple length cotton so that if it is known that a particular staple length cotton is suitable then the purchase of a higher staple length cotton would lead to an unnecessary increase in costs. Another factor related to the price paid is the amount of clean fibre actually present in the raw material, the true price per unit weight of fibres being the actual price paid per unit weight of fibre raw material divided by the clean fibre fraction present in the batch.

The aim of the present paper is to examine the various aspects related to the quality control of fibre raw materials. In the space available it would not be possible to give a comprehensive treatment for all textile fibres and the emphasis has been directed towards wool and cotton, the main natural fibres. The major control problems occur with natural fibres because of their inherent large variability in properties and the lengthy processing sequences involved. The general principles brought out in the text should however be applicable to all textile fibres.

The method of approach used is to first examine the practical significance of the various fibre properties and to indicate the various methods available for measuring these properties. Practical quality control is then covered. The first problem is to obtain a sample from which the various fibre raw material parameters can be derived. After determining the properties required it is necessary to decide on the parameters to be tested, the frequency of testing, the test methods to be used, etc. Here factors such as the type of production, the importance of fluctuations of parameters, the time involved, the cost, etc. are examined. The control of fibre raw materials is likely to be significantly affected by recent developments involving automated fibre testing and future developments in this area and their effects on fibre quality control are discussed.

2. The practical significance of fibre raw material properties.

2.1 The cost of fibres used in processing.

2.1.1 The effect of moisture content.

All textile fibres absorb moisture to a greater or lesser degree and the moisture content of a particular fibre may vary widely depending on atmospheric conditions and other factors. Because of this it is customary to base fibre weights on standard moisture contents so that the actual weight of fibres is calculated as the weight of the fibre in the dry state plus the weight of moisture required to bring the fibres to the particular standard moisture regain specified for that fibre plus additional allowances for finishes, etc. where applicable. Moisture content determinations are usually necessary to ensure that the price paid is based on the correct weight of the fibres. If checks are not made and the fibres contain more than the specified standard amount of moisture then purchases based on the apparent weight will lead to a higher fibre cost.

2.1.2 The effect of impurities.

Fibre raw materials such as wool and cotton contain a variety of impurities and are purchased in this form. Greasy wool contains such things as grease, suint, vegetable matter, dirt, etc. and the proportions of these impurities varies widely with wool type and the locality in which the wool is grown. The percentage of clean fibre present may range from as low as about 35% to an upper limit around 75%. For cotton the extraneous material consists of seeds, pieces of leaf, stalks, dirt, dust, etc. and the amount of foreign matter or trash may vary from about 1% to 15% of the raw cotton. Factors affecting the trash content are the type of cotton, the conditions of growth, the method of picking and the nature and efficiency of the ginning process.

Costing for fibre purchases must be based on the actual weight of clean fibre present in the raw material so that accurate assessments of the yield of clean fibre are required.

Suppose for example inspection of a particular greasy wool lot suggests that the clean fibres will have a value of 100c/lb. The price paid per lb of greasy wool will depend on the yield of clean fibre so that if the yield is 55% then the appropriate price to pay is 55c/lb of greasy wool. Suppose however this wool is assessed at 58% yield and hence purchased at 58c/lb of greasy wool. Based on a true yield of 55% this will mean a price of 105.5c/lb is being paid for the clean wool or 5.5c/lb more than it is worth. It is clear therefore that unless accurate knowledge of the yield of clean fibre is available there is a real danger of paying a price higher than the true value of the fibres. Accurate knowledge is also of advantage to the seller since inaccurate assessments may lead to lower prices paid in an effort to minimise the chance of paying too much for a particular batch of fibres.

2.2 The significance in processing and end-use.

2.2.1 Fibre fineness.

One of the most important parameters in processing and end-use is fibre fineness. In spinning, tests indicate that the finest yarn possible contains about 20 fibres in the cross-section irrespective of the fineness of the fibres used. (The finest commercial yarns usually contain 50 to 60 fibres). This means that finer yarns can be produced from finer fibres so that these latter fibres are much more versatile than coarser fibres.

When the same count is spun finer fibres give a more uniform yarn with less ends down in spinning. All other things being equal fine fibred yarns are stronger on the average and are less variable in strength than coarse fibred yarns. The flexibility and softness of assemblies are related to fibre fineness, finer fibres giving greater flexibility and softness. When twisting a greater torque is required with coarser fibred yarns and these latter yarns are more liable to snarling unless set.

In dyeing finer fibres have a greater rate of dye uptake but with a given amount of dyestuff fine fibre assemblies show less depth of shade. Fine fibres generally give lower abrasion resistance than coarse fibres but give better heat insulation than coarse fibres. The occurrence of neps is also related to fineness there being more liability to nep formation with finer fibres.

2.2.2 Fibre length.

The length of the fibres has an important bearing in processing and the finished product. It should be noted here that the raw material fibre length distribution is not the sole factor since considerable fibre breakage occurs in processing (particularly in carding) so that the mean fibre length is progressively reduced and the fibre length distribution is altered.

Fibre length affects the choice of machinery to be used in processing as well as the adjustments required for optimum spinning performance. Machinery is designed to handle particular ranges of length groups since control problems vary with fibre length. The differences between cotton and wool processing machinery are mainly brought about by the large length differences involved. For a particular set of machines adjustments (ratch settings) must be made to obtain best spinning performance.

For the same count longer fibres give more uniform, stronger yarns with less end breakages in spinning. Yarn hairiness brought about by protruding fibre ends increases as the fibre length decreases whilst increasing fibre length leads to more compact and smoother yarns. These factors become most pronounced in the case of short staple fibres such as cotton where fibre length has a limiting effect on yarn count and is more important than fibre fineness. As the length is increased changes in length become less important, diameter being the more important factor. Research indicates that there is no advantage in having a wool top mean fibre length longer than about four inches.

2.2.3 Fibre length variability.

Variability in fibre length is important for a number of reasons. When the variability in length is large (i.e. more short fibres) the problems of fibre control will be increased leading to more fly waste and more irregular yarns with a higher proportion of defects. Waste removed in combing will also be increased. A constant fibre length is undesirable in drafting since nip fluctuation is always present and this leads to fluctuations in the fibre leading end distribution. For constant length fibres this means that a corresponding disturbance is present in the trailing fibre end distribution so that the practice of reversing slivers between drafting operations will not have the desired effect of breaking up the imposed fibre groupings. Because of this constant fibre length leads to more irregular yarns with more ends down for the same count compared with a more variable fibre length distribution. The optimum fibre length distribution is somewhere between the two extremes and is affected by fibre breakage during processing.

2.2.4 Length-diameter relationships.

Length and diameter relationships can be important in fibre blends since these factors influence fibre mixing during processing. In woollen carding for example research has indicated that longer finer fibres tend to be retained longer by the card so that initially the carded material contains more short and coarse fibres whilst the final section has more long fine fibres. In spinning fibre migration is affected by the fibre dimensions and longer finer fibres tend to be in a higher proportion in the yarn centre whilst shorter coarser fibres are more prevalent in the outer layers of the yarn. When there is a large variation in fineness within a fibre lot or between fibres to be blended the final yarns are more irregular and feel harsher to the touch and more ends down in spinning increase processing difficulties.

2.2.5 Mechanical properties.

The mechanical properties of the fibres are a significant parameter in the mechanical behaviour of yarns and fabrics and also affect processing. Stronger fibres give less fibre breakage in carding and combing, a smaller combing loss, less fibre breakage in drawing and spinning and stronger yarns are produced. The larger fibre breakage rate for weaker fibres leads to a greater reduction in mean fibre length with its consequent effects on processing. Fibre strength and elongation behaviour is a significant factor in fibre migration so that blends where large differences in these factors occur are undesireable. Variability of strength along fibres is particularly important where some seasonal fluctuation has produced a similar weak spot in the same position in all fibres (e.g. tenderness in wool fibres). In carding all fibres will be broken at this point leading to a dramatic change in the fibre length distribution with its consequent effects on processing. Fibre friction is a significant factor in spinning but considerable modification of this behaviour is affected by the use of lubricants. The differential friction property of wool fibres is responsible for the felting behaviour of the fibres.

2.2.6 Fibre crimp.

Fibre crimp is responsible for increased bulk and softness in yarns and fabrics and man-made fibres are often artifically crimped in order to produce a bulking effect. The spinning performance of wools is affected by the level of crimp, the effect depending on the system used. Higher crimp levels give a better spinning performance on the Continental system whilst lower crimped fibres appear to do better on the Ambler system. On this latter system lower crimped fibres give finer counts with less ends down in spinning.

2.2.7 Fibre maturity (cotton)

Immature cotton fibres are produced when the secondary wall of the fibrefails to go through its full development as a result of various environmental factors. A proportion of immature fibres is always present in any cotton the average percentage of immature fibres being of the order of 30%. Immature fibres are a disadvantage and as the percentage of these fibres increases the spinning performance deteriorates leading to lower processing efficiencies. Immature fibres are relatively weak and can lead to excessive end breakages in spinning, winding and weaving. The fibres are particularly prone to nep formation leading to unsightly yarns and fabrics and to light spots on dyed fabrics. The dyeing characteristics of immature fibres differ from mature fibres so that maturity differences between batches may lead to different dyeing properties.

2.2.8 Colour

The colour of the fibre raw material can limit its use because of the effect on the dyeing behaviour. The presence of discoloration is a distinct disadvantage where white or pastel shades are required and even for darker shades the discoloration may affect the shade produced.

2.2.9 Foreign matter.

Foreign matter such as burrs in wool and trash in cotton must be removed in the processing sequence and difficulties arise as the proportion of this material increases. The removal of these impurities always involves the breakage of fibres as well as some fibre loss and these effects increase as the proportion of the impurity and the degree of cohesion between the impurity and the fibres increase. Some foreign matter may also pass through into the yarn leading to unsightly yarns and fabrics. For wool there are limits to the amount of burr that can be handled in conventional processing and if these limits are exceeded then carbonising is necessary to remove this vegetable matter. This usually results in mechanical weakening and entanglement of the fibres so that fibre breakage in carding can be severe.

2.2.10 Fibre entanglement and damage.

Fibre entanglement must be removed in carding leading to increased fibre breakage which gives shorter fibres with more fibre waste. Because of this effects such as cotting of the wool fleece and naps in cotton will have an adverse affect on processing and limit the fibres value to the spinner. Various forms of damage also lead to poorer spinning performance. Weathering damage with wool fibres produces fibres with weak tips, these tips being broken off in carding and combing leading to increased waste in these processes and to fly waste in drawing and spinning. Poor shearing as indicated by the presence of second cuts leads to increased fibre waste. Ginning for cotton can lead to defects such as neps, naps, gin-cut fibres, etc., and the presence of these defects leads to poorer performance in processing and to inferior assemblies.

3. The measurement of fibre raw material characteristics.

3.1 Quality assessments by grading.

Raw materials such as cotton and wool vary considerably in properties depending on factors such as type, breed, location, weather, desease, pests, etc. and subjective assessment of fibres by experienced classers has existed for many years and is still very important in the classification of fibre lots into various groupings. Although systems of classification are not standardised they all attempt to classify fibres according to the most important properties from a processing and end-use point of view.

3.1.1 Cotton.

In the system for classifying American cotton the parameters assessed are staple length, colour grade, standard of preparation and character. The staple length is obtained by hand stapling and fibres are placed in one of a series of staple length designations, these lengths being in increments of 1/32 of an inch. The accuracy of the test may be improved by comparative staple length tests on standard samples with known staple length characteristics. When determining staple length there may also be some attempt to give a qualitative description of the length variability eg. uniform, somewhat irregular, etc. Fibres are classified by colour e.g. white, spotted, tinged, yellow stained and gray and further subdivision into grades is done mainly on the basis of the amount of impurities present. Specially prepared standard samples are available to facilitate this classification procedure. Preparation by ginning affects the smoothness of appearance and the occurrence of defects such as neps, naps, gin-cut fibres, etc. and preparation standards are also included in the standard samples available for colour and grade classification. The character of the cotton involves subjective assessments related to such features as fibre fineness, maturity, strength, etc. and the classer's judgement is guided by such factors as visual examination, the feel of the cotton, breaking tufts by hand, etc.

3.1.2 Wool.

Wools are classified by breed, type, quality number and grade and the yield is assessed. Separation into type groups is done in order to channel wool into its appropriate processing outlet and further subdivision into type numbers (based on quality and grade) may also be carried out. The quality number which may range from 36s to 80s is mainly an assessment of fibre fineness and is assigned subjectively on the basis of sight and feel, the classer being guided by such factors as fineness, crimp, softness, etc.

The grade is an expression of the value of a large number of parameters. Within a particular fibre grouping there will be a range of mean fibre lengths possible and higher grade will beassigned for fibres of longer length. The soundness (tensile strength) of the fleece is important and the presence of tenderness results in down grading. The style or character is a subjective assessment of appearance and is mainly aimed at characterising the regularity of properties between fibres. A fibre lot with good character will have a good well defined crimp, a firm staple, small staples free from adjacent staples and a blunt tip (coarse wools) or a flat tip (fine wools). The tip shape is an expression of length variability and a tapered tip (high length variability) is more prone to weathering damage. Higher grades are of good colour and the presence of coloration is treated with caution since it may or may not be removed in scouring. The presence of cotting or matting and vegetable matter leads to down grading. The evenness of characteristics from fleece to fleece is also taken into account in assessing grade. The grade is designated by such descriptions as super AA, Average/inferior D, carbonising, etc. each of these terms having a particular meaning in terms of the foregoing characteristics.

The yield of clean fibre is assessed visually by experience.

A rough estimate is made from knowledge of the average yield of wool of the particular type and quality being examined and the final yield is obtained by correcting for various factors which may raise or lower the yield (e.g. appearance, feel, dryness, amount of handling, age, atmospheric conditions, grittiness, etc.).

3.1.3 The disadvantages of subjective grading systems.

Subjective assessment by classing has a number of disadvantages. One major problem is the variation in systems from country to country and the different emphasis placed on particular properties in determining the classification. Even within one system the subjective nature of the testing leads to assessment variation from classer to classer since different classers may use slightly different criteria in determining the classification. There is also the problem of preventing the drift of assessments with time. A classer for example in examining quality number differences between a group of wools will usually put the wools in correct relation to one another but their absolute position on the quality number scale may vary. The comparison with prepared standards to prevent drift is a useful procedure but even here this method is not infallible e.g. the colour of cotton standards will change with time leading to inaccuracy.

It is clear that the major requirement is for a system of accurate objective measurements which will be universally understood so that the need for checking and rechecking of characteristics will be removed. A range of objective tests have been devised to supplement and in some cases replace subjective assessment and some of these will now be discussed.

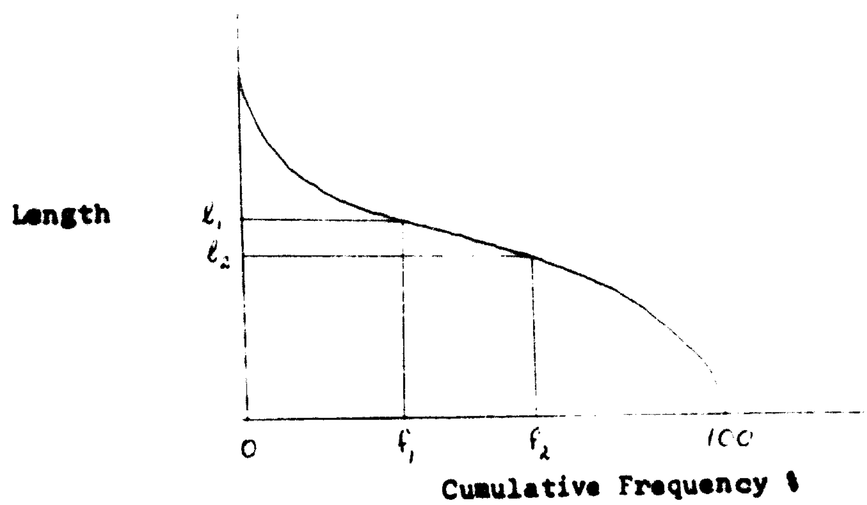
3.2 Techniques for measuring fibre characteristics.

Before discussing actual techniques of testing there are two points which should be examined since these have a major effect on the accuracy and hence the value of the tests. Correct sampling techniques are an absolute essential since it is useless obtaining accurate measurements on a sample which is not representative of the fibre batch. The testing room temperature and humidity are important because of the large changes in properties which can occur as a result of moisture content changes. It is essential that constant temperature and constant humidity be maintained for valid comparison of properties within the same laboratory. For interlaboratory comparison it is necessary that conditions be maintained at standard temperature and humidity conditions ($20 \pm 2^{o}C$ and $65 \pm 2\%$ RH)

3.2.1. The measurement of fibre length.

3.2.1.1 General.

To obtain accurate assessments of the length parameters of a particular lot it is necessary to obtain the distribution of fibre length throughout the sample. Thus the available methods of length measurement are aimed at obtaining a representation of the cumulative numerical distribution of fibre length or the cumulative weight distribution of fibre length. Figure 1 shows the type of diagram produced where length is



plotted against cumulative frequency where this frequency is in terms of the number of fibres or the weights of fibres. Interpretation of the diagram may be facilated by considering the lengths ℓ_1 and ℓ_2 as shown. There are f_1% of fibres (by number or weight) with lengths greater than ℓ_1, there are $(f_2 - f_1)$% of the fibres with lengths between ℓ_2 and ℓ_1 and

$(100 - f_2)$% of the fibres are shorter than a length ℓ_2. The number distribution may be converted to a weight distribution simply by noting that the weight frequency for a narrow fibre length range will be equal to the number frequency multiplied by the fibre length (assuming of course that fibre diameter may be considered as independent of length).

The distribution of fibre length may be analysed to give a variety of information. The shape of the diagram gives data on the variability of fibre length and various measurements may be used to express the irregularity and the proportion of short fibres present. For cotton measurements such as the effective length, the upper quartile length (length exceeded by 25% of the fibres by weight), the upper half mean length, span length, etc. as determined by various methods are used as measures of staple length. For wool fibres common measures are the barbe (the mean length of a numerical sample calculated on the basis of the weights of fibre within each length group, this is equivalent to the length biassed mean length) and the hauteur (the mean calculated on the basis of the number of fibres within each length group).

3.2.1.2 Single fibre length measurement.

The number distribution may be determined by measuring the lengths of a large number of single fibres by holding each fibre in turn against some measurement scale. This can be achieved in a semi-mechanical manner using the WIRA Single Fibre Length Tester (for wool). Single fibre methods are extremely slow so that their main use is in research, tuft methods being used for more routine testing.

3.2.1.3 Tuft Methods.

Tuft methods involve obtaining an alligned sample where one end of each fibre is in the same plane perpendicular to the fibre direction. The fibres all stretch out from this line in the same direction so that the distance the fibre extends away from the plane depends on the fibre length. A variety of methods are available for analysing such tufts of fibres for length characteristics.

Comb sorter techniques both manual and automatic aim at dividing the tuft into fibres of different lengths and weighing the fibres in each length group. The principle of operation is to hold the tuft in a series of combs and to move from the end of the tuft in steps extracting the protruding fibres at each step so that each group of fibres extracted are within a narrow length group. These methods are also relatively time consuming.

The most rapid methods of analysing the tuft attempt to measure the change in the number of fibres in each cross-section along the tuft as the tuft is traversed longitudinally. One such method for cotton, the Uster Sorter, measures the thickness variation along the tuft to obtain the cumulative length distribution. This method is limited in use since fibres taper towards their ends so that the thickness is not proportional to the number of fibres. The main methods rely on the fact that the transmission of light is related to the number of fibres present (the fibrograph for cotton) or that the capacitance is dependent on the weight of fibres present (e.g. the WIRA Fibre Diagram Machine and the Almeter for wool). The principle is to scan the tuft and to record changes in the light transmission or in the capacitance. Modern automatic versions of these machines give extremely rapid assessments of length but they have the disadvantage that they are quite expensive.

3.2.2 The measurement of fibre fineness.

There are a wide variety of methods available for the estimation of fibre fineness and these can be grouped under the gravimetric, microscopic, air flow, vibroscopic and particle size counting methods.

3.2.2.1 Gravimetric methods.

Gravimetric methods are based on weighing a number of fibres whose total length is known. A convenient method here is to take the fibre length groups obtained using a comb sorter, count the number of fibres in each group and weigh each group of fibres on a microbalance. If there are m groups with respective mean lengths ℓ_1, ℓ_2, ℓ_3,....ℓ_m, respective numbers of fibres n_1, n_2, ... n_m and respective weights W_1, W_2, ... W_m then the mass per unit length is

$$\frac{\sum_{i=1}^{m} W_i}{\sum_{i=1}^{m} n_i \ell_i}$$

For cotton it is common to cut a known length from the mid point of fibre length groups to produce fibre all of the same length. This method gives higher values than the whole fibre method because the fibres taper towards the tip. It is argued that this method is more suitable since it removes uncertainty as to fibre length and since the central portion must withstand higher loads in a spun yarn. For circular or near circular fibres where the density is known the value obtained can be converted to an estimate of fibre diameter. The diameter obtained will be the root mean square value of the diameter, a value which depends on both the average diameter and the coefficient of variation of diameter from fibre to fibre. Gravimetric determinations of fineness are fairly lengthy procedures and are not suitable for routine testing.

3.2.2.2 Microscopic method.

Microscopic methods are also time consuming but have the advantage that the variability of diameter is also obtained. For circular and near circular fibres the preferred method is to measure the profile diameters of a large number of short lengths of fibre. For wool the cut lengths are standardised to prevent adverse affects due to the ellipticity of the fibre cross-section (if the length is too short the profile diameter is biassed towards the length of the major axis of the ellipse). For non-circular fibres and particularly those with irregular shaped cross-sections (e.g. viscose rayon, acetate rayon, silk, dynel, et[illegible] not applicable and measurements from [illegible] sections can be used. If the cross-sect[illegible] are projected onto a material with uniform weight per unit area then individual fibre areas may be estimated [illegible] the fibre cross-section shape from the material and weighing this piece of material. For wool a fast cross-section method (The Rapid Comparator Method) has been devised. Here a slide of cross-sections is prepared and compared with slides of standards with known average diameter and diameter variability. The method is not particularly accurate when compared with the profile diameter method. Cross-sectional methods are limited because of difficulties encountered in specimen preparation e.g. not cutting perpendicular to the fibre axis, not producing a clean cut leading to fibre edges whose position is hard to define, distortion of the cross-section due to interfibre packing, etc.

3.2.2.3 Air-flow methods.

Air flow methods offer very rapid measurement techniques for the specific surface area (the surface area per unit weight) of a specially prepared wad of fibres and the method is particularly suitable for routine quality control in mills. When a current of air is passed through a uniformly arranged mass of fibres the ratio of air flow to differential pressure is uniquely determined by the specific surface area of the fibres and various constants. For fibres of circular or near circular cross-section and constant density e.g. non-medullated wool the specific surface area is directly related to the fibre diameter. The estimate of diameter given by the instruments is $d(1 + C^2)$ where d is the average diameter and C is the fractional coefficient of variation of diameter so that when the value of C is known the instrument can be calibrated directly in terms of diameter. For wool the WIRA instrument calibrated by using standard samples is used although a sonic tester (see future developments) appears likely to take over in the future. For non-circular fibres the air flow instruments may be used to estimate the specific surface area, the fibre cross-section perimeter or the mass per unit length depending on the dimensional relationships involved for the fibres tested. Tests on cotton are complicated by an effect due to maturity and the use of air flow instruments for cotton will be discussed when maturity measurement is treated.

3.2.2.4 Vibroscopic methods.

The vibroscopic method which measures the mass per unit length of single fibres relies on the principle that when a fibre is held under a fixed tension the resonant frequency of vibration is related to the mass per unit length of the fibre. If the frequency of vibration is set then the tension to produce a resonant vibration in the fibre is directly proportional to the mass per unit length. Because tests are done on one fibre at a time its use for routine testing is usually restricted to man-made fibres where denier variations from fibre to fibre are low so that the number of tests required is small.

3.2.2.5. Particle size counting.

Particle counting techniques have been applied to diameter measurement, the most promising device being the Coulter Counter. Fibre segments of fixed length are dispersed in an electrolyte, the solution is drawn through a minute orifice and the change in the current flowing through the orifice is monitored as each fibre particle passes through the orifice. The instrument can be used to obtain both the mean diameter and the variation in diameter for the fibre sample. It is fairly expensive and its principal difficulties are associated with rapid methods of preparing fibre segments of uniform length and drawing the segments singly through the orifice without stoppages.

3.2.2.6 Other methods.

Several other methods exist for estimating fibre fineness including a diffraction method where parallelised fibres act as a diffraction grating and a method using photo-extinction sedimentometry where the time for a fibre to sink in a liquid depends on fineness.

3.2.3 The measurement of the maturity of cotton fibres

3.2.3.1 General.

The standard test for maturity is to use 18% caustic soda to swell the fibres and to use the microscope to obtain maturity estimates. The British system involves counting normal, thin-walled and dead fibres and the maturity index is linearly related to the difference between the percentages of normal and dead fibres. The American system involves classifying fibres as mature or immature and determining the maturity as the percentage of mature fibres present in the sample. The two measures differ but tables are available to convert from one measure to the other. Fibre lots may be classified as very mature, mature, average, immature or very immature on the basis of the measure obtained.

3.2.3.2 Microscopic methods.

There are two other microscopic methods for estimating maturity, the first involving the use of polarised light and the second using a differential dyeing technique. The first method involves viewing the fibres between crossed polarisers and a selenite plate is used to produce colours in the fibres which are more readily distinguished. Mature and immature fibres appear differently coloured so that the number of fibres in each category may be counted. The differential dyeing technique uses a mixture of dyes which give a different fibre colour depending on the maturity of the fibre. Both methods have the disadvantage that they cannot be used for cotton from mixed growths.

3.2.3.3 Air flow methods.

Air flow measurements of cotton fineness are affected by maturity the measurement being directly related to the product of the maturity and the mass per unit length. Instruments such as the Micronaire, the WIRA, the Speedar and the Port-Ard give a combined maturity/fineness measurement. Methods have been developed to obtain fineness and maturity as separate quantities using air flow instruments. Two variations have been applied to the Micronaire instrument. The first uses a spacer to compress the sample further and the maturity index is calculated using the difference in readings with and without the spacer. The Causticaire method involves using a special scale on the instrument and the scale reading is determined before and after mercerising and a Causticaire maturity index is calculated from these readings. Both of these methods give only very approximate estimates and are seldom used. The Arealometer has been specially designed to obtain separate estimates of fineness and maturity and the values obtained are quite accurate. A specially prepared sample of fibres is compressed until the resistance to air flow matches that of a standard resistance. The resistance of the standard is increased and the fibres are further compressed until the fibre resistance matches the standard. Scale measurements taken at each compression are used to calculate the fineness and the immaturity.

3.2.4 Measurement of mechanical properties.

Single fibre testing is not practical for routine testing and the usual quality control tests involve breaking bundles of fibres. The Pressley, Clemson and Stelometer testers break short bundles of parallelised fibres and the fibre strength is determined using the breaking load and the weight of the test specimen.

3.2.5 Colour measurement.

The Hunterlab Cotton Colorimeter has been developed to provide objective measurement of the colour characteristics of cotton. Light reflected from a sample of cotton, placed over a window at the top of the instrument, passes through two filters and is measured photo-electrically. Two measures are made, brilliance and yellowness, and the result is indicated by the intersection of the shadows of two pointers on a translucent screen. This screen is calibrated in terms of colour and grade so that the designation can be immediately read off the screen. The method should prove useful for other fibres and work on adapting the instrument for wool is in progress.

3.2.6 Estimation of the clean fibre content of a fibre raw material.

The trash content of cotton may be determined using the Shirley Analyser. The basic principle is to thoroughly open the fibres so that the entrapped trash can be released. The open material is moved in an air stream where gravitation forces tend to divert material where the weight to surface area ratio is larger (e.g. trash) so that fibres tend to move with the air stream whilst trash tends to move under the force of gravity. Separation of the material into fibre and trash is achieved using a special procedure involving a number of passes through the machine.

Yield testing of greasy wool consists of a series of processes. A greasy sample is scoured, dried and weighed. Separate determinations of vegetable matter, ash and alcohol extractives are carried out on the scoured wool. These non-wool constituents are subtracted from the dry scoured weight to give the dry weight of wool fibres free of all impurities and the clean wool content is found by adding standard amounts of ash, alcohol derivatives and moisture. The vegetable content may be determined using a method where the wool is dissolved in caustic soda or by using a modified Shirley Analyser.

3.2.7 Processing performance testing.

Sample spinning plants are available for examining the spinning performance of a cotton using small samples. Devices are also available to test the liability of a cotton to produce neps in processing.

4. Practical Quality Control

4.1 Sampling

Before testing can be carried out it is first necessary to obtain a sample for testing from the particular batch of fibres whose characteristics are required. This sampling must be carried out in such a manner that an accurate assessment of a particular characteristic is obtained at minimum sampling cost. There are a number of factors affecting the cost and accuracy of the assessment and these will now be discussed.

The major requirement of any sample is that it is representative of the total population of fibres whose properties are desired. The obtaining of a representative sample from unprocessed fibres requires much more care than with processed fibres in assembly form (e.g. card sliver, top, etc.). In the latter case there has been a large degree of fibre mixing so that each length of sliver or top should be roughly representative of the batch. With fibres in their raw state however there exist large variations both within and between bales so that one sample of the required size taken from within one bale is hardly likely to be representative of the batch and hence parameter data from such a sample may differ significantly from the batch averages. In order to obtain reliable estimates it is therefore necessary to build up a composite sample by combining a number of individual samples taken from the batch.

In practice it is common to obtain a given number of individual samples by obtaining several samples from each of a fraction of the total number of bales so that two actions are involved viz. the selection of bales to be sampled and the sampling within bales. These will now be considered separately.

The selection of bales should be carried out in such a manner that the chosen bales will be representative of the bale to bale variation. Consider for example the problem of selecting

10 bales for testing from a batch total of 100 bales. If it is known that the movement of the bales prior to testing (i.e. between initial baling and storage at the mill) has resulted in a randomising of the arrangement of the bales then any 10 bales will have the desired properties and it will be simply a matter of sampling the first 10 bales. In practice however it is better to assume that the bales are not randomised and to arrange for random selection of bales within the batch.

Random number tables represent a simple and convenient method of obtaining a random sample. A book of random numbers consists of a series of tables where equal length numbers are arranged in rows and columns. These numbers have the property that at each point in the table the numbers 0, 1, 2, 3, 4, 5, 6, 7, 8 and 9 are all equally likely to occur. The bales will usually be stacked in some systemmatic manner so that they can be counted off in a systemmatic way i.e. each bale may be represented by its number in the counting sequence. The problem is reduced to obtaining 10 numbers at random from 1 to 100. This may be done using random numbers in the following manner:

(i) Select a starting point at random in the book. This is done by opening the book at any page and selecting a point on the page at random. From this point read off numbers to obtain the starting point for reading of the actual numbers. Suppose for example the number were 24 69 35 etc., then the starting point might be taken as page 24, column 6, row 9. The use in any particular case will depend on the arrangement of the set of tables used.

(ii) Begin at the starting point and continue to read off numbers until 10 different two figured numbers are obtained e.g. 68, 98, 00, 53, 39, 15, 47, 04, 83, 55 (00 represents 100). Test the bales with the above numbers.

The above method requires slight modification when the number of bales is different. Suppose for example 7 bales are to be selected at random from 43 bales. A simple method is to read off the series of numbers from the tables, divide these by 2, increase any fraction to the next whole number, discard all numbers greater than 43 and carry on until 7 different numbers are obtained. Applying this to the above numbers gives 34, 49, 50, 27, 20, 8, 24, 2, 44, 28 so that the bales tested are 34, 27, 20, 8, 24, 2, 28.

When sampling within bales it is important to ensure that the samples chosen are representative of the bale volume. In this regard it should be recognised that the outer layers of a bale represent a higher porportion of the bale volume than does the central portion so that a proportionately higher fraction of the samples should be taken from the outer layers. When selecting by hand from an opened bale it is desireable to take a large number of handfuls spread evenly over the whole volume of the material. For baled wool a mechanical method of obtaining samples from an unopened bale has been developed. This method known as pressure coring is used for characteristics such as yield and fineness determination but cannot be used for fibre length because of the fibre damage inherent in the method.

Even when a representative sample is obtained the sample may be biassed due either to the test method used or to personal bias on the part of the operative collecting the sample. The most common type of method bias is when the technique leads to what is called an "extent biassed" sample. The extent of a fibre is a measure of its effective length in the material and this depends on the fibre length and the degree of straightness of the fibre. An extent biassed sample will have a larger proportion of longer straighter fibres and a lower proportion of shorter more curled up fibres than exists in the material so that measurements on such a sample may lead to erroneous results. An extent biassed sample may be avoided by ensuring that large tufts are taken from each sampling point, these tufts being in the form of natural fibre units (e.g. clusters of fibres) from single seeds for cotton and natural locks for wool).

Operative bias may occur if care is not taken. Such bias may arise if the sampler in his selection tends unconsciously or consciously to be affected by a particular fibre feature. The operative for example may tend to choose samples which look better than the surrounding fibres (e.g. whiter, less disordered, less vegetable matter, etc.) and thus inaccurate estimates may be obtained for particular factors. It is important therefore that samples are taken in a systemmatic mechanical manner where the chance of operative bias is minimised.

When all the subsamples are combined together the sample may be too large for testing and a method of reducing the sample to a convenient size is by divide and reject sampling (zoning sampling). Here each subsample is carefully mixed and broken into two halves and one half is rejected at random. A similar procedure is carried out with the remaining half so that the subsample is further reduced in size. The procedure is continued until the combination of all the remaining subsamples produces a final sample of suitable size. The inter-mixing of each subsample gives a more representative sample and is therefore desireable. In the case of greasy wool any mixing is difficult so that at best mixing must be limited to very careful breaking up the sample into tufts and randomising these tufts before dividing the subsample into two portions.

The accuracy of an estimate will depend on the sample size. For the simplest case where the estimate is obtained from n random samples taken from a particular fibre batch and where the coefficient of variation of estimates between samples is C%, the percentage error in the average estimate is given by

$$E = \frac{tC}{\sqrt{n}}$$

where t is a constant whose value for practical purposes may be taken as 2. The error is inversely proportional to the square root of the number of samples taken so that to halve the error the sample size must be four times as great. If the cost of sampling and testing is proportional to the sample size then halving the error will increase the cost four times. In practice therefore the cost will rise faster as the accuracy is improved further and it will be necessary to determine whether the increased accuracy of an estimate justifies the extra cost in obtaining that estimate.

Consider now the case where the properties of a batch of N fibre packages is to be estimated by taking a random sample of n bales and by taking k samples from each package. If the coefficient of variation between packages is C_B and the coefficient of variation between samples within packages is C_W then the percentage error E in the average estimate is given by

$$E = 2\sqrt{\frac{(N-n)C_B^2}{Nn} + \frac{C_W^2}{nk}}$$

Given N the aim will be to choose n and k so that E is some specified value.

Suppose now that the cost of preparing a package for sampling is P and the cost of testing a sample from a package is T. The total cost of the operation will be given by (nP + nkT) and the aim will be to minimise this total cost.

Consider now a numerical example. Suppose C_B = 2% and C_W = 5% and N = 100 and a value of E = 1% is required. Consider the following three cases viz A, B and C where for case A, P = 2 and T = 1, for case B, P = 1.5 and T = 1.5 and for case C, P = 1 and T = 2, the cost being in arbitrary units. The following table shows the various combinations of n and k which produce an error of 1% together with the costs of sampling and testing.

n	k	Total Cost		
		Case A	Case B	Case C
100	1	300	300	300
57	2	228	256	285
43	3	215	258	301
35	4	210	262	315
31	5	217	279	341
28	6	224	294	364

It is clear from the above table that as the number of packages is decrease the total number of samples (nk) must increase to maintain the same percentage error. The costs involved vary with the sampling plan and it can be seen that for case A the most economical plan is to take 4 samples from each of 35 bales whilst for cases B and C the most economical plan is to take 2 samples from each of 57 bales. A similar type of analysis to the above is required in any particular practical case. ||Consider now the zoning method for determining a fibre property (e.g. the diameter or length). Suppose the sample size required for testing is m fibres and these are obtained by selecting p samples (zones) of a fixed size uniformly over the fibre batch volume and reducing each sample (by dividing and rejecting) until p subsamples each of $m/_p$ fibres are combined to form the final sample of m fibres. If C_Z is the coefficient of variation of the property between zones and C_R is the residual coefficient of variation of the property between fibres within a zone then the percentage error will be given by

$$E = 2\sqrt{\frac{C_R^2}{m} + \frac{C_Z^2}{p}}$$

It can be seen that the error will be reduced by testing more fibres from more zones, the actual values of m and p chosen depending on the values of C_R and C_Z and the required precision of the estimate.

4.2 Quality control procedures.

Quality control testing in a mill is required to assist the following functions:

(i) the optimum selection of the raw material to be purchased.

(ii) the verification of the characteristics of purchased materials.

(iii) the selection of the appropriate processing sequence and processing parameters (anticipating processing difficulties before they arise).

(iv) the selection of appropriate component material for fibre blends.

4.2.1 Determining the specifications required.

The first problem is to determine the specifications required of the raw material and this may be done with the aid of previous experience and experimentation. The first essential is that accurate records are kept of the performance of all materials previously processed. The records should include complete details of the source, variety, fibre properties, etc. of the raw material together with processing parameters, processing performance and properties of the final product. The aim should be to obtain a continuous record of the minimum fibre requirements needed for particular end-uses. These requirements should remain flexible so that changes can be made in the light of improved knowledge of fibre performance.

Experimentation will play an important role and in order to obtain optimum value in purchasing it will be necessary to continuously experiment with the raw material used in order to obtain the cheapest fibres which will meet the processing and end use requirements and specifications. In this regard any changes in raw material propertiesshould be gradual to minimise the chances of financial loss due to inferior performance. The experimentation for example may involve the gradual increase of a cheaper component in a blend to determine the point at which the performance shows signs of deterioration. It is undesireable to carry out large scale experiments and good results can be obtained by carrying out these investigations on a small percentage of the total production. The records of previous performance when combined with experimental results will give a guide to the necessary criteria on which purchases are to be based and the parameters which must be measured so that correct processing conditions can be used.

4.2.2. The testing scheme.

The actual testing scheme choosen (i.e. choice of parameters to be tested, frequency of testing, etc.) will be guided by experience and experimentation but will depend on a number of other factors and the main ones are listed below

(i) the cost of the raw material, the added value due to processing and the value of the final product.

(ii) the amount of information on the fibre parameters available at the time of purchase.

(iii) the reliability of this available data.

(iv) the type of fibre being processed.

(v) the availability of suitable test procedures.

(vi) the size of the mill.

(vii) the location of testing.

These factors will now be discussed.

High cost raw materials will usually be associated with higher quality end products, i.e. products where quality specifications are fairly strict. Because of this the price of errors can be quite severe so that a much more comprehensive test scheme will be necessary and parameters will require much stricter control. Control procedures for fine worsted suiting production for example would be much stricter than for the production of cheapwoollen blankets. The added value of the processing sequence (the value of the end product less the value of the raw material) will have an effect since this governs to some extent the money that can be spent on quality control. Where the added value is low this will also restrict the level of control that can be economically achieved.

The amount of information on the fibre properties at the time of purchase may vary from a subjective assessment by grading to a series of objective fibre measurements carried out on a representative sample taken from the fibres. This will obviously affect the testing scheme so that as the information available increases the amount of testing will decrease. There is an increasing trend towards more testing before sale so that more exact specifications of the fibres in a bale are available. This will have an important role in the future and will be discussed in the section on future developments.

The reliability of available data (the confidence a mill has in the data) will be an important consideration. Where the data available is only subjective assessment by a classer employed by the seller then there will always be a tendency to carry out a repeat assessment. Where subjective or objective assessment is carried out by an independent authority this will tend to increase buyer confidence and thus reduce the testing carried out.

The type of fibre being processed will alter the relative importance of fibre parameters and thus affect the testing scheme chosen. In the case of wool for worsted processing the fibre diameter will be the factor of prime concern, for cotton the length of the fibres will be the major parameter whilst for jute recent research indicates that the strength of twisted fibre bundles is the most significant factor.

In order to carry out adequate testing of a particular parameter a suitable test method must be available and the main criteria here are that the method should be low cost (both in terms of testing and the purchase of test equipment) and rapid. Where it is desireable to test a particular parameter but available methods are costly and slow this may mean that either checks are not made or else only occasional spot checks are made. Consider for example the testing of some of the main parameters for wool and cotton.

Although it is desireable to measure the fibre length of raw wool there are difficulties associated with the fibre arrangement and no completely satisfactory method has yet been devised which will give accurate reproducible results and have the desireable properties mentioned above. For this reason length measurements tend to be restricted to tops with length measurement at the raw wool stage being based more on subjective assessment. For cotton the fibrograph gives a rapid accurate assessment of length parameters but it has the disadvantage that the initial instrument is expensive

The fineness measurement of cotton and wool fibres may be conveniently carried out using air-flow techniques since these offer cheap rapid assessment. For cotton both fineness and maturity may be determined using the arealometer but often measurements are restricted to measurements with the Micronaire instrument. For a particular growth type this assessment is useful as a check for low maturity since heredity keeps the intrinsic fineness (related to the fibre perimeter) fairly constant so that lower micronaire values will to some extent indicate lower maturities. Control of both fineness and maturity for the same growth type may be achieved by setting a minimum value for the Micronaire value. Where trouble arises maturity checks using the caustic soda swelling test may be necessary. Routine mechanical tests on fibres are restricted to bundle strength and elongation tests.

As the size of the mill increases the potential for experimentation and quality control testing will be increased. The costs of testing depends to a large extent on the volume of tests required. In a large mill the purchase of expensive electronic equipment may be justified since the added cost per test will be much lower than for a small mill.

The facilities of a centralised testing laboratory set up by an independent authority might be available for testing of mill raw material supplies. An enterprise such as this because of the testing volume involved will be in a position to use the latest and best methods so that the cost of testing a particular parameter will be less than that of testing the parameter in the mill. Thus if easy access to outside assistance is available then a more comprehensive testing program may be carried out.

After the foregoing factors have been allowed for the appropriate testing scheme will be derived. For any situation there will be some minimal level of control testing required but it would be desireable to carry out regular checks on all significant factors. The actual scheme chosen will usually fall in between these two extremes the ultimate choice being a compromise between the cost of quality control and the economic benefits gained as a result of the control scheme.

4.2.3 Underdeveloped countries.

The position in underdeveloped countries is likely to differ from that of developed countries. Quality specifications for internal usage will be less subject to fashion demands and quality requirements are not likely to be as high as those in developed countries so that simpler control schemes may be applicable although this position will be expected to change in the future. Cost structure will be different (e.g. lower labour costs) so that this will influence the control program chosen. Testing which involves more labour may thus be preferred to rapid tests involving electronic equipment which if available would undoubtedly be significantly more expensive than in developed countries. The fibres used if locally produced may offer different control problems since the relative significance of fibre parameters may differ (this is already reflected in the different grading schemes existing from country to country). The mill size is likely to be smaller so that the difficulties in running an adequate control scheme will be increased. The advantages of centralised quality control laboratories to service a number of mill will be increased for underdeveloped countries.

5. Future Developments.

The need for testing of fibre raw materials is to a large degree a function of the degree of incertainty as to the fibre characteristics. This is particularly so in modern times where accurate knowledge of fibre properties such as length, fineness, maturity, etc. are required. In this regard man-made fibres have a distinct advantage in that fibre properties are controlled (and known) and remain fairly constant so that the consumer is buying a "guaranteed" product where the need for raw material testing is minimised. In contrast the natural fibres vary widely in properties both within and between bales and this together with the lack of certainty associated with subjective grading systems and the lack of objective measurements of specific properties puts these fibres at a real disadvantage when compared with man-made fibres. The need for checking and rechecking of subjective assessments and for carrying out elaborate objective measurements in the mill must inevitably lead to a lack of confidence in these materials with the consequent depression of prices and trends towards increased use of man-made fibres.

Future developments with natural fibres must be towards offering for sale a fibre raw material whose properties are known so that buyer confidence will be achieved and quality control testing minimised. The system could be such that each bale of fibres would be tested by some centralised laboratory so that each bale would be offered for sale with the various fibre characteristics stamped on the bale. The use of centralised laboratories to test the fibres should result in considerable economies in fibre testing because of the volume of testing.

One essential of a testing scheme for such an establishment will be a rapid automated testing line to achieve maximum throughput rates with minimum testing cost. Programs for developing such lines for wool and cotton are at present being carried out. The Textile Research Center and the Plains Cotton Cooperative Association in Lubbock, Texas, U.S.A. have automated testing lines that can analyse a sample of cotton every eight seconds. The prototype line could test 100 bales per hour at a number of test stations, data from each station being fed into a memory bank and recalled when the sample was completely tested. The testing stations carried out micronaire testing, length, strength and elongation testing, trash determination and automatic colour measurement.

Considerable research into wool testing has been done at the C.S.I.R.O. Wool Research Laboratories, Division of Textile Physics, Ryde, N.S.W., Australia, with the aim of producing an integrated testing line for greasy wool core samples. An improved sample washer and a centrifugal density separation method for vegetable matter determination have been developed with considerable advantages over previous methods, the main ones being a faster speed (30 samples per hour compared with 3 to 9 samples per hour) and a smaller cost per sample. Detailed research on the air-flow method of determining fibre fineness has been carried out in relation to core samples of greasy wool particularly with respect to the effect of impurities on measurements and corrections to calibrations based on standard tops. A sonic air-flow tester with advantages over the conventional air-flow method has been developed, the instrument having an electrical output ideal for automatic data collecting. When automated lines are fully developed the testing of every bale might be achieved by positioning the testing laboratory at a centralised position in relation to the production or sale of the raw material. A convenient position for cotton testing would be to place the testing line at the gin whilst for wool the selling centre could be a suitable location.

The sale of bales with fibre characteristics stamped on each bale will become an essential since the exact specification of the raw material in each bale is necessary to meet the increasing competition from synthetics with known properties. The fibre user will derive considerable benefit from such a service since the need for objective testing will be greatly reduced and the available data will allow more accurate purchasing and optimum use of the raw materials selected.

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