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Introduction to fabric testing

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Abstract: Fabric testing plays a crucial role in gauging product quality, assuring regulatory compliance and assessing the performance of textile materials. It provides information about the physical or structural properties and the performance properties of the fabrics. Today more and more countries and markets have a stake in the treatment and testing of fabric. As consumers become more aware and more demanding of products, the number of tests required for textile fabrics has grown. As a result the testing of fabrics is increasingly varied, in constant flux and full of the unprecedented challenges of globalization. This introductory chapter describes the importance, scope, current status and future trends in fabric testing.

Key words: scope of fabric testing, importance of fabric testing, future of fabric testing, standards for tests.

1.1 Introduction

Testing of textiles refers to numerous procedures for assessing myriad fibre, yarn and fabric characteristics such as fibre strength and fineness, yarn linear density and twist and fabric weight, thickness, strength, abrasion resistance, colour fastness, wrinkle resistance and stiffness. It is the application of engineering knowledge and science to the measurement of the properties and characteristics of, and the conditions affecting, textile materials. It involves the use of techniques, tools, instruments and machines in the laboratory for the evaluation of the properties of the textiles (Grover and Hamby, 1960). Textile testing has become more important in recent years as a result of the new demands placed upon the products of textile manufacturers. Advances in textile technology, combined with the rise in the number of knowledgeable consumers with firm demands for specific performance behaviour, have made it essential that the properties of a material must be well understood and must be maintained over a long period of time (Slater, 1993). An understanding of the principles of these procedures, a certain degree of skill in carrying them out and the expertise to interpret reported results are important steps in developing the ability to correlate structure with performance.

The main reasons for testing of textiles are control of product, control of raw materials, process control and analytical information. Testing is actually a two-way process, in which the incoming raw materials that will be needed to manufacture the company's products will be scrutinized to ensure that they meet the specifications. That is, any manufacturing problems will be minimized while also ensuring that the textile item thus made will not result in problems for the customers; namely, that the item being manufactured is a quality product (Adanur *et al.*, 1995).

Testing is important, mainly for customer satisfaction of the textile product as well as to ensure product quality for the market in which the textile manufacturer competes. Testing is also important in order to control the manufacturing process and cost. In the textile industry, it is very important to use testing to control the manufacturing process for cost and other reasons. The importance of testing cannot be disregarded for product satisfaction and control of manufacturing cost. There are additional reasons such as customer relations, reputation, employee satisfaction and sales. Proper testing programmes are a very important ingredient of the efficient manufacturing business. Testing informs us whether the product will be saleable or not (McCullough, 1978).

Quick response and just-in-time delivery have become increasingly important as textile suppliers and purchasers like to shorten the supply-side pipeline. Quality considerations, mandated by the International Organization for Standardization (ISO), have forced suppliers to update testing methods, explore opportunities for more rapid testing and develop entirely new test methods. One of the most compelling reasons for the rise of rapid testing of textile products is the increasing globalization of the textile industry (Mock, 2000). Materials for an individual garment or fabric are often sourced today from a variety of suppliers, literally from around the globe. This necessitates the testing procedures to be highly competitive and accurate to analyse the textile product's characteristics to meet a particular end use. The test procedures today need to be more objective than subjective. Instrumentation may definitely help in this regard. A key issue in modern testing is to understand the complexity of the instruments and their working principles and finally to interpret the results in a systematic and scientific way.

1.2 Fabric testing for innovation and commercial needs

Textile fabrics are manufactured for many different end uses, each of which has different performance requirements. The chemical and physical structures of textile fabric determine how it will perform, and ultimately whether it is acceptable for a particular use. Fabric testing plays a crucial role in gauging product quality, assuring regulatory compliance and assessing the performance of textile materials. It provides information about the physical or structural properties and the performance properties of the fabrics.

Physical properties include those that characterize the physical structure of the fabric and tests that measure these properties are sometimes called characterization tests. Physical properties include fabric thickness, width, weight and the number of yarns per unit fabric area (i.e. fabric count). Performance properties are those properties that typically represent the fabric's response to some type of force, exposure or treatment. These include properties such as strength, abrasion resistance, pilling and colour fastness. Performance properties are mostly influenced by their physical properties. Although performance properties are often the primary factors in product development, aesthetic properties are equally important such as the way a fabric feels or drapes in design and development decisions. In some cases, trade-offs occur between performance characteristics and aesthetics, while in others, decisions based on aesthetic factors can also enhance product performance (Collier and Epps, 1999).

Throughout the textile supply chain, from distributors and textile mills to dyers and finishers, speciality textiles continue to grow in complexity. Today, more and more countries and markets have a stake in the treatment and testing of fabric (Hildebrandt, 2006). As consumers become more aware and more demanding of products, the number of tests required for textile materials has grown. As a result the testing of fabrics is increasingly varied, in constant flux and full of the unprecedented challenges of globalization. With the onset of new types of fabrics for the apparel industry, the development of technical textiles for functional applications, and the increasing number of innovations taking place in the garment sector, fabric testing procedures have undergone tremendous changes and there is a need to understand all the procedures before a testing system is adopted to investigate the performance of fabrics. For example, photochromic textiles change colour when exposed to UV light and revert to their original colour in the absence of UV. Ultraviolet radiation, with wavelengths ranging from 280 to 400 nm, has significant detrimental effects on both synthetic and natural fibre fabrics. Also, various stab and ballistic resistant garments are worn by police, soldiers, prison correction officers and other types of security, military and law enforcement personnel. The new fabric testing programmes must include techniques that determine the fabric's quick photochromic response, colour fastness and impact resistance properties. It is required to develop improved ways for UV protection of a range of fabric substrates and their evaluation, through systematic approaches to analyse the efficacy of such a finish.

It is difficult generally to describe what is meant by the term 'performance'. One may say that it has to do with how well the fabric 'holds up' in its intended end use, or we often use another equally ambiguous term, 'durability'. Although 'performance' is not easily defined directly, there is seldom any doubt in describing poor performance. A fabric may be deemed unacceptable because it fades, wrinkles, tears or shrinks or because it is too stretchy, or for numerous other reasons that are obviously important factors in the fabric's performance. The desirable level of fabric performance is defined in terms of the intended end use, ultimately by the user.

It is very important to predict a textile fabric's performance by testing. Fashion merchandisers, apparel designers, interior designers and textile scientists who have an understanding of textile properties and testing are equipped to make decisions that will benefit their clients and enhance profits for their businesses. Knowledge of fabric testing and its performance analysis can contribute to efficiency in solving consumer problems with textile products, and to the development of products that perform acceptably for consumers. As indicated above, retail buyers and producers of apparel and textiles are among those who use the fabric testing data and results in making decisions about their products. Most textile or apparel manufacturers will use either test methods or performance specifications that are published by testing organizations.

Innovations in fabric development have taken a new path. The applications of high performance and functional fabrics have been expanding rapidly. These fabrics have enhanced performance attributes and functionalities over commodity fabrics, and are used in areas such as:

- Protective garments (e.g. ballistic and stab resistant fabrics, UV protective wear)
- Functional fabrics (e.g. photochromic textiles)
- Textiles for acoustic applications (e.g. in automotives)
- Smart and electronic textiles (e.g. fabric sensors and actuators).

According to textile intelligence, 'performance textiles' represent one of the fastest growing sectors of the international textile and clothing industry. It has been estimated that in the European Union, the sports market alone is worth over 37 billion euros. In the USA it is worth around US$46 billion.

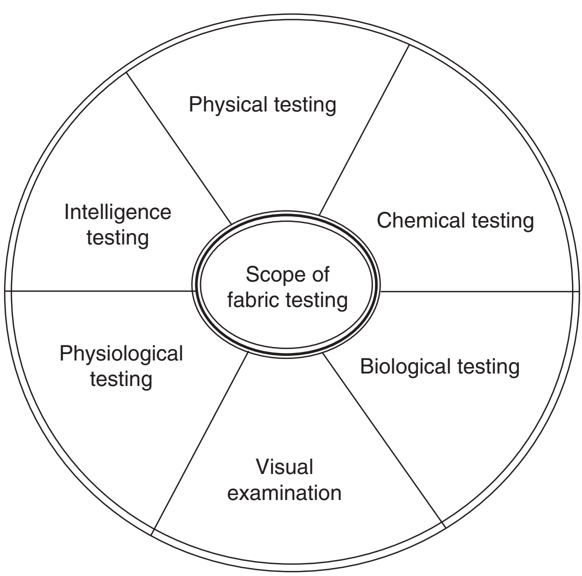
1.3 Need for integration of fabric testing literature

A number of textile research and testing organizations have published data on fabric testing and their procedures. There is a wide range of textile testing procedures for different fabrics for different end uses. The current literature on fabric testing is available in the form of textbooks and published articles. Researchers all over the world have been constantly involved in developing newer methods of fabric testing so as to meet the ever growing globalization and quality requirements. Their researches have resulted in extensive quality data and testing procedures for fabrics. These results should provide industries, fabric suppliers, apparel manufacturers, exporters, fashion designers and retailers with an enormous amount of information about the testing aspects of fabrics and apparel to meet the international standards. It appears that coverage of the existing literature in textbooks on fabric testing procedures and results is insufficient, although there have been many research achievements by scientists, researchers and industry experts in the areas of apparel, industrial fabrics such as technical fabrics, intelligent fabrics for special applications, nanotechnology applications, medical textiles, etc. Hence, a systematic approach towards integrating the knowledge available in the literature on fabric testing and developments in different aspects of fabric testing and the achievements of researchers and industry veterans would greatly benefit all those involved in quality assessment and evaluation of textile products.

1.4 Scope of fabric testing

The performance of a fabric is ultimately related to the end-use conditions of a material. The physical, chemical, physiological and biological influences on fabrics affect their end-use performance (Saville, 1999). Although all agents affect textile performance at the fibre, yarn and fabric levels, emphasis is generally given to fabrics since they represent the largest class of textile structures in a variety of applications.

Thus, a fabric is usually the most complex and representative form of a textile structure that is subjected to these agents and influences in most end uses. Testing of fabrics and quality control is broad in its scope (Fig. 1.1). It



1.1 Scope of fabric testing.

can include, for instance, the means for determining and controlling the quality of a manufactured product. It can be used to measure the outside factors that influence the test results. Testing of fabrics to the above influences of a physical, chemical and biological nature would be of great help to manufacturers in adjusting their process control parameters to produce the right material. An understanding of the visual examination of fabrics for their surface characteristics, shape, texture, etc., would be useful to designers in making proper selection of fabrics for a particular end use. These days, a number of fabrics are being modified to act as 'smart fabrics' in various industrial applications. These fabrics incorporate wearable electronic devices and gadgets to serve a specific function such as heat resistance, breathability, protection against external conditions, biomimicry, etc. The testing of the intelligent properties of these fabrics is increasingly important in the modern textile world.

1.4.1 Physical testing

The first broad class of factors that affect the performance of fabrics are physical agents and influences. These may be further subdivided into mechanical deformation and degradation, tactile and associated visual properties of fabrics (such as wrinkling, buckling, drape and hand) after their use and manufacture, and their response to heat, liquids and static charge. The testing of fabrics to mechanical deformation is very important and refers to fabrics that are subjected to variable and complex modes of deformation. They include tensile behaviour, compression, bending or flexing, shrinkage, abrasion resistance, frictional rubbing, torsion or twisting, and shear. Fabrics with special features or constructions require either additional tests or modification of existing tests for conventional fabrics to characterize adequately their mechanical and related properties. Coated fabrics must be evaluated not only for their mechanical integrity and behaviour but also for their bonding integrity of the coating to the fabric (Vigo, 1994).

The development of new fabrics for industrial and functional purposes has introduced a new set of physical testing procedures for these fabrics. Conductive fabrics used in conjunction with metals for detecting electromagnetic signals need to be tested for their electromagnetic behaviour. High performance clothing demands the testing of parameters such as impact resistance, thermal resistance, moisture vapour transmission, etc. Comfort and aesthetic properties of speciality fabrics is another area that needs to be addressed. Wear resistance of protective fabrics has to be considered in physical testing.

1.4.2 Chemical testing

Chemical and photochemical exposure of textiles may lead to yellowing or discolouration of undyed fabrics, to fading of dyed fabrics, and/or to degradation of dyed and undyed fabrics. These adverse results are due to depolymerization of the polymer chain in the fibre that may occur by hydrolysis, oxidative processes and/or crosslinking. Textile fabrics have varying degrees of resistance to chemical agents such as water and other solvents, to acids, bases and bleaches, to air pollutants and to the photochemical action of ultraviolet light. Resistance to chemical agents is dependent on fibre type, chemical nature of the dyes, additives, impurities, finishes present in the fibre, and to a lesser extent on the construction and geometry of the fabric. The testing of fabrics towards the above influences is very important in assessing the performance of the fabrics for various end uses (Jones, 1981). The development of chemically resistant protective clothing and textile filtration media has led to test methods relevant to these end uses.

1.4.3 Biological testing

Textile fabrics may be adversely affected by various microorganisms and insects. The effect of biological agents on textile fabrics is important for enhancing their end-use performance in many areas. Fabrics will have desirable aesthetic qualities if they can suppress odour-causing bacteria and other types of odour-causing microorganisms. The hygienic and medical effectiveness of fabrics is required to prevent the growth of dermatophytic fungi (those that cause skin disease), pathogenic and potentially lethal microorganisms on fabrics and to prevent their infestation by insects. Finally, prevention of fibre discolouration and degradation, usually by fungi and insects, prolongs the useful life of the material. Testing of fabrics and evolution of specific test methods for the above biological influences would help manufacturers, retailers and users of fabrics to develop strategic ways to maintain and protect their fabrics in storage and transportation. These tests would be useful for rapid screening of various modified and unmodified fabrics for their ability to withstand biological attack.

1.4.4 Visual examination

Fabrics can be evaluated for a variety of attributes to assess their performance by visual assessment either manually (subjective assessment) or by objective evaluation techniques. Visual examination of fabrics includes evaluating the texture, surface characteristics, dye shade variations, design details, weave patterns, construction particulars, pilling assessment, etc.

Subjective or objective measurement techniques may be employed to determine the above properties of fabrics. New types of fabrics and garments require careful examination of their surfaces for change in functional groups due to the application of finishes such as shape memory polymers or plasma treatments. Detailed microscopic examination can reveal distinctive microscopic and macroscopic features of fabrics. SEM, TEM and other microscopic tests may be used to identify the details. Objective measurement using image analysis is a new area in which a fabric's surface is analysed for texture, change in colour and surface modification due to a special finish application. High performance scanning can be used to visualize the colour aspects of a dyed and printed fabric, and colour coordinates can be measured using advanced colour physics principles.

Defect analysis is another major area today and is widely discussed in the textile industry. Defects are bound to occur in fabric during manufacture for a number of reasons. The quality of the final fabric is assessed based on the minimum number of defects present in it. Visual examination is a preliminary tool to detect faults in the fabric before they are being processed further. A good visual examination technique would help identify the faults and ensure that necessary corrective measures are undertaken by the respective departments to reduce the incidence of faults. Computerized image processing techniques are now widely used in the textile industry. The complex problem of fabric quality control through defect analysis may be solved by means of computer vision using advanced digital signal and image processing tools. Many of these image processing applications aim at detecting textural characteristics and textural defects of fabrics, including colour detection and dye shade variations.

1.4.5 Intelligence testing

In the last decade, research and development in smart/intelligent materials and structures have led to the birth of a wide range of novel smart products in aerospace, transportation, telecommunications, homes, buildings and infrastructures. Although the technology as a whole is relatively new, some areas have reached the stage where industrial application is both feasible and viable for textiles and clothing.

Intelligent textiles are fibres and fabrics with a significant and reproducible automatic change of properties due to defined environmental influences. They represent the next generation of fibres, fabrics and articles produced from them. They can be described as textile materials that think for themselves. This means that they may keep us warm in cold environments or cool in hot environments or provide us with considerable convenience and even fun in our normal day-to-day lives, for example through the incorporation of electronic devices or special colour effects. The most important intelligent materials at present are phase change materials, shape memory materials, chromic materials and conductive materials. Many intelligent textiles already feature in advanced types of clothing, principally for protection and safety and for added fashion or convenience. The testing programmes must include the testing of these fabrics to meet the ever growing demand for hi-tech fabrics and garments.

A shift in consumer values has occurred; instead of wanting the finest natural materials, people look at the engineered beauty, innovative design and intelligent aspects of products. Working closely with the clothing industry will develop the base that is needed to offer developments in intelligent clothing with huge commercial potential at minimum risk. At a later stage of development, such cooperation is likely to create more solid product assortments. Veterans expect that smart clothing technologies will be launched in the market within the next five to ten years. Hence there exists an absolute necessity to understand these new fabrics and their technologies. Testing of fabrics hitherto limited to traditional fabrics such as apparel, home furnishings and some varieties of technical textiles may not help in the long run to understand the properties of these new fabrics. New methods of testing and evaluation for intelligent and smart fabrics will become extremely important in the industry as the future relies more and more on these textiles.

We are still far from taking full advantage of the potential of information technology services, but the future for fully soft electronic products is very attractive and requires a different, but interesting, design approach. The geometric and mechanical properties of textiles (large flexible area) differ strongly from those of conventional electronics and can create new computer designs and architectures.

1.4.6 Physiological testing

Fabric physiology deals with the physiological characteristics of fabrics that are expressed in the well-being, performance and health of the wearer. It covers the areas of physics, chemistry, medicine, physiology, psychology and textile technology. Three important physical parameters that are instrumental in the physiological processes of fabrics are heat transmission, moisture transport and air permeability (Welfers, 1978). The physiological properties of fabrics relate to what the fabric or garment feels like when it is worn next to the skin, such as too warm, too cold, sweaty, allergic, prickly, etc. The psychological properties include mainly the aesthetics of the fabric such as colour, fashion, prejudice, suitability for an occasion, garment style, fabric finish, etc. (Smith, 1986).

Clothing is designed to maintain a hygienic and comfortable zone about the human body in which one feels well, even if inner or outer influences change rapidly. The zone in which the temperature, moisture and air circulation are properly matched is called the 'comfort zone'. The so-called microclimate that prevails there is defined by definite physical and physiological conditions. There are physiological and psychological positive comfort sensations but these tend to be more individualistic and less frequently noticed in the wearer of the garment. Therefore, in the assessment of a fabric or garment for a particular end use, the comfort of that product is considered to be very important. Fabric testing therefore needs to address the comfort properties of fabrics.

1.5 Importance of fabric testing

Globalization of the clothing industry and increased competition in the world market have encouraged consumers to expect high-quality garments at affordable prices. The quality of a garment, as normally perceived by a customer, depends on its aesthetic appeal, its ability to drape gracefully, its 'handle' and durability. These depend largely on the quality of the fabrics used and the making-up process (Potluri *et al.*, 1995). However, a more expensive fabric does not necessarily result in a better-quality garment. The colour and design of a fabric, along with drape, contribute to the aesthetic appeal of a garment.

During the past few years, the demand for quality textiles has increased globally, with the steady growth in population and income resulting in a rise in production and usage of different types of fibres, yarns and fabrics. To compete, especially in the world market now, there is greater demand for consistency in quality rather than for quantity of products. This implies production processes that guarantee overall quality – 'built-in' instead of merely 'inspected-on'. Today, quality assurance programmes have become necessary for survival not only in textiles but in every branch of industry.

Testing of fabrics has attained an important position in the textile industry due to the development of new types of fabrics for various apparel, furnishing and industrial applications. It has become almost mandatory for any textile manufacturing activity to carry out testing and evaluation of their textile products such as yarns and fabrics to meet international standards and the customer's satisfaction. Fabrics undergo a number of deformations during their use and a systematic analysis of the defects occurring in the fabrics is a key role played by the testing department.

The importance of fabric testing lies in the fact that in order to control the product and its cost, testing the performance of the goods becomes absolutely necessary. Fabric testing would benefit many in the industry and those involved in the export business. Professionals developing new fabrics use results from testing in selecting the right raw materials (Shaw, 1985). Decisions based on the accurate results of testing result in fewer rejections and customer complaints. Designers who create new fashions for the high-fashion industry are sometimes confronted with the problem of selection of the right quality of fabric for their garments. Fabric testing results would help them to understand the construction, properties and behaviour of fabrics for a particular end use. The textile scientist also stands to gain from a thorough understanding of fabric testing and analysis. Although one may be a specialist in textile chemistry or textile engineering, an understanding of how physical tests relate to fabric performance and consumer expectations is a necessary prerequisite to successful development of new textile fabrics. There are various stages in which fabric has to undergo quality inspection and this would reduce the burden on management to supply a fabric consignment with minimum defects. Proper testing on a regular basis can make the difference in the success or failure of a product and indeed the whole business.

There are a number of points in the production cycle at which testing may be carried out to improve the product or to prevent sub-standard fabric progressing further in the cycle. Fabric testing becomes important from the point of view of the following considerations.

1.5.1 Quality control for manufacturing

The meaning of the term quality is elusive: everybody has their own idea of what is meant by it, but it is difficult to express the idea in a concrete form. However, in order to produce a quality product, manufacturers need to have a definition of quality which will allow them to measure how far their products meet the requirements. Quality can be defined in two broad dimensions: perceived quality and functional quality. The perceived quality supports the corporate image, creates interest and generates an initial purchase. The buying is done on the basis of three basic parameters – the item looks good, feels good and offers good value for money – whereas the functional quality is related to the supplier and involves make, size and performance.

The buyer is responsible for selecting the best product on the basis of perceived quality (Garner, 1977). The supplier must produce this product and also achieve the functional aspects of quality. The key to all quality is the need for a 'standard'. A customer (buyer) in total expectation of quality demands a 'standard' quality and therefore this must be defined as 'an agreed' standard between the customer and the supplier.

Quality control refers to the performance on a periodic basis of certain tests designed to measure the characteristics of the raw or processed material. Regular controls on the quality of fabric produced at every stage of manufacture become most important for the fabric to live up to international standards. Such controls must conform with the following:

- The testing standards established by an individual organization, for example most of the big importers and retail store-chains have their own standard specifications and test methods for various clothing items.
- Established scientific specifications, such as those laid down by ASTM, AATCC, ISO, etc., and by other authorities of various countries.
- Market requirements or standards, such as meeting the requirements for width, ends/picks and weight for certain staple fabrics listed periodically in trade journals.
- Consumer needs or demands, for example to forecast the effectiveness of a material to meet consumer needs for wear or dye-fastness or to assess its satisfactory performance for the end use of the fabric.

1.5.2 Selection of fabrics

The production cycle as far as testing is concerned starts with the delivery of raw material. If the material is incorrect or sub-standard then it is impossible to produce the required quality of final fabric. Proper selection of fabrics becomes highly important for fashion designers, retailers, exporters and scientists and a thorough checking of fabrics for defects and construction particulars is a key step in preventing rejection of final consignments. Fabric manufacture consists of a number of separate processes such as winding, warping, sizing and weaving before the final fabric is produced. Knitted and non-woven fabrics form a separate section and all these processes demand the checking of quality at every stage of their production. The final product has to be checked for the required properties so that unsuitable material can be rejected or appropriate adjustments made to the production conditions.

1.5.3 Production monitoring

Production monitoring, which involves testing fabric samples taken from the production line, is known as quality control. Its aim is to maintain, within known tolerances, certain specified properties of the product at the level at which they have been set. A quality fabric for these purposes is defined as one whose properties meet or exceed the set specifications. Besides the need to carry out the tests correctly, successful monitoring of production also requires the careful design of appropriate sampling procedures and the use of statistical analysis to make sense of the results.

Online production monitoring systems monitor fabric quality and raise product packing efficiency. Using these systems it is possible to inspect the final product and collect all fabric defect data. This data provides precise information on the fabric rolls to optimize packing, to give access to all fabric defect data which gives the true picture of fabric quality, and to make snap cost-saving decisions in the manufacturing. In addition, online production monitoring tools provide an organization with a complete inventory of defects, while the fabric is being inspected on the folding table. They record all the defects, their location on the roll and their severity. Based on the final product specifications, it is possible to present an optimal cutting–mending master plan.

1.5.4 Assessing the quality of the final fabric

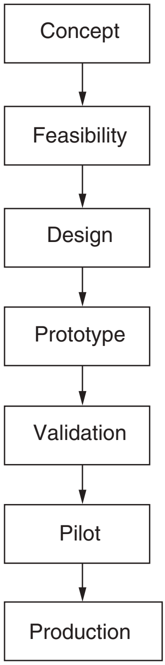
In this process the bulk production is examined before delivery to the customer to see if it meets the specifications. By its nature this takes place after the fabric has been produced. It is therefore too late to alter the production conditions. In some cases selected samples are tested and in other cases all the material is checked and steps are taken to rectify faults. For instance, some qualities of fabric are inspected for faulty places which are then mended by skilled operatives; this is a normal part of the process and the material would be dispatched as first quality.

1.5.5 Investigation of faulty material

If a faulty material is discovered either at final inspection or through a customer complaint, it is important that the cause is isolated. This enables steps to be taken to eliminate faulty production in future and so provide a better quality product. Investigations of faults can also involve the determination of which party is responsible for faulty material in the case of a dispute between a supplier and a user, especially where processes such as finishing have been undertaken by outside companies. Work of this nature is often contracted out to independent laboratories that are then able to give an unbiased opinion.

1.5.6 Product development and research

Product development is an important aspect in any manufacturing activity. The need for new product development arises from aggressive global competition, rapidly changing technologies, increasing complexity of markets and diversifying consumer trends. Today's consumer in the textile industry wants more variety in fabrics and garments, and better quality products at a lower price. Before the 1980s, competition in the business was in manufacturing capacity, whereas during the 1980s competition arose in product development and since the 1990s product development has been the battleground in any textile and garment business. The product development process converts ideas (inputs) into products (outputs) using the company's



1.2 Product development cycle.

workforce of designers, marketers, production personnel and accountants. A product development cycle can be represented as shown in Fig. 1.2.

Textile fabrics are evaluated during the development process. This helps textile scientists determine how to proceed at each stage of development. In the textile industry technology is changing all the time, bringing modified materials or different methods of production. Before any modified product reaches the marketplace it is necessary to test the material to check that the properties have been improved or have not been degraded by faster production methods. In this way an improved product or a lower-cost product with the same properties can be provided for the customer.

A large organization will often have a separate department to carry out research and development; otherwise it is part of the normal duties of the testing department. This section also includes testing in order to study theories of fabric or fibre behaviour. With advances in research and development, new products and processes may require testing procedures that are not provided through standard test methods. Test methodologies developed for a specific research application within one laboratory often gain wider acceptance and eventually are developed into industry-wide standard test methods.

1.5.7 Ecological considerations

In the past, the quality requirement of consumers for textile and garment products has concentrated on the comfort and performance of fabrics. Accordingly, regular testing usually focuses on the dimensional stability test, colour fastness, fabric construction and composition analysis, fabric performance test, fibre and yarn tests, etc. In developed Western countries, this perception is changing and a new element, ecological concern, is also becoming important. Especially in northern Europe, there is an increased awareness of environmental protection and the potentially harmful effects to human health from chemical processes and ingredients in food and clothing (Chan, 2007). This has resulted in an extra demand on testing and product certification of textile products. New laws and directions require manufacturers to make their products safer by minimizing the use of chemicals with hazardous substances and heavy metals such as cadmium, azo dye, chromium, lead and arsenic. While improving the quality of textile fabrics, ecological factors cannot be overlooked. The textile industry uses many chemical pollutants, allergens and carcinogens. These have to be severely restricted by laying down ecological requirements (Bhattacharya and Varadarajan, 1993). Only limited use of various chemicals such as azo dyes, heavy metals, harmful odours, etc., should be permitted. The textile industry also needs to address the problem of indiscriminate disposal of waste water loaded with toxic chemicals. Added quality control not only covers the materials purchased, but also includes all stages of production, quality control, final processing, garment wash, even the packaging and stock management. It thus provides much greater assurance and peace of mind. From the point of view of ecological requirements, testing of parameters such as prohibited azoic dyestuffs, carcinogenic and allergy-inducing dyestuffs, formaldehyde, pesticides, chlorinated phenols, chloro-organic carriers, extractable heavy metals, nickel, phthalates in baby articles, butyltin compounds (TBT and DBT), emission of volatile components, odours, etc., becomes extremely important.

1.5.8 Teaching and scientific institutions

A large number of technical and fashion institutes and universities are today offering quality education in textile engineering, technology and fashion-related subjects. Textile testing is a major subject of study in their courses. The testing of fabrics needs to become a regular subject in the curriculum, as fabrics play the major role in the textile and garment industry. Textile fabric testing should include laboratory experience for students, although there is hardly time in one semester of laboratory work for a student to perform all or even most of the tests that are included in fabric performance specifications. Students need to become comfortable reading actual standard specifications and test methods as they carry out their laboratory work. A systematic approach towards teaching of testing of fabrics using subjective and objective techniques will help the students and the faculty to understand the newer methods of testing.

Today's textile industry is in the transition zone between traditional textile production and the realization of highly focused design and production of added-value textiles. The innovative field of smart and intelligent fabrics is becoming increasingly popular and commercially successful because it combines product use with new material properties. More and more instrumental analysis techniques and the evolution of new test methods for testing intelligent textiles, for example testing the thermoregulatory response of a phase change material, or the shape memory effect of a shape memory garment, photo-responsive testing of fabrics, self-cleaning tests, testing of medical textiles and implants, and testing of technical textiles, would really help both students and the faculty to enrich their knowledge of testing procedures and standards. It is necessary to introduce future-oriented design concepts and textiles with high quality and added value that are focused on people's needs and that integrate high technology and design in a sensible manner. It is important to educate fashion and textile designers within the area of advanced fabrics and state-of-the-art technologies to prepare students for situations they will face once they have entered the job market. In addition, interaction between academic institutions and the industry needs to be improved by coordinating the testing activities, and they need to help each other in developing new testing procedures and standards for establishing constant quality standards for the industry.

1.6 Current status of fabric testing

Concern about product quality is universal in business and industry. Everyone in the industry needs his product to be tested according to the international standards so as to ensure quality in all respects. This will largely depend on the testing programme adopted by the testing house to evaluate the quality of the fabrics. Currently, fabrics are tested at different testing houses for their quality particulars before being exported or sold in the market. There are large commercial organizations that have set up their own laboratories and standards to assess the quality of their products to satisfy their customers. On the other hand, there exist a vast majority of private testing organizations that take up testing of fabrics on a commercial basis for the industries, testing their products as per the standards. In addition, there are a number of governmental and approved research organizations throughout the world that test and certify the fabric testing results to meet the standards. Hence, the whole scenario of fabric testing is not integrated to a particular area and the testing is not completely standardized and integrated.

1.6.1 Commercial testing

Globalization has clearly led more and more companies to produce newer products to meet the ever-growing demands of the textile industry. A company in the USA buying products from Asia and Europe may use a number of external testing laboratories and these companies are looking for more testing methods that will satisfy everyone. Today there are many laboratories for testing fabrics. They include in-house company or manufacturers' laboratories for testing. Thorough testing of fabrics is carried out in these in-house laboratories before being released to the market. On the other side, the buyers who buy the products may have their own testing laboratories for testing the incoming goods for their quality and standards.

Commercial testing of fabrics by private and governmental nodal agencies has made tremendous progress as these agencies have set up their laboratories throughout the world to undertake testing of fabrics according to the international standards. Laboratories such as AATCC, SGS, TRI, the Atlas Material Testing Laboratory in the USA, the Hohenstein Institutes in Germany, the Centro Controllo Tessile in Italy, the Korea Textile Inspection and Testing Institute in Korea, Covitex in Europe, Contexbel in Belgium, Inotex in the Czech Republic, BTTG in the UK, the Textiles Committee and SGS in India, etc., have been continuously catering to the needs of the industry and the exporters. The laboratories set up by the research organizations also cannot be ignored. The contribution of these non-profit testing organizations is tremendous in developing new sets of testing standards and procedures for various types of fabrics. These laboratories incorporate advanced testing instruments and objective techniques to carry out testing of fabrics to meet customer requirements.

Most competent fabric manufacturers have their own test procedures in addition to the recommendations of the above professional organizations. New and innovative fabrics that are coming on to the market, such as intelligent fabrics, nano-textiles, medical implants and various technical fabrics, must be watched carefully and new testing schemes must be introduced in order to ensure performance of these fabrics and their acceptance by customers. It is most important to test the fabrics in order to control their cost.

1.6.2 Research and development

The role of the research organizations involved in testing of fabrics and other products is to collect relevant data or facts and invent falsifiable hypotheses about relationships among these facts. Experiments or tests are then conducted to verify the predictions of the hypotheses. In addition, the organizations set up standards for the testing of fabrics and garments to be eventually followed by the industries. A great amount of time and effort has been spent by researchers and scientists to develop new fabrics to cater to the needs of the industry. The direction of research suggests that these new fabrics will make headway in the coming years and a revolutionary change might be expected in areas such as industrial textiles, intelligent fabrics and medical textiles. The credit goes to the scientists and researchers of various textile institutes of great repute and the research community in the industry and several other nodal organizations. A wealth of information is available on their research and it is time for industries, exporters and buying houses to borrow their scientific findings and research results and to incorporate them into their manufacturing and testing programmes. Such an effort to integrate the results of researchers and scientists with the test procedures followed by the industry would go a long way towards understanding the procedures for testing new types of fabrics and their characteristics in order to alleviate the problems of misunderstanding among manufacturers, retailers and exporters. The integration of industry practices and the scientific results would help standardize the testing practice for existing as well as newer types of fabrics in the long run.

1.7 Standards for tests

The term 'standard' is used often in regard to testing of products. It may be ambiguous at times as it can have several different meanings. It can refer to the actual test methods or to the minimum acceptable level of performance on a particular test. Any testing which is to be done on a product will need to be done by employing standard test methods. In this way, every possible variable within the test method will be precisely controlled. The reason for this is that reproducibility must be absolutely assured. That is, the test results in a plant or laboratory will need to be the same as those obtained within the customer's laboratory; otherwise, lawsuits would abound.

Test methods are developed for textiles and textile products by several different organizations. They are typically developed in response to a need expressed by an individual manufacturer, a product user, or occasionally by a consumer group. In most organizations that develop standard test methods, once the test procedure is clearly defined, the proposed method then undergoes interlaboratory trials. Interlaboratory testing can reveal problems with procedures that must be corrected and they can also be used to determine whether the test method is applicable to a particular type of product; for example, does the method work only on woven fabrics, or can it also be used to determine the precision of the test? Precision indicates whether the tests will repeatedly produce the same results on the same fabric specimen. Interlaboratory tests determine the reproducibility of the test from one lab to another and from one operator to another. A test which has a high level of precision has good interlaboratory reproducibility and good between-operator reproducibility.

Throughout the world there are numerous organizations that develop standard test methods and performance standards for textiles. Because of the increasing global market in textiles and apparel, a growing need exists for uniformity of standards on an international basis. This would alleviate some of the problems faced by manufacturers that export, and countries that import from foreign manufacturers. For example, products that are imported to the United States must meet standards set by the United States, regardless of the standards or methods that exist in the country where the products are manufactured.

1.7.1 International organization for standardization

The International Organization for Standardization (ISO), based in Geneva, Switzerland is an organization that serves member organizations throughout the world. There are three categories of membership in ISO. These are member body, correspondent member and subscriber member. A member body is the national organization that is most representative of standardization in its country. The member body which represents the United States is the American National Standards Institute (ANSI). Other countries have comparable organizations that are member bodies, such as the Standards Council of Canada (SCC), the British Standards Institution (BSI), Standards Australia (SAA), the Bureau of Indian Standards (BIS), the China State Bureau of Technical Supervision (CSBTS) and Ente Nazionale Italiano di Unificazione (UNI), which represents Italy. Member bodies are responsible for informing potentially interested parties in their respective countries of relevant international standardization initiatives and assuring that a concerted view of each country's interest is represented during international negotiations leading to standards agreements.

1.7.2 Major American organizations

American National Standards Institute

ANSI represents the United States member body in the ISO. The purpose of ANSI is to coordinate voluntary standards development and use in the United States and to serve as liaison between standards organizations in this and other countries, through the ISO.

American Society for Testing and Materials

The purpose of this organization is to develop standards on characteristics and performance of materials, products, systems and services. The standards developed by ASTM include test methods, specifications and definitions and usually deal with physical properties of materials. ASTM writes standard tests not only for textiles but also for virtually every other product such as steel, plastics, lumber, etc. For textiles, ASTM writes primarily physical-type tests such as methods for testing the tensile strength, abrasion resistance, twist determination, fibre maturity, denier and yarn count, among many others.

American Association of Textile Chemists and Colourists

AATCC was founded to promote greater knowledge of textile dyes and chemicals and therefore is concerned specifically with textile products. This organization works very closely with ASTM but writes chemical-type tests. In addition to the development of test methods, AATCC sponsors scientific meetings and promotes textile education. The activities are concerned primarily with the chemical properties of textiles in contrast to ASTM's emphasis on physical properties.

1.7.3 Other national organizations

Apart from international organizations and major American standards organizations, many countries have their own national standards organizations, for example BSI (Britain), BIS (India), JIS (Japan) and DIN (Germany) standards. The same arguments that are used to justify national standards can also be applied to the need for international standards to assist worldwide trade, hence the existence of International Organization for Standardization (ISO) test methods and, within the European Union, the drive to European standards.

Japanese Industrial Standards

Japanese Industrial Standards (JIS) specifies the standards used for industrial activities in Japan. The standardization process is coordinated by the Japanese Industrial Standards Committee and published through the Japanese Standards Association. The JIS in many ways has been Japan's answer to ISO. The JIS is extremely sophisticated and complex and goes beyond the requirements of the ISO 9000 series but essentially performs the same quality management function. The JIS is more rigorous and comprehensive in standards, making it extremely challenging for an organization to successfully implement. This fact has led to its adoption almost exclusively in Japan and makes its requirement outside Japan very rare. Organizations that have a JIS certification can be considered to be at least as good as if not better than an organization that has an ISO 9000 certification, with most JIS systems being closer in scope to ISO 9001.

Bureau of Indian Standards

The Bureau of Indian Standards (BIS), the national standards body of India, is involved in the development of technical standards (popularly known as Indian Standards), product quality and management system certifications and consumer affairs. Apart from setting standards for textiles, the organization sets standards for other major industries in the country. It resolves to be the leader in all matters concerning standardization, certification and quality.

British Standards Institution

The British Standards Institution (BSI) is the world's leading standards organization, and facilitates the setting of standards, inspections and quality management. It is a non-profit distributing organization, independent of government, industry or trade associations, whose operating divisions (product certification, quality assurance, standards, testing and training services) are designed to further the use of standards. Manufacturers, importers and retailers rely upon BSI testing to independently assess the performance of their products for safety, reliability and quality. Its certification trade mark, the Kitemark, has been established for more than 90 years.

German Institute for Standardization

With its 81 standards committees the German Institute for Standardization (DIN) is the responsible standardization body of the Federal Republic of Germany. Within the framework of its terms of reference, DIN is the German member in the European and international standardization organizations. DIN represents the interests of German standardization at both the national and international levels. Maintaining a collection of more than 38 000 documents, DIN offers standards covering everything from textiles to standard methods for analysis of contaminants in water, to screws and bolts. Standards offered by DIN provide companies and individuals doing business in Germany or with German businesses a solid basis for quality, safety, and minimum functionality expectations.

1.8 Future trends

The textile industry is poised for a phenomenal growth in the coming years. With the introduction of new types of fibres, yarns and fabrics for high-end applications, the testing for the performance of these new materials has to undergo rapid changes and take new dimensions. Fabrics are no longer meant only for traditional apparel and the demand for new types of fabrics such as technical fabrics and medical textiles for applications in industrial segments is increasing. The traditional way of testing fabrics for their performance properties may not be critical for the sustainable growth and requirement of standards for fabrics to meet the international challenges. New methods of testing and procedures are the need of the hour because fabric testing plays a crucial role in gauging product quality, assuring regulatory compliance and assessing the performance of textile materials for future requirements. In the wake of globalization and faster assessment of fabric quality parameters and to meet the international challenges, the future of fabric testing relies on the following considerations.

1.8.1 Manual to automatic testing

Fabric testing relies more on the manual methods of testing. There is always an element of human error in the testing process, which leads to spurious results and affects the final product evaluation. In addition, the reproducibility of the results may not be possible with manual methods to reconfirm the results of testing. There is a limitation on the testing speeds that one can achieve during manual testing. The increased stress factor on the human mind also cannot be ignored. All these factors have resulted in the introduction of automatic testing procedures using high-speed instruments to evaluate the performance of the fabrics.

The trend is definitely changing. Many fabric and garment tests that once required manual preparation and expert judgement have adapted to accommodate devices that take over part or all of the testing processes (Thiry, 2002). Instrumental testing is fulfilling the needs in quality testing labs, in the production environment and in research and product development. One of the most compelling reasons for the rise of instrumentation in fabrics and garment testing is the increasing globalization of the textile industry. Materials for an individual garment or a line of garments are often sourced today from a variety of suppliers, literally from around the globe. It is important to retailers to increase the amount of testing offshore before the garments arrive at their destination. However, they find that it is impossible to standardize testing conditions around the world. Appropriate instruments help disparate labs to produce reliable and repeatable results. In addition to the several reasons mentioned above, the move towards instrumentation in the testing of fabrics has come as a result of the need for repeatable and reliable results, the lack of educated manpower to perform manual tests, the savings in time and money and the globalization of the textile industry. In some areas, instrumentation is well established. In others, researchers are developing new technologies. Despite compelling needs, the movement towards instrumentation is progressing in fits and starts, and as instrumentation moves more into fabric and garment testing, test methods will have to be adapted to include instrumental measurements for accurate and reliable results.

With the development of new sensors and faster computers at cheaper prices, online measurement and quality control is becoming a reality in the textile industry. Online measurement of length, speed and shrinkage of a fabric, using the latest online equipment, is widely used in automotive testing. Online fabric fault detection using digital image processing, opto-electronic processing and online monitoring for uniformity of non-woven fabrics has to be considered in future. Fabric mechanical properties vary along the length of a fabric roll. The properties measured on a few fabric samples do not adequately represent the entire length of the fabric roll. Therefore, it is desirable to measure properties continuously along the length of a fabric (Potluri *et al.*, 1995). Very little progress has been reported in this area. The ultimate objective of automation should be to achieve online continuous measurement of all the fabric properties, during finishing or the final inspection process. The fabric property data can be supplied with each roll of a fabric, which may be utilized during the making-up process.

Based on extensive research, it has been well established that garment quality and its making-up process can be controlled based on fabric mechanical and surface properties. Widespread use of this technology in industry would depend on the availability of totally automated test equipment, to eliminate human errors and improve productivity, in terms of the number of samples tested in a given duration. The development of robotic systems, capable of conducting all the fabric tests on a single sample without operator intervention, would completely eliminate the human handling and operative errors to achieve the best results of fabric testing.

1.8.2 Artificial intelligence

Artificial intelligence is a branch of computer science dedicated to the study of computational activities that require intelligence when carried out by human beings. Artificial neural networks and expert systems technologies have been particularly helpful in solving an array of problems in the textile industry and are one of the promises for the future in computing. Offering an ability to perform tasks outside the scope of traditional processors, they can recognize patterns within vast data sets and then generalize those patterns into recommended courses of action (Liu and Mandal, 2006a). Artificial neural networks offer the textile and apparel industry numerous opportunities, with potential applications in fabric inspection, fabric colour fastness grading, fabric comfort control and layout planning in apparel manufacture. The application of artificial intelligence through neural networks will become crucial in future testing of fabrics and garments. Such techniques can prove to be very useful in correlating the fabric structure with its properties and hence predicting the performance of the fabric. Simulation of fabric shapes and patterns for a particular body configuration can be studied through artificial intelligence techniques and a variety of fabric data can be handled at a great pace.

1.8.3 Subjective to objective measurement

In the clothing industry traditionally, the experts relied on their subjective estimations of the fabric properties without using any testing equipment. They examined the fabric by performing certain physical movements, such as stretching, bending, shearing and rubbing, and expressed their feelings in terms of subjective sensations, such as stiffness, limpness, hardness, softness, fullness, smoothness and roughness. These expressions formed the basis for fabric selection, though such subjective evaluation is not very accurate. This manually oriented estimation is being followed even today in the majority of clothing industry production lines and particularly in fabric handling for sewing.

These days, fabric testing is changing from subjective to objective measurement techniques. The objective measurement of fabric properties has attracted the interest of researchers from the beginning of the previous century. Fabric objective measurement of mechanical, geometrical, surface and large deformation properties represents a very powerful tool for quality control of fabric manufacturing, finishing and refining operations. It enables the setting up of an integrated computerized scientific database incorporating in objective terms the enormous wealth of experience of numerous experts who have worked in the textile and clothing industries over many years in different countries throughout the world. Test methods that require an advanced level of expertise and skilled judgement are today being performed by a workforce with diminishing abilities and experience. In the research community as well as in the clothing industry, there is wide interest in the objective measurement of fabric properties.

1.9 Conclusions

Textile testing has attained an important position in the textile industry. It has become absolutely necessary for any textile manufacturing activity to subject its products for scientific testing before being released to the market.

Fabric testing, a part of textile testing, is gaining importance as a variety of fabrics are being introduced in the market for specific end uses. The main objective of any textile operation is to make a profit. The past two decades have seen the marketplace change dramatically, making this objective harder to reach. Competition around the world in every area of textiles has become more difficult. In order for a company to make a profit, it has to change its strategy.

Fabrics are used in a wide range of applications in apparel, domestic and industrial areas. Applications include not only clothing and accessories, bedding and interior decoration, but also textile structures that are used to make cables, cords, parachutes, hot-air balloons, tents, etc. Further, new fabric composites and other textile fabrics can be traced in space structures, aircraft, machine parts, civil engineering, marine engineering, artificial limbs, sports goods, musical instruments and so on. The ever increasing application of textile fabrics in various fields is making textile companies emphasize value. In order to thrive in the marketplace they have to gain a sustainable competitive advantage. In order for many companies to achieve targeted competitive advantage, manufacturing facilities have to undergo a major transition in their testing programmes. This transition requires new tools and technologies for managerial decisions. More new and advanced fabric testing techniques such as automatic testing using high-tech instruments, and objective measurements of fabric sensory and mechanical properties must be introduced. Artificial intelligence techniques for quality and process control must become the routine test procedures for the testing houses and research organizations. The future certainly lies with the ability to test fabrics reliably and cost-effectively. This is only possible with the availability of totally automated test systems, to enable their use in an industrial environment.

The tedious process of sample preparation should be eliminated in future developments. A test system capable of measuring fabric properties on a large fabric sample should be developed, to eliminate the need for sample preparation and the difficulties associated with free curling edges. The programme of quality control in any organization must include instrumental analysis of data, neural networks for prediction of fabric properties, and assessment of colour and defect analysis through image processing techniques to streamline and simplify test methods. Finally, it is envisaged that online measurement of fabric mechanical, surface and dimensional properties would become a reality in the near future.

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2
Sampling and statistical analysis in textile testing

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Abstract: The nature and the major reasons of sampling are described at the beginning of this chapter. In the study of sources of error, particular attention is put on the discussion of measurement precision of test methods in relation to repeatability and reproducibility. The essence of statistical analysis is on the treatment of variability. The reduction of variability is briefly discussed. In the application side, both point estimation and interval estimation are mentioned with special emphasis on the determination of sample size, i.e. number of tests. The methodology of comparing means using ANalysis Of VAriance (ANOVA) approach is illustrated with solid examples in the textile field.

Key words: statistical analysis, source of error, precision, accuracy, repeatability, reproducibility, point estimation, interval estimation, sample size, comparing means, hypothesis testing, analysis of variance, interaction effect, fabric sampling

2.1 Introduction: the requirement for sampling and statistics in textile testing

A sample is a subset of a population. The researchers have to decide on how to obtain the sample and, once the sample data are in hand, how to use them to estimate the characteristic of the whole population. Sampling involves questions of sample size, how to select the sample, and what measurements to record.

Sampling is usually distinguished from the closely related field of experimental design, in that in experiments one deliberately adjusts the parameters of a population in order to see the effect of that action. In sampling, one wants to find out what the population is like without disturbing it.

Sampling is also distinguished from observational studies, in which one has little or no control over how the observations on the population were obtained. In sampling one has the freedom to deliberately select the sample, thus avoiding many of the factors that make data observed by happenstance or convenience.

In many daily cases sampling is the only practical way to determine something about the population. Some of the major reasons for sampling include:(14)

- The destructive nature of certain tests. In the area of textile product development, yarns, fabrics and similar products must have a certain minimum tensile strength. To ensure that the product meets the minimum standard, the quality control department selects a sample from the current production. Each piece is stretched until it breaks, and the breaking point is recorded. Obviously, if all the fabrics or all the yarns were tested for tensile strength, none would be available for sale or use.
- The physical impossibility of checking all items in the population. The populations of fabrics are continuous pieces instead of isolated items. For each test specimen, the portions of the fabric not fixed by the jaws in the test machine are not involved in the tensile test, and in this sense not the whole population is evaluated even though all the fabric rolls in the population are cut into test specimens for testing.
- The cost of studying all the items in a population is often prohibitive.
- To include the whole population would often be too time consuming. In the commercial world, buyers will not wait for a year for test reports on their newly purchased fabric lots.
- The adequacy of sample results. Even if funds were available, it is doubtful whether the additional accuracy of 100% sampling (that is, studying the entire population) is essential in most problems.

2.2 Sampling and statistical techniques used

Sampling design[20] is the procedure by which the sampling units are selected from a population. Most inference problems in sampling are to estimate some summary characteristics of the population, such as the mean or the variance, from the sample data. Additionally, in most sampling and estimation situations, one would like to assess the confidence associated with the estimates; this assessment is usually expressed using confidence intervals.

Theoretically, if the sample size were expanded until all N units of the population were included in the sample, the population characteristic of interest would be known exactly. The uncertainty in estimates obtained by sampling is due to the fact that only part of the population is observed.

With careful attention to the sampling design and using a suitable estimation method, one can obtain estimates that are unbiased for population quantities, such as the population mean and variance, without relying on any assumptions about the population itself. The estimate is unbiased in that its expected value over all possible samples that might be selected with the design equals the actual population value. Additionally, the random or probability selection of samples removes recognized and unrecognized human sources of bias, such as conscious or unconscious tendencies to select units with larger (or smaller) than average values of the variable of interest. Such a procedure is especially desirable when survey results are relied on by persons with conflicting sets of interests. In such cases, it is unlikely that all parties concerned could agree on the purposively selected sample.

A probability design such as simple random sampling thus can provide unbiased estimates of the population mean and also an unbiased estimate of variability, which is used to assess the reliability of the sampling result. In addition to the unbiased or nearly unbiased estimates from the sample, researchers are looking for precise or low-variance estimates and procedures that are convenient or cost-effective to carry out.

In sampling theory it is assumed that the variable of interest is measured on every unit in the sample without error, so that errors in the estimates occur only because just part of the population is included in the sample. Such errors are referred to as sampling errors. But in real situations, non-sampling errors may arise as well. Errors in measuring or recording the variable of interest may also occur. Careful monitoring throughout every stage of a sampling process is needed to keep errors to a minimum.

2.3 Sources of error

The *Encyclopaedia Britannica* has the following description on measurement error. Measurement begins with a definition of the measurand, the quantity that is to be measured, and it always involves a comparison of the measurand with some known quantity of the same kind. If the measurand is not accessible for direct comparison, it is converted or 'transduced' into an analogous measurement signal. Since measurement always involves some interaction between the measurand and the observer or observing instrument, the effects of such interaction can become considerable in some types of measurement and thereby limit accuracy.

The problem of error is one of the major concerns of measurement theory.[(11,16)] A measurement is useless without a quantitative indication of the magnitude of that error. Such an indication is called the uncertainty. Without knowing the uncertainty,[(9,10,13)] the comparison of a measurement result with a reference value or with results of other measurements cannot be made. Among the various types of error that must be taken into account are errors of observation (which include instrumental errors, personal errors, systematic errors and random errors), errors of sampling, and direct and indirect errors (in which one erroneous measurement is used in computing other measurements). The above description of measurement error can be summarized through the following expression: measurement error = methodology error + instrumental error + personal error.

2.3.1 Precision and accuracy

A great deal of attention has been given to the measurement of the precision of test methods under ideal conditions.[(7)] Ideal conditions within a laboratory might be considered to involve one operator, using the same instrument, testing a sample of standard material, and duplicating the test within a short period of time (repeatability[5,15]). Performance under ideal conditions may have little relevance to the precision of the test method under routine conditions of use. In commercial tests – between buyer and seller, upon shipment and receipt, in national and international trade – it is important to know the routine but not the ideal precision so that decisions to accept or reject are not made on falsely optimistic premises. It is desirable to adopt a concept of the precision of a test as the inherent variation in results when a test method is used to compare materials in commerce. The inherent variation must be measured under conditions of actual use. Differences larger than the inherent variation, then, are real differences in material that have economic consequences in buying and selling.

Precision is a measure of the scatter of results when a test method is repeated. The standard deviation is a basic measure of scatter when the variable measurements follow a normal distribution. Within-laboratory precision limits would include random variation in material, different operators, different instruments and different days. Between-laboratory precision limits should be based on using samples of the same homogeneous material and a completely different set of operators and instruments and no restriction on time (reproducibility[5,15]).

Precision implies a state of control. Within a laboratory a state of control means that instruments are properly calibrated, operators are well trained and follow standard procedures, chemicals and reagents are fresh and environmental conditions are stable. A state of control indicates that variations in test results are random; departure from control means that some assignable, non-random cause has affected the result. Thus, precision involves random scatter only. The more precise a method, the smaller the random scatter.

Between laboratories the scatter is usually greater than within a laboratory because of differences in instruments, in calibration or operating procedures, in operator training, in reagents, or in environmental control. Differences between laboratories should be random differences rather than fixed biases. Inter-laboratory control[6] can be maintained by participation in check sample programmes (inter-laboratory calibration, or proficiency test).

Accuracy is the degree of agreement between the experimental result and the true value. Precision is the degree of agreement among a series of measurements of the same quantity; it is a measure of the reproducibility of results rather than their correctness. Errors may be either systematic (deterministic) or random (stochastic). Systematic errors cause the results to vary from the correct value in a predictable manner and can sometimes be identified and corrected. A popular cause of systematic error is improper calibration of an instrument. Random errors are the small fluctuations introduced in nearly all analyses. These errors can be minimized but not eliminated. Statistics is used to estimate the random error that occurs during each step of an analysis, and, upon completion of the analysis, the estimates for the individual steps can be combined to obtain an estimate of the total experimental error.

2.3.2 Reduction of test variability

It is stated in the ASTM Standard D4853[3] that there are three circumstances a test method would require to reduce test variability:

1. During the development of a new test method, ruggedness testing might reveal factors which produce an unacceptable level of variability, but which can be satisfactorily controlled once the factors are identified.
2. Another circumstance is when analysis of data from an inter-laboratory test of a test method shows significant differences between levels of factors or significant interactions which were not desired or expected. Such an occurrence is an indicator of lack of control, which means that the precision of the test method is not predictable.
3. The third situation is when the method is in statistical control, but it is desired to improve its precision, perhaps because the precision is not good enough to detect practical differences with a reasonable number of specimens.

Identifying probable causes of test variability

Sometimes the causes of test variability will appear to be obvious. These should be investigated as probable causes, but the temptation should be avoided to ignore other possible causes. To aid in selecting the items to investigate in depth, plot frequency distributions and statistical quality control charts. Make these plots for all the data and then for each level of the factors which may be causes of, or associated with, test variability. In examining the patterns of the plots, there may be some hints about which factors are not consistent among their levels in their effect on test variability. These are the factors to pursue.

2.4 Applications

The statistical theory has extensive applications in textile testing. Based on the theory, R&D personnel could determine the quantity of sampling units and estimate the range of their product's quality level under prescribed tolerance and chance factors. The details of the applications of the statistical theory are described in the following sections.

2.4.1 Point estimations of mean and variance

The estimations of population mean and variance are the major tasks in the general textile evaluation. The average quality is mostly recognized as the representation of the product quality. Sometimes uniformity of quality may be even more important than its average performance, e.g. for yarn strength, weavers would prefer more uniform yarn with slightly lower average strength instead of a high-strength yarn with occasional ultra-weak points.

In random sampling, the sample mean $\bar{x}$ and variance s^2 are unbiased estimators of the population mean μ and variance σ^2, i.e. $\hat{\mu} = \bar{x}$, $\hat{\sigma}^2 = s^2$.

$$\mu = \frac{\sum_{i=1}^{N} x_i}{N}$$

$$\sigma^2 = V(X) = \frac{\sum_{i=1}^{N} (x_i - \mu)^2}{N}$$

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

$$s^2 = \hat{V}(X) = \frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}$$

$$V(\bar{X}) = \begin{cases} \dfrac{\sigma^2}{n} & \text{for infinite population} \\ \dfrac{N-n}{N-1} \times \dfrac{\sigma^2}{n} & \text{for finite population with size } N \end{cases}$$

$$\hat{V}(\bar{X}) = \begin{cases} \dfrac{s^2}{n} & \text{for infinite population} \\ \dfrac{N-n}{N-1} \times \dfrac{s^2}{n} & \text{for finite population with size } N \end{cases}$$

The quantity $(N - n) / (N - 1)$ is the finite population correction factor, when N is much larger than n, i.e.

$$\lim_{N \to \infty} \frac{N-n}{N-1} = 1$$

On the other hand, when the sample size n is close to the population size N, the variance will become smaller until when $n = N$ the variance is zero, since there is only one possible way to take the sample and $\bar{x} = \mu$.

2.4.2 Interval estimation of mean and variance

With the point estimates of the population mean, it is desirable in addition to make an assessment regarding the precision of the estimate. This can be done by constructing a confidence interval within which it is sufficiently sure that the true value lies under the assumption that bias does not exist. The $100(1 - \alpha)\%$ confidence interval (I) of a population parameter θ is derived from the probability equation $\Pr(\theta \in I) = 1 - \alpha$. For the population mean μ, its $100(1 - \alpha)\%$ confidence interval I is given as

$$\left(\bar{x} - t_{\alpha/2,n-1} \times \frac{s}{\sqrt{n}}\sqrt{\frac{N-n}{N-1}}, \bar{x} + t_{\alpha/2,n-1} \times \frac{s}{\sqrt{n}}\sqrt{\frac{N-n}{N-1}}\right)$$

where n is the sample size, N is the population size, $\bar{x}$ is the sample mean, and $t_{\alpha/2,n-1}$ is the value of the Student's t-distribution with $n - 1$ degrees of freedom and right tail area $\alpha/2$ (see Fig. 2.1).

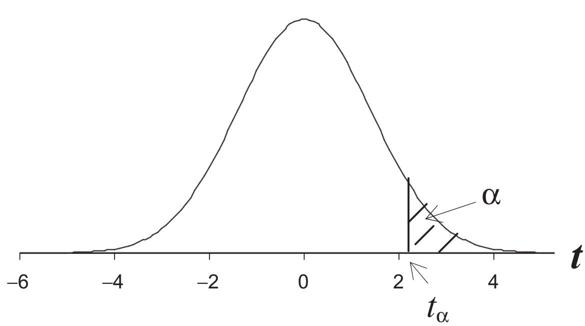
For the population variance σ^2, its $100(1 - \alpha)\%$ confidence interval I is given as:[12]

$$\left(\frac{(n-1)\times s^2}{\chi^2_{\alpha/2,n-1}}, \frac{(n-1)\times s^2}{\chi^2_{1-\alpha/2,n-1}}\right)$$

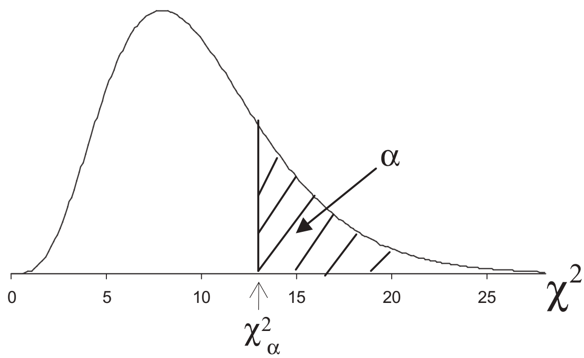
where s^2 is the sample variance as defined in Section 2.4.1, and $\chi^2_{n-1,\lambda}$ is the value of the χ^2 distribution with $n - 1$ degrees of freedom (see Fig. 2.2) and right tail area λ ($\lambda = \alpha/2$ or $\lambda = 1 - \alpha/2$).

2.4.3 Number of tests

For the purpose of calculating the number of specimens per laboratory sampling unit for testing, information is needed on the variability of individual observations made as directed in the method to be employed. The variability of individual observations depends upon the test method itself,



2.1 Student's *t*-distribution.



2.2 Chi-square distribution.

upon the experience and training of the operator, upon the calibration and maintenance of the apparatus used, and especially upon the variability of the property in the material being tested. For this reason, it is preferable for the user of the test to determine the variability of individual observations experimentally under the actual test conditions of interest and upon specimens from the types of material to be tested by use of the method.

In addition to the variability of individual observations, the required number of specimens depends upon the values chosen for the allowable variation and probability level. Both of these factors are based on engineering judgement.

For a normal population with mean μ and variance σ^2, when the population mean is to be estimated, the number of tests n is determined as follows:[20]

$$\Pr(|\hat{\mu}-\mu| > d) < \alpha$$

$$\Rightarrow z \times \sqrt{\frac{N-n}{N-1} \times \frac{\sigma^2}{n}} = d$$

$$\Rightarrow n = \frac{1}{\dfrac{1}{n_o} + \dfrac{1}{N}} \quad \text{where } n_o = \left(\frac{z_{\alpha/2} \times \sigma}{d}\right)^2$$

where $z_{\alpha/2}$ is the value of the standard normal distribution with right tail area $\alpha/2$, d is the acceptable error or the tolerance, and α is the probability that the estimated mean is within tolerance.

When σ is directly proportional to μ, the relative error d/μ is acceptable instead of the absolute error d. The number of tests n is also determined as above with n_o defined as:

$$n_o = \left(\frac{z_{\alpha/2} \times V}{P}\right)^2 \quad \text{where } V = \frac{\sigma}{\mu} \text{ and } P = \frac{d}{\mu}$$

Normally the variability of individual observations made under conditions of single-operator precision is considered. Other sources of variation, such as differences between instruments, operators or laboratories, or differences with time, may also have to be taken into account when certain test methods are being written or revised.

According to the standard ASTM D2906,[2] the components of variance are combined to obtain the total variance S_T^2:

$$S_T^2 = S_B^2 + S_W^2 + \frac{S_S^2}{n}$$

where S_S^2 = single-operator component of variance

S_W^2 = within-laboratory component of variance (all laboratory variation except single-operator variation)

S_B^2 = between-laboratory component of variance (calibration practice, etc.)

n = number of observations by a single operator in each average.

The contributions of the variability of lot sampling units, laboratory sampling units and test specimens to the variation of the test result of a sampling is fully explained in the ASTM Standard D4854.[4]

In the absence of necessary information, the standard advises a somewhat larger number of specimens than would ordinarily be obtained from an estimate of the variability of determinations in a user's laboratory, with 1.414 times the best estimate for a typical value of the variability,[1] i.e. twice the number of specimens.

Remarks

- When variability is directly proportional to the mean, use CV% to replace standard deviation, and % error to replace absolute error.
- When a property needs to be controlled in only one direction instead of both directions, use one-sided limits. (Yarn count is an example of a property that ought to be controlled in both directions. Fabric strength is an example of a property which needs to be controlled in only one direction, since fabric strength has no maximum limit.)
- When the frequency distribution of the data is markedly skewed or the standard deviation is correlated with the mean but not proportionally, consider making a transformation of the original data which will result in a normally distributed variate with standard deviation being independent of the mean. Please refer to the standard statistical texts for the choice of suitable transformations, e.g. *Statistical Theory with Engineering Application*, by A. Hald, John Wiley & Sons, New York, 1952.

- Selection of the probability level is largely a matter of engineering judgement. Experience has shown that for both one-sided and two-sided limits, a 95% probability level is often a reasonable one.
- The allowable difference d is the smallest difference of practical importance,[19] small enough to ensure that the variability of the test results will not exceed the normal needs of the trade but not so small that an unrealistically large number of observations are required.

2.4.4 Significance test

Hypothesis testing by performing a significance test is the inference of unknown population parameters, e.g. the average tensile strength of a fabric lot, or the variance of water-resistance capability of fabrics coming out from several coating machines. Random samples are taken from the populations to shed light on the values of the parameters. Based on the probability theory, whether the hypothetical statement (null hypothesis) is rejected or not will depend on whether evidence is sufficient or insufficient. When the null hypothesis is rejected, the alternative hypothesis will be accepted. The sufficiency of evidence is judged with reference to a fixed level of significance.

Testing for differences among many population means

One-way analysis of variance (ANOVA) is the extension of the pooled t-test to several samples. The pooled t-test compares two means, $\bar{x}_1$ and $\bar{x}_2$, and tests the null hypothesis H_0: $\mu_1 = \mu_2$, which can be written as H_0: $\mu_1 - \mu_2 = 0$. We could use $\bar{x}_1 - \bar{x}_2$ to infer $\mu_1 - \mu_2$.

When we are going to test the equality of the population means of more than two populations, we have to use another approach – the ANOVA approach using the F-test. The F-test for the one-way analysis of variance will tell you whether the averages of several independent samples are significantly different from one another. This replaces the pooled t-test when you have more than two samples and gives the identical result when you have exactly two samples.

The null hypothesis for the F-test in the one-way analysis of variance claims that the k populations (represented by the k samples) all have the same mean value. The alternative hypothesis claims that they are *not* all the same, that is, at least two population means are different. For the one-way study, the null hypothesis is

$$H_0: \mu_1 = \mu_2 = \ldots = \mu_k \quad \text{where } k \text{ is the number of populations} \qquad 2.1$$

Let

$$\mu_1 = \mu + \tau_1,\ \mu_2 = \mu + \tau_2,\ \ldots,\ \mu_k = \mu + \tau_k \qquad 2.2$$

Table 2.1 Data from *k* samples

	Sample				
	1	2	3	...	k
	x_{11}	x_{21}	x_{31}	...	x_{k1}
	x_{12}	x_{22}	x_{32}	...	x_{k2}
	x_{13}	x_{23}	x_{33}	...	x_{k3}
	...	...	...	...	...
	...	...	...	...	...
	...	...	...	...	...
	x_{1n}	x_{2n}	x_{3n}	...	x_{kn}
Mean	$\bar{x}_1$	$\bar{x}_2$	$\bar{x}_3$	...	$\bar{x}_k$

We have k samples from k populations which are independent and normally distributed with common variance σ^2.

$$x_{ij} = \mu_i + e_{ij} = \mu + \tau_i + e_{ij}$$

where e_{ij} is the random error of the jth observation in the ith sample.

The data set for the one-way analysis of variance consists of k independent univariate samples, as shown in Table 2.1. The sample sizes may be different from one sample to another. For simplicity, the sample sizes of all the k samples are set to n. These data values are different from one another due to the following two sources of variation here:

1. One source of variation is due to the fact that the populations are different from one another. This source is called the *between-sample variability* (S_A^2). The larger the between-sample variability, the more evidence you have on the differences among the populations.
2. The other source of variation is due to the diversity within each sample. This source is called the *within-sample variability* (S^2). The larger the within-sample variability, the more scattered are the data within each of the populations and the harder it is to tell whether the populations are actually different or not.

We define S_A^2 and S^2 such that they represent the between-group variation (the effect) and within-group variation (the error) respectively.

$$s_A^2 = \frac{n \times \sum_{i=1}^{k} \left(\bar{x}_i - \bar{\bar{x}}\right)^2}{k-1} \qquad s^2 = \frac{\sum_{i=1}^{k} \sum_{j=1}^{n} (x_{ij} - \bar{x}_i)^2}{nk-k}$$

$$E\left(S_A^2\right) = \sigma^2 + \frac{n \times \sum_{i=1}^{k} \tau_i^2}{k-1} \qquad 2.3$$

$$E(S^2) = \sigma^2 \tag{2.4}$$

where n is the size of each group (or sample), k is the number of groups, $\bar{\bar{x}}$ is the grand average (see below) and $E(X)$ stands for the expected value (mean value) of the random variable X.

Because the null hypothesis claims that all population means are equal, we will need an estimate of this mean value that combines all of the information from the samples. The *grand average* is the average of all of the data values from all of the samples combined. It may also be viewed as a *weighted average* of the sample averages, where the larger samples have more weight.

$$\text{Grand average: } \bar{\bar{x}} = \frac{\sum_{i=1}^{k} \bar{x}_i}{k}$$

To test	H_0: $\mu_1 = \mu_2 = \ldots = \mu_k$,
	H_1: At least two μ_i's are unequal
is the same as to test	H_0: $\tau_1 = 0, \tau_2 = 0, \ldots, \tau_k = 0$,
	H_1: At least two τ_i's are non-zero
or to test	H_0: $\sigma_A^2 = \sigma^2$ from eqns 2.1, 2.2
against	H_1: $\sigma_A^2 > \sigma^2$ from eqns 2.3, 2.4

Since under H_0, $\tau_i = 0$ for $i = 1, 2, ..., k$, $E(S_A^2) = \sigma_A^2 = \sigma^2$, the test statistic is $F = S_A^2/S^2$. We reject H_0 when $S_A^2/S^2 > F_{k-1,\, nk-k;\, \alpha}$ (critical F value – see below).

The F statistic for a one-way analysis of variance is the ratio of variability measures for the two sources of variation: the between-sample variability divided by the within-sample variability.

The *between-sample variability* is an estimator which measures the differences among the sample averages. This would be zero if the sample averages were all identical, and it would be large if they were very different. The number of degrees of freedom of this estimator is equal to $k - 1$. One degree of freedom is lost (as for an ordinary standard deviation) because the grand average was determined from the k averages.

The *within-sample variability* is an estimator which measures how variable each sample is. Because the samples are assumed to have equal variability, there is only one measure of within-sample variability. This would be zero if each sample consisted of its sample average repeated many times, and it would be large if each sample contained a wide diversity of numbers. The square root of the within-sample variability is in fact an estimator of the population standard deviation. The number of degrees of freedom of this estimator is equal to $nk - k$, since all nk data values are involved in the calculation of the within-sample variability but have lost k degrees of freedom because k different sample averages were estimated from the same set of data.

The F-table is a list of critical values, $F_{k-1, nk-k; \alpha}$ for the distribution of the F statistic when the null hypothesis is true. If the F-statistic as calculated from the sample data exceeds the critical F-value, the null hypothesis will be rejected with a level of significance of α. This indicates greater differences among the sample averages. To find the critical F-value, use your numbers of degrees of freedom to find the row and column in the F-table corresponding to the level of significance you are testing at. It is usually the case with hypothesis testing that when you can't reject the null hypothesis you have a weak conclusion in the sense that you should *not* believe that the null hypothesis has been shown to be true.

Nowadays we perform the ANOVA test by computer using statistical software, e.g. SPSS, SAS, Minitab, etc. The advantages of using computer processing are obvious: tedious calculation work can be eliminated, careless mistakes can be largely avoided, and more importantly the level of significance of a calculated F-value can be obtained with as many decimal places as required (this is called the significance of F; normally three decimal places are enough). We don't need to compare the calculated F-value with the critical F-value as obtained from an F-distribution table. Instead we could refer the significance of F to a level of significance of 0.1 (slightly significant), 0.05 (significant), 0.01 (highly significant) and 0.001 (very highly significant). In practice, the 0.05 level is the generally accepted significance level.

Example 1: One-way ANOVA

Table 2.2 shows the results of an experiment designed to compare the effectiveness of four types of shower-proof fabric. Five pieces of each type were chosen at random and subjected to a test in which the time for water to penetrate the fabric was measured.

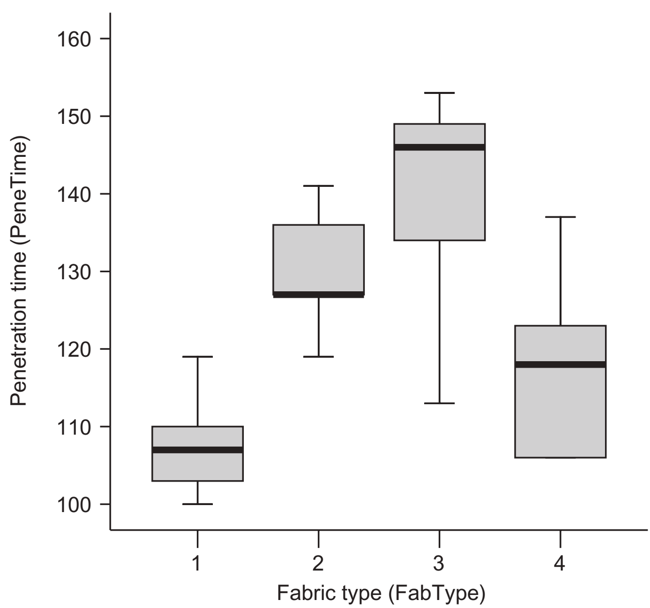
Table 2.2 Sample data of four types of fabrics

	Type of fabric			
	1	2	3	4
Penetration time (seconds)	103	127	149	123
	110	141	113	118
	107	136	146	106
	100	127	134	137
	119	119	153	106
Mean	108	130	139	118

Preliminary examination of the data using a box plot

The analysis of variance might tell you that there are significant differences, but you would also have to examine ordinary statistical summaries (means and standard deviations) and a box plot to actually see those estimated differences. Box plots are particularly well suited to the task of comparing several distributions because unnecessary details are omitted, allowing you to concentrate on the essentials. Here is a checklist of things to look for when using box plots or histograms to compare similar measurements across a variety of situations:

- Do the medians (dark lines in Fig. 2.3) appear different from one box plot to another? This provides an initial, informal assessment for which the analysis of variance will provide an exact, formal answer. From Fig. 2.3, it can be observed that the specimens of fabric type 3 stand out to have the best water-resistance property, while specimens of fabric type 1 are consistently the worst.
- Is the variability reasonably constant from one box plot to another? This is important because the analysis of variance will assume that these variabilities are equal in the population. The variability is represented by the interquartile range (height of the boxes in Fig. 2.3). If, for example, the higher boxes (with larger medians) are systematically wider (indicat-



2.3 Box plot of water penetration data.

ing more variability), then the analysis of variance may give incorrect answers. This systematic change in variability cannot be observed in Fig. 2.3.

The one-way ANOVA table

The computer output in Table 2.3 shows an ANOVA table for this example, using a standard format for reporting ANOVA results. The sources include the factor (this is the fabric type, indicating the extent to which the four types of fabrics vary systematically from one another), the error (the random variation within a type of fabric) and the total variation. The sums of squares (SS) are in the next column, followed by the degrees of freedom (df). Dividing SS by df, we find the mean squares (MS), which are the between-sample and the within-sample variabilities. Dividing the factor MS by the error MS produces the *F* statistic in the next column, followed by the significance of *F* (also called the *p*-value) in the last column, indicating that the differences in water-resistance property among the four types of fabrics are highly significant. From Table 2.3, the significance *F* is equal to 0.004 which is less than 0.01, so we could conclude that the differences in water-resistance performance of the four types of fabrics are highly significant.

Example 2: Two-way ANOVA with replication

The tensile strengths (in N/cm) of three types of fabrics were measured in two independent testing laboratories. The results are shown in Table 2.4. Based on the results of the *F*-tests on main effects, we need to determine whether there is a difference in fabric strength due to fabric type, and to investigate the consistency of the fabric strength test between the two laboratories.

Table 2.5 shows the significance test results of the two main factors, fabric type (Fabric) and testing laboratory (Lab). The significance of the *F*-test on Fabric is equal to 0.000, which is less than 0.001. We can conclude that the difference in fabric strength among the three types of fabrics is very highly significant. For the other main factor Lab, the significance of the *F*-test is equal to 0.323, which is even larger than 0.1. We can conclude that the

Table 2.3 One-way ANOVA

Dependent variable: PeneTime

Source	Sum of squares	df	Mean square	*F*	Sig. *F*
FabType	2795.400	3	931.800	6.683	0.004
Error	2230.800	16	139.425		
Total	311060.000	20			

Table 2.4 Strengths (in N/cm) of three types of fabrics tested in two laboratories

	Fabric 1	Fabric 2	Fabric 3
Lab. A	27.6	64.0	107.0
	57.4	66.9	83.9
	47.8	66.5	110.4
	11.1	66.8	93.4
	53.8	53.8	83.1
Lab. B	49.8	48.3	88.0
	31.0	62.2	95.2
	11.8	54.6	108.2
	35.1	43.6	86.7
	16.1	81.8	105.2

Table 2.5 Analysis of variance

Dependent variable: Strength

Source	Type III sum of squares	df	Mean square	*F*	Sig. *F*
Fabric	19317.331	2	9658.665	51.172	0.000
Lab	192.027	1	192.027	1.017	0.323
Fabric * Lab	177.144	2	88.572	0.469	0.631
Error	4529.948	24	188.748		
Total	145959.890	30			

strength test results are not significantly different between the two testing laboratories.

Example 3: Two-way ANOVA with interaction effect

The tensile strengths (in N/cm) of three types of fabrics were measured under two atmospheric conditions: dry and wet. The results are shown in Table 2.6 with averages shown at the lower right-hand sides.

The data were processed using the SPSS statistical software and the results are shown in Table 2.7. The dependent variable is fabric strength (STRENGTH) and the two factors include fabric type (FABRIC) and testing condition (COND). The purpose of this study is to determine the effect of the two factors on the dependent variable. Table 2.7 shows the results of the significance tests of the two main effects – fabric type (FABRIC) and testing conditions (COND) – and also the interaction effect between FABRIC and COND. The significance *F* of the main effect FABRIC

Table 2.6 Strength of three types of fabrics in dry and wet

	Woollen fabric		Nylon fabric		Cotton fabric		Row average
		Mean		Mean		Mean	
Dry	77.6		64.0		64.0		
	72.0		66.9		72.0		
	65.0		62.5		78.0		
	62.0		58.8		75.4		
	59.0	*67.12*	53.8	*61.20*	68.0	*71.48*	**66.60**
Wet	60.3		58.3		88.0		
	51.0		62.2		80.5		
	41.8		44.6		89.3		
	35.1		65.0		86.7		
	66.1	*50.86*	51.8	*56.38*	79.4	*84.78*	**64.01**

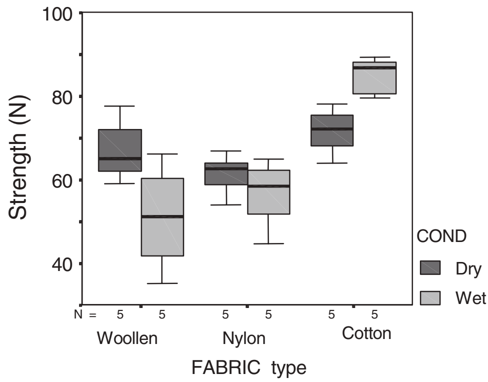
Table 2.7 Tests of between-subjects effects

Dependent variable: STRENGTH

Source	Type III sum of squares	df	Mean square	*F*	Sig. *F*
FABRIC	2 468.051	2	1234.025	20.227	0.000
COND	50.440	1	50.440	0.827	0.372
FABRIC*COND	1 110.835	2	555.417	9.104	0.001
Error	1 464.244	24	61.010		
Total	133 029.3	30			
Corrected total	5 093.570	29			

is equal to 0.000, which is less than 0.001, so fabric type has a very highly significant effect on fabric strength. The significance *F* of the other main effect COND is equal to 0.372, which is larger than 0.1, so the testing condition does not have a significant effect on fabric strength. When looking further at the interaction effect, the significance *F* of the interaction effect FABRIC*COND is equal to 0.001, which is less than 0.01. Now we encounter a significant interaction effect.

The interpretation of the significant interaction effect can be visualized in the box plot as shown in Fig. 2.4. For the woollen fabrics, the dry strength is higher than the wet strength, while for cotton fabrics it is just the opposite. Nylon fabrics are similar in fabric strength in dry and wet. A significant interaction effect means that different levels of a main effect lead to a different behaviour of the other main effect, i.e. dry condition tends to increase



2.4 Box plot of two-way ANOVA.

Table 2.8 Independent samples test (fabric type 3)

	t-Test for equality of means			
	t	df	Sig. (two-tailed)	Mean difference
STRENGTH (equal variances assumed)	–4.125	8	0.003	–13.3000

Table 2.9 Independent samples test (fabric type 1)

	t-Test for equality of means			
	t	df	Sig. (two-tailed)	Mean difference
STRENGTH (equal variances assumed)	2.448	8	0.040	16.2600

the fabric strength only for a particular type of fabric (woollen fabric), not for the other types of fabrics. The positive effect of the dry condition on woollen fabrics is counterbalanced by the negative effect on cotton fabrics. That explains why the main effect COND does not have a significant effect on fabric strength. This can be proved by performing a pooled *t*-test with results as shown in Table 2.8.

Table 2.8 shows the significance test results for the effect of testing condition COND on fabric strength only for fabric type 3 (cotton fabrics). The significant *t* is equal to 0.003, which is less than 0.01. This demonstrates the fact that the testing condition has a significant effect on fabric strength, and similarly for fabric type 1 (woollen fabrics) as shown in Table 2.9.

This example illustrates the importance of studying the interaction effect and the use of a box plot on exploring the data set. Further in-depth analysis is necessary when there exist significant interaction effects in multi-factor analysis of variance.

2.5 Sampling of fabrics

According to British Standard BS EN12571,[8] theoretically correct methods of sampling from lengths or rolls of fabric require that laboratory samples be taken at intervals along the length of the fabric. In practice, rolls of fabric can be very long, and there are economic and practical handling difficulties in applying such methods. In most cases fabrics cannot be cut, except at the ends of the fabric piece, and therefore sampling cannot be carried out across the whole population.

If a particular fabric property is known to vary along the length of the roll, then tests carried out only at the ends of the roll will not be representative of the whole length of the fabric. In this case a statement to this effect is included in the test report, and if the results are to be used as a basis for quality standards, then this is agreed between the interested parties.

In special cases, for example where faults or changes in a property along the length of the fabric are to be examined, samples may need to be taken at intervals along the whole length of the roll. In this case, the number and arrangement of samples depend on the specific requirement and are agreed between the parties.

The number of cases (containers, etc.) and the number of rolls to be inspected are specified in the British Standard.[8] In practice, samples from the selected rolls are taken by cutting, not tearing, at a distance of 1 m from the end of the roll. The size of the sample taken is sufficient to carry out the required tests. Any visible irregularities, damage or colour differences are avoided. In addition, no two specimens should contain the same set of warp or weft threads.[18]

2.6 Future trends

The experimental measurement of sampling results can be carried out more satisfactorily through the improvement of the performance of measurement equipment according to particular requirements.[17] There is a continuous demand for measurement instruments that perform better with respect to speed (faster), dimensions (smaller), applicability (wider range, higher environmental demands), automation (to be embedded in automated systems), quality (higher accuracy, higher sensitivity, lower noise levels), energy (minimizing power consumption), reliability (more robust, long lifetime) and cost (cheaper).

Rapid growth in microprocessors and computer science has contributed to an expansion of software tools for the processing of measurement signals. The computer is gradually taking over more and more instrumental functions. The development of 'virtual instrumentation' is still expanding. The advancement of virtual instruments simplifies the set-up of a measurement; however, it also tends to mask the essences of a measurement: the transformation from quantifiable properties to an electrical signal and the associated measurement errors. A measurement can never be done by software alone, since measurements must be made by hardware.

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