8
Quality assurance

8.1 Introduction

In any manufacturing environment it is essential that there should be some form of quality assurance system in place, not only to protect the customer from receiving faulty goods, but also of equal importance to protect the manufacturer from spurious claims against his produce.

As a prerequisite to any worthwhile quality assurance testing schedule it is essential that all methods of testing have clear written standards. Equally, if not more important, is that all operatives engaged in the testing and measurement of these parameters are adequately trained and that all are of a comparable standard.

In a complete quality management system this would ensure that all incoming goods as well as outgoing goods have some form of documented quality procedure and records of tests determined by these procedures maintained. Some checks that may form part of the testing regime are described below.

8.2 Raw materials

The term 'raw materials' is very broad. In a manufacturing environment it must be taken to mean more than just the properties of the POY used as feedstock for the texturing process. The various machine components that are wear items and on whose quality the maintenance of the machine in good order depends, must also be considered. Ancillary items such as tubes, interlace jets, coning oil and packaging should be routinely inspected. The quality of the services provided at the manufacturing plant such as water, compressed air and electrical power supply should also be considered as raw materials and reviewed as such.

8.2.1 Machine components and ancillaries

In the majority of cases replacement machine components may be purchased from the original manufacturer. However, in today's economic climate more and more items are being purchased from specialist component suppliers at reduced cost. Though these are usually reputable, the prudent textile technologist will have a system whereby an objective measure of the supplier's performance can be made. This can take the form of a simple assessment of the ability to supply components on time and at economic cost. Alternatively the incoming goods themselves may be tested against a standard previously agreed between supplier and consumer. It may not be possible to perform any meaningful testing on some components delivered owing to limited time and resources. In this case some arrangement for the return of and compensation for faulty goods must be agreed.

One item that can be simply checked and is of vital importance to the viability of the product is the tube on which the textured yarn is wound (see Section 4.3.7). It is very easy to set up a system whereby tubes can be checked for weight, dimensions and concentricity. All of these are important for reasons of correct shipping weights and elimination of package build problems caused by poor tube manufacturing tolerances.

8.2.2 POY feedstock

The quality of the feedstock employed in the draw-texturing process is of fundamental importance; if this is not of first-rate quality then no amount of changes to the parameters at which the textured yarn is produced can compensate.

All of the following are prime requirements of the POY and must be both within specification and consistent:

1. yarn denier (linear density);
2. uniform linear density (U%);
3. number of filaments present;
4. lustre (titanium dioxide content);
5. spin finish level;
6. molecular orientation;
7. tensile properties;
8. filament cross-section uniformity;
9. freedom from package build faults;
10. Package identification.

With the exception of 2, 5, 6 and 7, all of these can be simply and cheaply tested with a reasonable degree of accuracy in a moderately well-equipped laboratory, or in some cases in the POY marshalling area. Tests for the uniformity of linear density ('*Uster*' value, known universally as the U%), molecular orientation and tensile properties require the use of more sophisticated and expensive equipment.

Though this book is not intended as a reference on testing of materials, it is worthwhile briefly considering how these test procedures can be carried out. Guidelines for the testing of and tolerances for these parameters are discussed below.

8.2.2.1 Denier

Denier is defined as the weight in grams of 9000 m of fibre or filament and is a unit of linear density or mass per unit length. The standard unit of denier is the tex; this is the unit that should be used for all yarns. The tex is the mass in grams of one kilometre of the product. The decitex (dtex) unit is more convenient and avoids the use of the decimal point for the finer-filament yarns. It is the tex count multiplied by ten. In fact there is widespread use of both decitex and denier throughout the texturing industries. Denier is more commonly used in the USA and Japan and for polypropylene yarns in wide areas of the world.

The decitex of a yarn can be easily and routinely checked with the use of a wrap reel having a circumference of 1 m and a balance capable of weighing accurately to four decimal places. The decitex of the POY is calculated by wrapping a skein of 100 m of yarn and weighing it. To obtain the result in units of decitex the weight in grams is multiplied by 1000. For end uses in apparel, upholstery and automotive markets denier tolerances of not greater than ±1% are desirable.

8.2.2.2 Uniformity of denier

This is a measure of the mass variability per unit length of yarn. The unit of measure is U%, which is a unit in use throughout the textile industry and is statistically equivalent to the percentage mean deviation. The test is based upon a system whereby yarn is passed at constant speed through a capacitance cell. The changes in capacitance seen are represented on a chart as the U% value. The change in capacitance, recorded by the tester, can be directly related to the mass of the fibre within the measuring cell. For textile operations the U% value of the POY should ideally be $<0.8\%$.

8.2.2.3 Number of filaments

The number of filaments present is directly related to the denier of the yarn. If filaments are missing due to problems during extrusion, it may be possible to determine this from a low denier measurement. However, if this method is not available there is no alternative but to count the number of filaments in the yarn bundle. POY with low filament count may also be detected on the texturing machine by use of on-line monitoring (see Section 8.3.1.2). The yarn tension will be lower than expected.

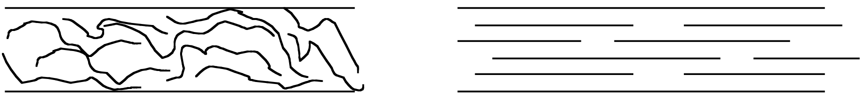
8.2.2.4 Lustre

The consistency of the lustre of the POY is determined by the homogeneity of the polymer. If the polymerisation and extrusion processes are carefully controlled and sufficient blending and mixing has taken place, this should not be an issue. If, however, there is a problem during these stages of the process, it may sometimes be seen on the sides of the POY package, either as a mottled appearance or as discrete bands of varying lustre. These visual checks are the only ones that can be made without the use of sophisticated and expensive test equipment, but they may nonetheless be sufficient for a problem to be identified. Obviously such an occurrence will lead to apparent shade differences when dyed, and as such, any packages found must be segregated before being placed in the texturing machine creel.

8.2.2.5 Spin finish level

Spin finish is the lubricant applied to the POY during the extrusion process. The lubricant is usually applied as an emulsion in water by a metered system. The spin finish has two important roles to play. Not only must it impart the correct frictional properties to allow for the formation of a POY package free from winding faults, but it must also offer sufficient protection to the filaments to allow them to survive the draw-texturing process without sustaining damage. As these two requirements are to an extent contradictory, the choice of lubricant and its uniform application at the correct level are of vital importance for the efficient processing of the yarn on the texturing machine.

Spin finish level may be determined by traditional soxhlet extraction using a suitable solvent such as petroleum ether or it may be determined by the infrared analysis of specific carbon groupings. In this case a calibration must first be carried out with samples of known concentration. Both of these methods will give an accurate determination of the overall level of spin finish applied to the filaments. Levels of the order of 0.2–0.5% by weight of yarn are usual for texturing applications. The measurement of the uniformity of application along the length of the yarn is more difficult. However, it may be determined by examination of U% charts (see above) Since these are capacitance based the level of moisture present from the applied emulsion will have a discernible effect. Alternatively, non-uniform application can be determined from the tension traces generated by on-line monitoring systems on the texturing machine itself (see Section 8.3.1.2).



Orientation in POY as spun

Orientation in fully drawn yarn

8.1. Orientation in POY and drawn yarn.

During the production of BCF yarns the level of finish applied is measured using a technique called nuclear magnetic resonance. By this means the level can be measured either in-line using a hand-held instrument or in the laboratory. Both require calibration and the former is used mainly for comparative checking.

8.2.2.6 Molecular orientation

The orientation of the molecules in the POY is a measure of the degree to which the individual polymer chains are aligned along the main axis of the filament. When spun as POY this alignment of the polymer chains is somewhat haphazard. The action of drawing brings the polymer chains into greater alignment (see Fig. 8.1).

The degree of orientation, sometimes referred to as draw-force, a reference to the degree of force applied to the POY to extend it by a predetermined amount, has a significant effect upon how the POY will process on the texturing machine. In particular it will greatly affect the processing tensions and dye uptake of the yarn. The degree of orientation in the fibre is influenced by conditions during the extrusion process; in particular the temperature at which the filaments are extruded, the draw-down of the filaments from the extrusion head to the winder and the quench conditions applied to the extruded filaments to cool them.

One instrument that can be used to measure the degree of orientation present in POY is the *Dynafil* manufactured by *Textechno*. The orientation can be measured by a system whereby heated POY is drawn at constant rate between two rolls and the tension generated in the yarn by this drawing action is measured. The resulting tension may be represented as a number or, alternatively, a chart may be generated which represents graphically the uniformity of orientation along the length of the yarn.

To avoid downstream problems with dye shade variation it is advisable to maintain the variation from package to package within limits of ±5% of the target mean. The test instrument can also be fitted with an electronic balance, which calculates the denier of the yarn from the weight of the drawn test length used to evaluate the orientation of the yarn.

Another type of device consists of a standard laboratory knitting machine to which a heater and a set of drawing rolls have been attached. The POY is heated and subjected to constant drawing, subsequently being fed directly into the knitting machine at constant tension. This has the advantage that the measure of orientation used is the dyeing process itself. By using this method it is possible to remove any POY packages that show light, dark or uneven dye uptake before they are placed on the creel of the texturing machine. A variety of knitting head sizes is available to accommodate a wide range of spun-yarn counts. This kind of test can be carried out on a *Hot Draw Knitting* (*HDK*) machine made by *Lawson-Hemphill*.

A cruder indication of the POY orientation can be obtained by carrying out shrinkage tests on a skein of POY in boiling water, though the accuracy and reproducibility of this procedure cannot be compared with the more specialised test methods described above.

8.2.2.7 Tensile properties of POY

Tensile tests on POY are often carried out in the laboratory. The manner in which these tests are performed is described in Section 8.3.2.1 below. They are usually performed on the same test equipment that is used for textured yarns. It should be noted that tensile test results obtained from different types of instruments cannot be directly compared (see Section 8.3.2.1).

These tests give an objective measurement of the physical strength of the POY by measuring the percentage extension to break and the load required to reach this so-called break elongation. Typically the elongation of polyester POY would lie in the range 120–140%. The measured breaking load will obviously differ according to the spun denier, but the tenacity or specific strength should remain stable between 2.1 and 2.4 cN/dtex with:

$$\text{tenacity} = \frac{\text{breaking load(cN)}}{\text{decitex (denier)}} \qquad [8.1]$$

When the polymer has been modified, for example to enable the yarn to be dyed with cationic dyes, the tenacity will be significantly lower with values in the region of 1.6–1.9 cN/dtex.

The break elongation percentage of nylon yarns is significantly lower. A range of 63–70% with tenacity values in the region of 3.5–4.0 cN/dtex is typical.

8.2.2.8 Filament cross-section uniformity

The uniformity in cross-section of the individual filaments that comprise the POY feedstock used on the texturing machine will have a significant bearing on the number of broken filaments generated. Variation will also cause dye problems. Those of smaller diameter, i.e. the weaker filaments, are more prone to generate broken filaments during texturing, whereas those of larger diameter will also tend to break because they are less able to withstand the mechanical deformation during drawing and twisting. These large filaments will show a dark dyeing fleck at the point of break when observed in fabric.

Filament cross-section uniformity is dependent entirely on the extrusion process. It can be caused by several factors including pockets of degraded polymer reaching the spinneret (unlikely in a well-designed spinning beam), partially blocked filters in the spinning pack or poor housekeeping procedures during the making up of the spinning packs. This can be conveniently and quickly checked by mounting a sample of the cross-section of the filament bundle in a suitable slide and by observing through an ordinary or a projection microscope.

8.2.2.9 POY package build faults

The build of the POY package will obviously impact upon its unwinding performance and therefore by inference impact on break rate problems that may arise in the texturing process. All of the package build faults discussed in Section 4.3.6 are just as applicable to POY packages as they are to textured yarn packages. These are best checked prior to the packages being loaded in the texturing machine creel. If necessary packages which do not conform can be segregated at this point. All POY packages should have a well-presented transfer tail (see Section 4.3.6.7). Obviously if this tail is missing, or badly presented, the package is incapable of transferring successfully to a second package and an unavoidable yarn break will be the consequence.

8.2.2.10 Package identification

Though seemingly obvious, it cannot be stated strongly enough that the POY must be correctly identified. With many different products running in a manufacturing environment each having a different denier, lustre and cross-section, the chances of a mix of POY on the texturing creel are real and the consequences of this can be disastrous, if it is not discovered until the yarn is in fabric.

The prime method of identification is by tube colour. Other methods are available such as the use of fugitive tints or a label in the tube itself with a product description. Whatever method is chosen, it is important that the labelling should be both highly visible and unique to each individual product.

It is advisable also that each individual POY package should be labelled in such a way that it can be traced to the exact position on the spinning machine on which it was produced and the time it was produced. Thus if a POY package is isolated due to an obvious problem, all other packages from that position on the spinning machine can be segregated prior to being loaded on the texturing creel and can be submitted for further testing. This is being facilitated by the introduction of bar coding.

8.2.3 Polymer chip

In the case of the BCF process the starting material is polymer chip or granules. Though normally carried out by the supplier of the polymer, the following tests may have to be carried out by the yarn producer:

1 relative viscosity (of the molten polymer);
2 moisture content;
3 amine end group count (nylon);
4 extractable impurities;
5 chip or granule particle size;
6 colour (visual inspection);
7 titanium dioxide content (dulling agent).

Most of these tests require specialised test equipment but there are service test laboratories that can be used if the testing is required infrequently.

8.3 Quality assurance of textured yarn

Quality assurance of the textured yarn product can be broken down into three distinct parts, the first being on-line process control, the second being off-line yarn testing and the last a thorough visual inspection of the package prior to packing and despatch.

Process control is carried out in the manufacturing environment itself, whereas yarn testing is done in a suitably equipped laboratory, which should be maintained at stable conditions of temperature and humidity. These laboratory tests will be considered separately below.

The aim of any quality assurance system must be to ensure that the physical and dyeable properties of the yarn are those that will enable it to perform satisfactorily in its destined end use. Circular knit, warp knit, woven goods, both as warp and weft, and of course automotive type products, all have their own distinct requirements.

The criteria used to classify the yarn will vary from product to product. Obviously a yarn destined for use in a warp must be of the highest quality, whereas one destined for use in the construction of undyed net curtain material does not have to meet the same critical requirements. Broadly, yarn can be classified into six major groupings as far as quality requirements are concerned, though obviously each manufacturing plant will have its own in-house classifications. These are:

1 automotive yarns;
2 weaving warp yarns;
3 weaving weft and circular knit yarn;
4 printed fabrics;
5 whites only;
6 off quality.

8.3.1 Process control

8.3.1.1 Machine monitoring

Process control can be defined as the constant auditing of parameters on the texturing machine. This is an active control system and consists of continually checking the production parameters on the machine itself to ensure that no parameter drifts outside the specified range. Process control can take the form of manually checking shaft speeds by use of a tachometer or stroboscope and comparing the result against its specified value, or of simple visual checks of the integrity of the yarn thread-path and monitoring of any services supplied to the machine such as compressed air.

On modern machinery there is often some form of self-monitoring which continually checks such factors as shaft speed and heater temperature. The system will show a visual alarm if the system detects any parameter outside pre-set limits. Though such systems are generally reliable, the question of who checks the checker will always arise and must be addressed as practically and economically as possible. Also to be included in this type of process control is the routine monitoring of thread-line tension, especially where polyurethane discs are involved because of their well-documented wear characteristics.

The items that should be considered in a process control system are those simple basic checks that at first glance may seem so obvious as to be totally unnecessary, but if not carried out conscientiously will be sure to lead to problems. Such checks should include the following:

1 correct POY or polymer feedstock;
2 all shaft speeds on the machine within tolerance;
3 all heater temperatures within tolerance;

4 friction units or other texturing device, with correct sense of rotation and disc stacking, if applicable;
5 correct jets on the machine operating at the correct air pressure and temperature, when in use;
6 all package build parameters such as taper angle, stroke length and cradle damping settings as specified;
7 the correct textured yarn tube in use on the machine.

These basic checks should be carried out at the start of each production run and then at such periods as are deemed necessary to protect the integrity of the product whilst it is in production.

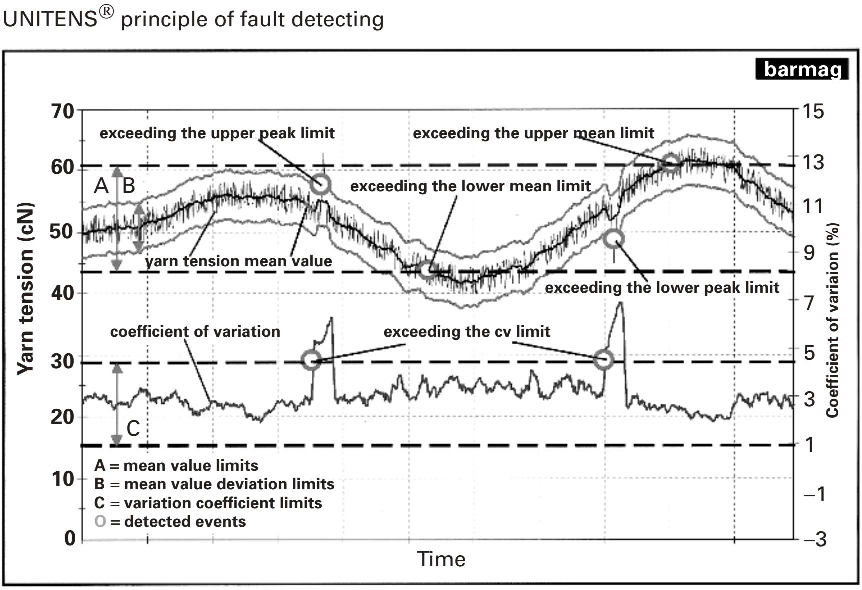
8.3.1.2 On-line monitoring

The most common form of on-line monitoring present on modern, false-twist texturing machines monitors the yarn tension. A suitable tension measuring head is mounted directly after the friction unit. This measures what is commonly known as the T_2 tension (see Section 4.3.3). The textured yarn continually runs over the tension head, stabilised by a suitable guide system.

There are two systems that are commonly in use for this purpose. The first of these relies on a Hall sensor (*Retech-Temco OLT*) whilst the second is based on an electronic strain gauge (*Barmag UNITENS*). Both systems continually display the tension measured at all running positions on the machine simultaneously in tabular and graphic form and in real time. Any deviations in tension measured, which fall outside pre-set limits, are automatically displayed against the position on the machine where the fault occurs and a historical record of that fault is logged in the computer memory. Faults stemming both from the POY and from within the texturing process are easily discernible by their characteristic fingerprints, when viewed in the form of a graphic (see Fig. 8.2).

These systems also hold a limited amount of historical information, which can be useful in segregating suspect packages of yarn. Faults are stored in the computer memory and a history of all faults occurring within a package during one doff can be created. The data can be compiled to present a detailed report of the number of faults generated within one package of yarn. This is then used to determine whether the package meets the criteria for a first-quality package or if the number and types of fault observed require it to be classified for a lower quality end use.

On-line yarn tension monitoring can also be applied to air-jet and hot-fluid jet processes. However, this is not yet common and may never become so, since the nature of jet processes means that other parameters give a more meaningful indication of divergent yarn quality.



8.2 *Unitens* trace. Courtesy of Barmag-Saurer Group.

Yarn clearers of the kind used during spun yarn production are sometimes fitted to air-jet texturing machines. The system software is designed to detect yarn defects after the texturing jet and to gather data on thick and thin places in the yarn. In the case of air-jet textured yarns it is the thick places, often resulting from bunched or excessive filament loops, that are counted and that indicate faulty yarn. Since these sensors also give an indication of the average denier of the yarn being textured, they are in some instances sufficiently sensitive to be used to signal missing ends.

On-line monitoring systems can be employed on both false-twist and air-jet texturing processes to monitor the number of ends down out of production at any one time. These types of monitoring system are obviously useful not only for collecting data on the performance and efficiency of individual products or processes but also for compiling to give an instantaneous picture of the overall efficiency of the plant.

There are also available systems that can be put on the false-twist machine that will continually monitor the degree of interlace placed into an air-entangled yarn. These systems, while being useful in determining if there are any positions running where the degree of interlace is outside pre-set tolerances, are of somewhat limited use as they cannot determine the strength of the interlace in the textured yarn. This can only be measured off-line either manually or by using suitable instruments.

On-line systems are invaluable as they both identify problems at source and also allow the problem package to be removed from the system at that point, saving any further testing or out-sorting. The faults observed, which are attributable to POY packages, are used to classify and identify suspect spinning positions. The POY packages thus identified are segregated before being put onto the texturing creel. In a vertical manufacturing plant this information can be passed directly to the extrusion plant for immediate corrective action. This is an obvious cost saving and as such should be enthusiastically pursued.

Of course, extrusion, drawing and texturing are carried out in one sequence during the production of BCF carpet yarns. Various process parameters have been monitored on-line experimentally. There is no consensus concerning the parameter(s) to be monitored but there is a lot of development activity at the moment and it can be safely predicted that most BCF processes will be monitored continuously in the future.

8.3.2 Laboratory testing of textured yarn

The aim of laboratory testing is to ensure that the physical properties of the textured yarn are those that enable it to meet the requirements necessary for it to perform satisfactorily in its destined end use, whether it be warp or circular knit, warp or weft or in a carpet. These requirements can be sorted into four main categories:

1 those that affect its tensile (physical) strength;
2 those that affect its behaviour in carpet or fabric;
3 those that affect its dye uniformity;
4 those that affect its performance (process efficiency) during knitting, warping, weaving or tufting.

Obviously, when considering the above, it has to be understood that no one attribute of the textured yarn can stand alone. Each property of a yarn will inevitably impact upon another and, as such, a set of physical results that describe the character of a yarn should be looked at as a whole and not as a series of individual properties to be addressed. Some of these yarn tests are described briefly below.

8.3.2.1 Tensile testing

Tensile tests determine the overall strength of the yarn by measuring its resistance to stretching when pulled in one direction and are similar to those described for POY in Section 8.2.2.7 above. Tensile testing instruments, by exerting a force on the yarn and pulling it in one direction, measure both the overall percentage extension to break and the force required to reach that extension (breaking load).

It should be noted that the tensile testing results obtained from different test instruments cannot be directly compared, since each type of instrument will differ in the method of clamping the yarn, the specimen length and the rate of extension. Even though the last two of these parameters can, and indeed must, be preset if comparisons are required, this cannot be done if two different types of instrument are being used for the comparison.

From the results, together with the measured denier of the yarn (see Section 8.3.2.2 below), a calculated value of tenacity can be obtained using equation [8.1]. This is a measure of force per unit linear density; as such it can be used to compare yarns made from different polymers or which do not have the same structure. Examples would be yarns made from polymers intended to produce a different molecular structure, perhaps a higher tenacity or to compare the effects of applying alternative texturing processes.

8.3.2.2 Denier testing

The testing of the denier of a textured yarn is carried out in the same manner as described for POY (see Section 8.2.2.1 above). One major difference is that the yarn is now in a textured and hence elastic state (if it has been through a friction spindle). It is therefore usual for a small but constant load to be applied to the yarn during winding onto the wrap wheel. This helps to ensure constant length and therefore reduce errors caused by the elastic nature of the yarn. This traditional method of testing the denier of a textured yarn is described in ASTM D1577-96. There is a special section that describes the treatment of textured yarns (crimped fibres).

Denier testing can be automated or combined with other test procedures. One advantage of automated or semi-automated testing is that the winding tension is applied consistently and is capable of being pre-set according to the yarn being tested. The 'operator effect' is therefore eliminated. One such test method carries the ASTM number Z6996Z.

8.3.3 Fabric behavioural tests

By this heading is meant the yarn tests which predict how the yarn will perform during fabric formation and finishing.

8.3.3.1 Yarn-skein shrinkage

The shrinkage of the textured yarn, as developed on the texturing machine, can be measured in a bewildering variety of ways. Over the years, many different tests have been developed with measurements made both in hot air and in wet conditions. Within these two broad classifications many different variants exist. As with tensile testing above, care should always be taken to compare like with like when discussing the shrinkage values of textured yarns. The important point is that the measurements should give a reliable prediction of the development of bulk or crimp in the yarn during subsequent fabric finishing.

Opinions differ as to the relative merits of wet-versus dry-skein shrinkage tests; some believe that wet shrinkage methods give a more accurate representation of how the yarn will behave in fabric, or in the case of package dyeing, in the dye vessel. However, providing the results from these tests can be related to subsequent behaviour in downstream processing either method can be considered to be relevant.

The basis of any shrinkage test is to wind a skein of yarn, and measure the length of the yarn loop under load L_0. The skein is then subjected to either hot air or hot water, at known and constant temperature, for a stated period of time and the length of the skein measured again under the same loading L_1. The percentage difference in the two lengths is what is known as the yarn shrinkage. Hence:

$$\text{yarn-skein shrinkage } \% = \frac{L_0 - L_1}{L_0} \times 100\% \qquad [8.2]$$

The ASTM standard test procedure for this is D4031. It makes a distinction between skein shrinkage (as defined above) and crimp contraction, which it describes as the yarn's ability to contract under tension.

8.3.3.2 Degree of bulk, crimp or texture

Skein shrinkage as described above is used as an indication of the degree of bulk or crimp in North America. In Europe the properties of a textured yarn are defined (and therefore measured) differently. Crimp contraction (sometimes known as crimp retraction) starts with a loading which fully extends the yarn and measures the reduction in length when subject to certain standardised conditions of heat for a given time. The crimp stability is given by measuring the crimp contraction a second time after the textured yarn has been subjected to a greater load. The stability is the percentage crimp retained after the loading.

The crimp contraction properties of false-twist textured yarns are tested according to procedures which are defined in the standards. For example there is a DIN standard that describes the exact details for winding the skein, heating and measuring. Its number is DIN 53840–1 (11.83). The handling of the yarn is similar to that described previously for measuring yarn-skein shrinkage. It is therefore a laborious procedure. Instruments for measuring crimp properties are now in widespread use throughout Europe; these enable a number of hanks of textured yarn to be tested as a batch, thus introducing more standardisation to the handling and allowing the difference between hanks within a batch to be computed. The productivity of testing is also increased. The most widely used instrument for this purpose is the *Texturmat*.

An alternative, described in an ASTM test draft [Z7667Z], measures the crimp and shrinkage properties dynamically. In this test the yarn runs through the *TYT* (*Textured Yarn Tester*) test instrument continuously. The yarn is first tensioned at a pre-set level and is then fed through a feed roll into a 1.7 m tube heater. The heater generates crimp and shrinkage force. A set of intermediate rolls maintains the test yarn under a constant, low tension through the heating tube. The computer measures the speed variation of the two sets of rolls (R_1 and R_2) to calculate the total crimp recovery of the test yarn. The speed of the input roll is normally set at 100 m/min. The first zone sensor control is set at 1 mg/dtex:

$$\text{total recovery (a measure of crimp level)} = \frac{R_1 - R_2}{R_1} \times 100\% \qquad [8.3]$$

where R_1 and R_2 are respectively the roll speeds pre- and post-heater. This test method has two advantages over the static methods. First the result is available immediately at the computer. This not only enables comparisons between batches to be made, but also gives the ability to read out the standard variation within a sample as it passes through the instrument. This test instrument is also in widespread use for testing BCF carpet yarns. This is important because streaks in carpets have been found to have a high correlation with crimp rather than with dye variations.

8.3.3.3 Stability of bulk, crimp or texture

Both the test methods described in the previous paragraphs enable the sample to be treated further, in order to measure the stability of crimp or bulk. In the case of the dynamic test instrument there is a second sensor zone using the same principle. The speed of the third roll is set to eliminate the crimp generated after the heater, leaving only the residual fibre shrinkage in the yarn. To confuse everyone this value is defined as the fibre shrinkage in North America and as the crimp stability in Europe! Thus:

$$\text{yarn (fibre) shrinkage} = \frac{R_1 - R_3}{R_1} \times 100\% \qquad [8.4]$$

8.3.3.4 Bulk in an air-jet textured yarn

Because the bulk in an air-jet textured yarn is developed by the physical rearrangement of the filaments rather than by the application of heat, the bulk has to be characterised by the increase in specific volume. To make this clearer, when the process was developed originally, *DuPont* specified bulk by measuring the size of the textured yarn package and comparing it with a package of the same weight of yarn wound without texturing. Of course this was before the days of draw-texturing.

Current dynamic test instruments measure the core diameter of the yarn and also characterise the loop structure by counting the loops at different diameters. This is done by means of a sensitive camera with a scanning range of 2048 pixels horizontally and 1 pixel vertically for each reading (1 pixel = 3.25 μ) and the necessary PC with corresponding software. The instrument is known as *EIB* (*Electronic Inspection Board*) and is made by *Lawson-Hemphill*. This has resulted in the creation of a 'Bulk Index' using loop frequency and loop-size distribution to characterise and qualify air-jet textured yarns.

8.3.3.5 Assessment of expected cover in fabric

An assessment of the type of cover to be expected from a yarn when in fabric, particularly in knitted goods, can be obtained from the visual examination of an undyed, scoured, knitted sleeve. This is a subjective assessment and as such needs to be done by a skilled operator.

A knitted sleeve is placed in a dye bath and subjected to the same type of dye cycle as it would see in fabric dyeing. The exception is that the procedure is carried out with no dyestuff present in the system. The greige test sleeve is then removed and, after drying, examined on a black test board. The amount of black surface that can be seen when viewing through the test sleeve can be used to give a subjective assessment of the amount of cover to be expected from the test yarn when in fabric.

8.3.4 Package-to-package dye uniformity

Ensuring that all packages, within a specific product, dye uniformly is of paramount importance in ensuring that the finished fabric is of even appearance and free from either streakiness or barré. Examination of a dyed, knitted sleeve can prove invaluable in out-sorting packages of yarn that display not only variations in dye uptake but also specific physical faults that give the characteristic appearance of uneven dyeing.

A sample knitted sleeve is prepared on a small knitting machine. Each knitted sleeve is given its own unique reference and the order in which the packages of yarn are knitted in that sleeve must be accurately recorded. Care must be taken to ensure that all packages are knitted with the same yarn tension going into the knitting head. If this is not controlled, the tension variation from package to package will be apparent in the dyed sleeve, making a critical assessment impossible. For this reason specially designed laboratory knitting machines with automatic stitch control such as the *FAK* (*Fabric Analysis Knitter*) manufactured by *Lawson Hemphill* should be used. Automatic stitch control is essential when knitting false-twist textured yarns with stretch characteristics.

The test sleeve is dyed in a small dye machine using a suitably critical dyestuff. Since polyester is normally a disperse-dyeable fibre, the size of the dye molecule has a distinct bearing on its ability to penetrate the molecular structure and will affect the depth of shade achieved. Dye cycles, i.e. the temperature, time and pressure at which the knitted sleeve is dyed, must also be chosen carefully to give the maximum opportunity for level dye application.

The addition of a carrier agent is frequently incorporated during dyeing. This helps to swell the fibre and ensure better dye penetration. Dyeing carried out at atmospheric pressure is much more critical but this practice is not usual in day-to-day quality assurance testing. Dye assessment of nylon yarns is basically the same as for polyester but as nylon yarns are dyeable using acid dyes, a carrier agent is not required and dyeing carried out at atmospheric pressure can suffice for the purpose of routine quality assurance.

After the knitted sleeve has completed its dye cycle and been dried it is then inspected under suitable lighting conditions. It is advisable to carry out this assessment with the dyed sleeve being viewed against both a black and a white background, as the colour of the background can affect the manner in which the eye perceives the shade. Purpose-designed, colour-matching test equipment can be also used in the assessment of dye uniformity. Even though a visual assessment is somewhat subjective, assessment by a well-trained and skilled technician can detect subtle shade differences both package-to-package and along-the-length variations that can defy an electronic assessment.

From this assessment it is possible to identify those packages that show shade differences compared with the main body of the knitted sleeve and also any packages that show a tendency toward streakiness. These packages, which are removed, can be classified into a lower quality category, depending upon the severity of the fault, or simply designated for a whites-only end use.

8.3.5 Process efficiency tests

8.3.5.1 Oil on yarn

The amount of coning oil, if applied to the yarn after texturing, is determined by the fabric construction for which the yarn is destined. Application levels would normally lie between 1 and 3% but may vary from these figures. Usually those products destined for knitting end uses would have higher oil application than those destined for weaving. Some nylon yarns, particularly those for use on high-speed hosiery or sock knitting machines, may have higher levels.

The level of oil is determined by wrapping a suitable sized skein of yarn, weighing it (W_1) and then removing the oil and reweighing after drying (W_2), the oil content being the percentage difference between the two weights. Hence:

$$\text{percentage oil on yarn} = \frac{(W_1)-(W_2)}{(W_1)} \times 100\% \qquad [8.5]$$

The oil may be removed by traditional soxhlet extraction using a suitable solvent or by simply washing in hot water with detergent added. More sophisticated test methods can also be used, such as infrared analysis, but for everyday control of oil level, simple extraction tests usually suffice.

8.3.5.2 Intermingle or interlace testing

The level of intermingling applied to a yarn can have a profound effect on how the yarn will perform during both knitting and weaving but, of these two, the behaviour in weaving is more important (see Effect of intermingling in Section 5.3.5.2). This is because intermingling has largely replaced the twisting and sizing of warp yarns.

Intermingling of a yarn can be quantified in a variety of ways, various attributes of the quality of the intermingling being measured to quantify its characteristics. The number of entanglement points inserted, the regularity of these insertions and the strength (or resistance to removal) of the entanglements can all be used to quantify and qualify intermingling.

Several specialised pieces of test equipment are now in use, which are designed for quantifying the degree of intermingling present in a yarn. Though they operate by different principles of measurement they have the following in common:

1 an initial count (count 1) of the number of interlace points per unit length;
2 subjection of the yarn to a small and constant draw between two rolls. This draw, or extension, can be programmed for a series of stepped

increases so that a profile of the strength of the intermingling points can be found over a range of values;

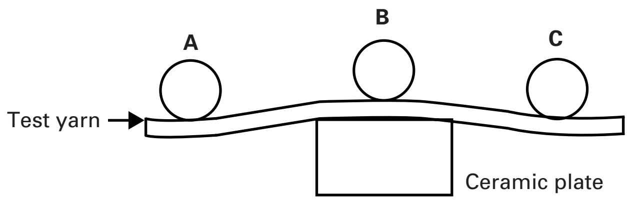
3 a second count of the interlace points (count 2). This enables the strength of the intermingling points to be calculated as a percentage of these points remaining after the yarn has been subjected to the drawing action:

$$\text{percentage knot retention or knot strength} = \frac{\text{count 2}}{\text{count 1}} \times 100\% \qquad [8.6]$$

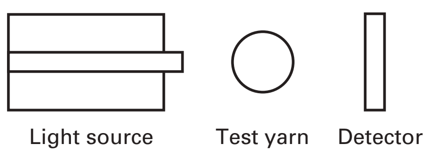
Instruments that enable this double count to be made include those by *Enka Tecnica* (*Itemat*) and by *Fibreguide* (*Fibrevision*). The *Itemat* works by scanning the variation in thickness of the yarn bundle under test. The yarn is subjected to small constant pressure which will tend to flatten the areas of non-interlaced yarn. When an interlace point is detected, the more compact circular form of the yarn at the actual intermingling point prevents the pressure applied from flattening the yarn bundle and hence the movement of the pressure plate is restricted. It is this variation in movement of the pressure plate which is used to determine the number of intermingling points present in the yarn (see Fig. 8.3).

The *Fibreguide* instrument works on a different principle. This instrument uses a laser to scan the yarn as it passes through the measuring head, detecting interlace points as the variation in the degree of light received by the detector which is placed opposite the light source (see Fig. 8.4).

Other information such as the distance between the interlace points and the length of the interlace points themselves can be presented both statistically and graphically if required.



8.3. The *Itemat* instrument. A and C are the thread guides and B is the measuring pressure plate.



8.4. The *Fibreguide* instrument.

The instruments that are used today either 'feel' the yarn or use optical methods including lasers to count the number of intermingled knots. An older technique inserts a short needle between the filaments of the yarn. Each time a knot passes the needle it is deflected and a knot is counted. This technique is still in use but mainly for counting knots in yarns that have not been textured.

For the day-to-day checking of the level of intermingling in the textile laboratory, it is quite feasible to quantify the interlacing present in the textured yarn by the simple expedient of counting the number of interlace points present in a measured length of yarn. This should be carried out with the yarn placed upon a suitable dark background. It is somewhat laborious and depends to a certain extent on the operator, since the tensioning of the yarn before counting and the decision as to what comprises a knot cannot be precise. The method chosen will depend to a large degree upon the criticality of the end-use yarn and on economic considerations.

Some yarns do not exhibit visible interlacing points. Laying the yarn on the surface of a water bath, where the water is replenished continuously, can still assess them. The surface tension causes the filaments to separate as far as possible, thus revealing the degree of entanglement. Again, it helps if the water bath is dark in colour, at least when assessing an undyed yarn. (This method is commonly used for assessing intermingling in POY.)

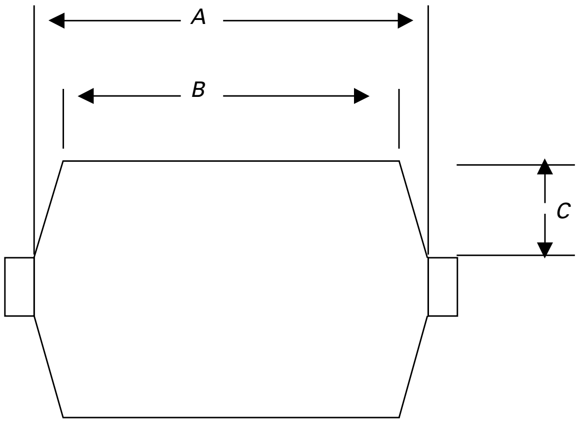
8.3.5.3 Package density measurement

The control of density on package dye yarns in particular is of vital importance, the density of the package having a dramatic effect on the ability of the dyer to obtain an even dye distribution throughout the package. This applies with equal importance to batch-to-batch shade uniformity. The density of the package can be measured manually by taking measurements of the initial and final stroke lengths and the depth of yarn on the package. From these measurements it is possible to calculate the volume of yarn on the package and then, by recording the net weight of yarn on the package, the overall density can be found (see Fig. 8.5) as follows:

$$\text{package density} = \frac{954.9297 \times D}{2(AC + 2BC + 112.5A + 112.5B)}\ \text{g/cm}^3 \qquad [8.7]$$

where A = initial stroke length, B = final stroke length, C = yarn depth (tube wall to outside of package), D = nett package weight in grams and 954.9297 is the reciprocal of $1/3\,\pi \times 1000$.

Making these measurements is not only time-consuming but is also a source of many errors, with the required number of measurements per package being high. Purpose-designed instruments are available for the measurement and calculation of package density. These incorporate a



8.5. Package density measurements.

weighing mechanism and package-dimension measuring devices that may be camera-based or simple mechanical swinging arms that converge on the package. These instruments can be linked to a PC and the data presented both as a table and graphically with full statistical analysis. Whichever system is employed, it is essential that the results are both reproducible and consistent or severe problems may be encountered by the dyer.

When measuring package density it is important that all packages tested should be of equivalent weight, i.e. use full-size packages wherever possible. This is to account for the apparent difference in calculated density from small and large yarn packages, which is caused by the change in winding tension from start to completion of package winding.

The on-line measurement of package density during texturing has been demonstrated and applied already in a few plants. On the other hand, there are new, more sophisticated take-up systems that have been developed for the latest texturing machines and which may also be available as conversion kits. These enable a much closer tolerance to be applied to the winding of the packages and hence to their density.

8.3.5.4 Package unwinding characteristics

An objective measure of how the yarn will unwind from the package can be made by the use of purpose-designed instruments such as the *PPA* (*Package Performance Analyser*) made and sold by *Rieter–Scragg*. These work by unwinding a package of yarn at constant speed over a tension-measuring head, the tension in the yarn as it unwinds being monitored continuously. The data from the tension head is sampled at up to 1000 times per second using the software provided.

This information is processed and stored in the form of a cumulative tension distribution and on completion of the test the stored data is analysed. Taking account of both peak (highs and lows) tension and the overall tension distribution observed during unwinding, a value known as the *PPF* (package performance factor) is calculated.

The *PPF* is a statistical value unique to the *Rieter–Scragg PPA* device and can be used to judge how the package will perform during subsequent unwinding. The instrument, as well as giving a simple statistical summary, can also show the unwinding of the package graphically. It does this by sectioning the overall unwinding time into 100 equally distributed time periods and displaying both the overall and peak unwinding tensions observed in the form of a histogram. This is particularly useful in determining if there is any particular region in the package which is subject to unusually large variations in unwinding tension.

Package unwinding is obviously important in any further processing, especially of fine decitex (denier) nylon hosiery yarns that are destined for use on high-speed four- or eight-feed knitting machines. As weavers are now exploiting advances in loom developments, package unwinding is assuming a greater importance in yarns for weft insertion.

The most up-to-date instruments also incorporate a package density measurement system that continually monitors yarn depth and package weight. The density value at any point in the package can be determined and checked for possible correlation against any suspect unwinding regions.

There is an alternative type of package analyser. This unwinds the yarn from the package at slow speed and charts an exact replication of the manner in which the yarn has been laid on the package by the traverse mechanism. Though of limited use in the routine day-to-day control of package unwinding, it is a useful analytical tool for determining if the stroke-modification system in particular is performing its correct function.

8.4 Visual inspection prior to despatch

The final stage in any quality assurance scheme must be a visual inspection of the finished package by a trained inspector prior to the package being boxed for despatch to the customer. This is the last line of defence in the manufacturing environment to prevent a faulty package getting into fabric at the customer and as such needs to be carried out conscientiously. To enable the inspector to carry out this work effectively, there must be established and clearly written standards for each product type, against which the package can be assessed.

At this stage the product should be segregated after classification into various qualities based upon physical properties and dye checks. The inspector is specifically looking for packages that fall outside these categories.

The categories are:

1 dirt marks on the yarn;
2 secure transfer tail;
3 package build faults that would lead to unwinding problems;
4 presence of high numbers of broken filaments;
5 uniform intermingling, if present;
6 damaged tube, container or bobbin;
7 package size and weight;
8 correct tube colour for the product.

All of the above, with the exception of 7, can be checked by a quick visual examination of the surfaces of the package and by simply unwinding a few metres so that the regularity of the interlace can be seen. Should any fault be noted, then its nature and the position on the texturing machine from whence it came should be recorded. The information should then be relayed to the manufacturing plant for corrective action and the faulty package downgraded into a suitable category.

For the measurement of package size and weight (7 above) it is advisable that all the packing stations should be equipped with both a simple go-no-go gauge for overall package diameter and a simple top pan balance of suitable capacity (see Section 9.4).