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Abstract: The fundamental structure of fabrics is fibers. The identification of fibers is often the first task when an unknown fabric has to be analyzed. The chemical identification of fibers based on the solubility, stain and burning tests is presented. The determination of common fabric chemical qualities, such as pH and metals that are mostly concerned by textile wet processors is discussed together with fabric whiteness and absorbency that are important for finished textiles. The analysis of auxiliaries such as sizing agents, surfactants and softeners is provided for quality control purpose. The identification of dye classes and finishing agents often required in a forensic investigation, confirmation of dye and finish application, and environmental, health and safety concerns is given. The testing for damage to textiles is also mentioned.

Key words: chemical testing, chemical analysis, dyes, finishing agents, formaldehyde, auxiliaries, quality.

5.1 Introduction: definition and role of tests

Fabric chemical testing is a broad topic and can range from a simple pH test to a complicated colorant identification using HPLC. As the name indicates, chemical testing is basically the test of the fabric samples either using chemicals or for their chemical properties, and very often both. Sometimes, a Bunsen burner (oxidation reaction) is sufficient to conduct the fiber identification, while the dye analysis may need to use an HPLC (adsorption and desorption processes). It is also very important that the professionals involved in the chemical testing have fundamental knowledge of fibers, dyes, auxiliaries and finishing agents as well as the basic understanding of yarns, fabrics, and their formations. With the right lab facilities and well-trained personnel, fabric chemical testing can be performed successfully.

As a rule of thumb, the fabric samples need to be prepared properly before the testing according to the test method to be used. The sample preparation usually means the samples should be conditioned at regulated temperature and humidity. It also requires that the sampling process should be conducted following certain protocols in order to make sure the sample to be tested can represent the batch/shipment/bulk. During the chemical testing, personnel protection is one thing that will never be overstressed, due to the nature of the chemicals used in the testing. Overlooking the

possible hazardous situation is a guarantee of mishaps. Therefore, wearing of goggles and gloves is a must for handling any chemicals. Preparation of chemical stocks and standard solutions should be performed cautiously. If volatile organic chemicals (VOC) are to be involved in the chemical testing, a ventilated fume hood should be used. At the end of testing, the test results should be reported based on statistical analysis using industrial standard formats to facilitate the communication between the testing lab and the client.

The testing performed on the fabric samples can meet one or a combination of the following requirements:¹

- To provide a service to the customer
- To conform to a standard
- To assess the effect of textile processes
- To develop a new product
- To establish a specification
- To investigate problems a product has.

Many standard testing methods (AATCC, ASTM, EN, JIS, and ISO) are available nowadays. Whenever possible, the standard testing methods should be used unless customers have different requirements, or the lab/sample conditions necessitate the modifications. If the test is not performed exactly as the standard test, any modifications should be presented in the testing report.

This chapter presents the basic description of some standard methods for fabric chemical testing. For detailed procedures in each testing, readers should access the reference materials listed at the end of this chapter.

5.1.1 Instrumentations

The basic facilities a fabric chemical testing lab should have include the following:

- Balance, capacity up to 300 grams with accuracy 0.1 mg
- A pH meter, ideally with three-point calibration function and readability 0.1 unit
- Microscope, optical magnification up to $\times 1500$
- Standard light booth, ideally with daylight, horizon light, cool white light and UV light, or lights to be useful for the localized applications
- Spectrophotometer, for visible range between 380 and 780 nm, ideally with UV range (200 to 400 nm) measurement and dual modes for both transmission and reflection measurements
- Stopwatch, with readability of 1/100 second
- A lab-sized atmospheric dyeing machine

- Oven with temperature control
- Crockmeter
- Gray scales
- Access to water, gas, electricity, and drainage.

A well-equipped testing lab can also have the following:

- Soxhlet extractor
- Auto-titrator
- HPLC, high performance liquid chromatography apparatus
- FTIR, Fourier transform infrared spectrometer
- DSC, differential scanning calorimeter.

A temperature and humidity conditioned environment is a must for textile physical testings, and a plus for chemical testing. Many fabric chemical testings can be performed under non-environmentally controlled conditions. However, it is sometimes more practical to use an environmentally controlled container to have fabric samples conditioned and then conduct testing in a non-controlled environment. This is especially true for some small in-house testing facilities. Consequently, the test results would deviate from the real values and should be reported accordingly, if environmentally controlled conditions are listed in the relevant standard testing methods.

5.1.2 Factors affecting tests

The general factors that could affect the testing results include sample size/weight, sample contamination, chemical concentrations/assays, instrument calibration, personnel error, and environmental variables such as temperature and humidity. The effects of these factors are generally detectable if an error source is identified. The most important managerial action is to have a quality control and quality assurance system in place, which can significantly minimize the effects of the influential factors. It is worth noting that many of these factors can be eliminated if the quality control and quality assurance system is maintained and executed properly.

5.2 Chemical identification of fibers

5.2.1 Fiber classification

Textile fibers can be easily classified based on their sources, natural fibers and synthetic fibers. The common natural fibers can be divided into two groups, cellulose and protein. In the cellulose group, cotton and rayon (viscose) are the most common ones. The other cellulosic fibers that have become more and more popular are linen, ramie, and bamboo. The protein group has silk and wool. Sometimes, cashmere, angora, and mohair are

used in knitting. The common synthetic fibers are polyester, nylon, and acrylic.

The comprehensive fiber identifications and both qualitative and quantitative analysis can be found in AATCC Test Methods 20 and 20A.² The methods include physical approaches: visual and microscopic examination, density, drying twist, and melting point; chemical pathways: burning, solubility and stain; and instrumental ways: FTIR, DSC and SEM, etc. In this section, only the qualitative chemical identifications of common fibers are introduced.

5.2.2 Chemical identification

Solubility test

Separate a few fibers from the fabric. Cut them into short lengths of about 5–7 mm ($\frac{1}{4}$ inch). Put four or five cut fibers into a test tube with 10 ml of solvent as listed in Table 5.1 or Table 5.2. Observe their dissolution in each solvent. If necessary, raise the temperature of the solvent by immersing the test tube in a temperature-controlled water bath. For the common natural fibers, using the inorganic solutions shown in Table 5.1 under the set conditions, a positive identification can be made.² For the common synthetic fibers, using the organic solvents shown in Table 5.2 under the set conditions, a positive identification can be made.²

Table 5.1 Solubility of common natural fibers in different inorganic solutions and conditions

	5% sodium hypochlorite, 20°C, 20 min	59.5% sulfuric acid, 20°C, 20 min	70% sulfuric acid, 38°C, 20 min
Cotton	Insoluble	Insoluble	Soluble
Rayon	Insoluble	Soluble	Soluble
Silk	Soluble	Soluble	Soluble
Wool	Soluble	Insoluble	Insoluble

Table 5.2 Solubility of common synthetic fibers in different organic solvents and conditions

	85% formic acid, 20°C, 5 min	Dimethyl formamide, 90°C, 10 min	<i>m</i> -cresol, 139°C, 5 min (use a glycerol bath)
PET	Insoluble	Insoluble	Soluble
Nylon 6	Soluble	Soluble	Soluble
Nylon 66	Soluble	Insoluble	Soluble
Acrylic	Insoluble	Soluble	Plastic mass formed

Table 5.3 Burning behavior of common fibers

	Melts near flame	Shrinks from flame	Burns in flame	Continues to burn	Appearance of ash	Smell from flame
Cellulose	No	No	Yes	Yes	Light grayish	Burning paper
Silk	Yes	Yes	Yes	Slowly	Soft black bead	Burning hair
Wool	Yes	Yes	Yes	Slowly	Irregular black	Burning hair
PET	Yes	Yes	Yes	Slowly	Hard black	Burning wax
Nylon	Yes	Yes	Yes	Yes	Hard gray	Characteristic odor
Acrylic	Yes	Yes	Yes	Yes	Hard black	Characteristic odor

Stain test

For uncolored fabrics, staining or dyeing can provide a quick identification of unknown fibers in a sample including the blend samples. DuPont Fabric Dyestain #4 (available from Testfabrics, Inc., West Pittston, PA) is a common stain widely used in textile testing labs, which is a mixture of C.I. Acid Blue 298, Acid Red 182, Direct Blue 218, Disperse Orange 25, Disperse Yellow 3, and Direct Yellow 11.³

The unknown sample strip, measuring 2.5×10 cm (1×4 inches), is boiled with a multifiber standard (also available from Testfabrics) in a 1% DuPont Fabric Dyestain #4 solution (also at pH 4.5 at a liquor ratio of 1:20 for 10 min. After rinse and drying, the color of the sample strip is checked against the multifiber standard to identify the unknown fiber. Depending very much on the number of fiber types on the multifiber standard, many commercially available textile fibers can be positively identified.

Burning test

The burning test is the simplest test for fiber identification. A Bunsen burner is all it needs. However, caution should be exercised in order to avoid confusion caused by fiber blends and fiber finishes. Generally, the observations shown in Table 5.3 can help distinguish a few types of fiber.²

5.3 Fabric quality

5.3.1 pH value⁴

Treat 10 grams of fabric in 250 ml boiled distilled water at boiling temperature for 10 minutes, cool down, remove the sample, then measure the pH of the solution.

5.3.2 Whiteness⁵

Before measuring the whiteness using a spectrophotometer, it is necessary to make sure the fabric has no fluorescent whitening agents (FWA). A UV light in the light booth can be used to detect the presence of FWA on the samples in a dark room. The fluorescence shown indicates the existence of FWA, which will affect the whiteness measurement. A specialized spectrophotometer should be used to compensate or control the FWA effect.

A sample with an adequate opacity, usually folded a few times to achieve this, is measured by a reflectance spectrophotometer using D_{65} illuminant and 10° observer, and a whiteness index is reported by the software associated with the spectrophotometer. Usually, a sample needs to be measured at least four times to get an averaged result. The higher the whiteness index, the whiter the sample.

5.3.3 Absorbency⁶

The absorbency of the fabrics is determined by the time the sample takes to absorb a fixed amount (usually a drop) of distilled or deionized water. Sample conditioning is extremely important as the residual moisture on the sample to be measured can affect the absorbency results considerably. The sample under a set tension (mounted on an embroidery hoop) is placed vertically at the prescribed distance from the end of a burette with water. The time starting from the moment the water drop touches the surface of the sample to the moment the water drop is completely absorbed by the sample (disappearance of the liquid reflection) is taken on a stopwatch. One sample should be measured at least five times to get an averaged result. The longer the time, the lower the absorbency. A more critical examination of fabric absorbency can be achieved using a 50% or 65% sucrose solution, because the sucrose solution is more viscous and is absorbed more slowly than water, thus distinguishing between samples with very small differences in their water absorbency.

5.3.4 Metals and NO_x detection⁷

Calcium

Ash 5 g fabric in a crucible, move the ash to 10% hydrochloric acid, and add ammonium chloride and ammonia ($d = 0.88$) until the solution is alkaline. Filter off any precipitate. Acidify the ammoniacal filtrate with acetic acid. Precipitate calcium out as calcium oxalate using oxalic acid. Spot the precipitate onto a platinum wire and place it into a flame. A red flame color indicates the presence of calcium.

For quantitative determination, wash the filtered calcium oxalate with a minimum amount of distilled water and move it into warm 20% sulfuric acid. Titrate the solution using 0.1*N* potassium permanganate solution. Each 1 ml 0.1*N* potassium permanganate solution consumed in the titration is equivalent to 2.004 mg calcium. The total calcium percentage in the sample is calculated using the following equation:

$$\text{Calcium \%} = \frac{\text{calcium from titration, mg}}{\text{sample weight, mg}} \times 100\%$$

Iron

Place a small piece of sample on a watch glass and add 1–2 drops of 5% nitric acid. Alternatively, dissolve the ash of a small piece of colored sample in 10% nitric acid. Add 2–4 drops of 10% potassium thiocyanate after allowing the sample to stand for 3 minutes. A pink color indicates a low content of iron, while a dark red color indicates a high content. The color intensity is proportional to the content of iron in the sample. Copper may interfere to generate a yellow-brown color.⁸

Copper

Spot the ash of the sample with 5–10 drops of 10% nitric acid. Add diluted ammonia until the ash is alkaline. A blue color shows the presence of copper. The test may be performed on fabric directly using 0.1% sodium diethyl dithiocarbamate solution after the above-mentioned procedures. A brown color shows the presence of copper. However, iron may interfere to generate a brown color too.

NO_x

The presence of NO_x can cause yellowing on bleached fabrics, including those with FWAs. The detection of NO_x can be performed using Saltzman's reagent. Add 1–2 drops of 1% w/v sulfamic acid (H₃NSO₃) in 30% acetic acid to the test sample. After 1 minute, add 1–2 drops of 0.05% w/v *N*-(1-naphthyl)ethylenediamine hydrochloride. A deep to vivid purplish red color indicates the presence of NO_x.

5.4 Auxiliaries testing – sizing agents⁹

5.4.1 Starch and its derivatives

Starches are natural polymers called polysaccharides that have multiple anhydroglucose units. The chemical formula for starch and its derivatives

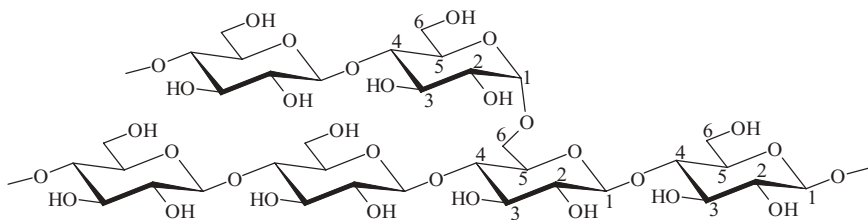
is $(C_6H_{10}O_5)_n$. Starch has chemically two moieties, an amylose part which is anhydroglucopyranose units joined by α -D-1,4 glycosidic bonds, and an amylopectin part which is anhydroglucopyranose units linked by α -D-1,6 glycosidic bonds as shown in Fig. 5.1. Amylose has a linear chain and amylopectin a branched chain. Starch can be decomposed by pyrolysis and acidic hydrolysis. British gums and dextrans are the products derived from starch. They have lower molecular weight and better water solubility.

Qualitative testing of starch and its derivatives can be conducted using an aqueous solution containing 1.4 g/L I_2 and 2.4 g/L KI.¹⁰ The existence of starch (specifically amylose) will turn the yellow-orange color of the solution to a dark blue color. When tested with I_2/KI solution, British gums and completely degraded dextrans give a reddish brown color, partially degraded dextrans a violet color, and white dextrin a blue color.¹¹

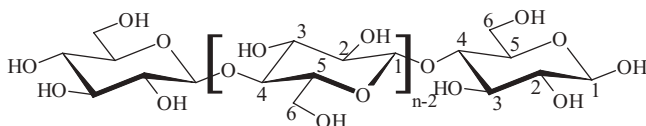
5.4.2 Cellulose derivatives

Cellulose is another natural polymer belonging to polysaccharides. The chemical formula for cellulose is also $(C_6H_{10}O_5)_n$. It has a chemical structure very similar to amylose. Instead of α -D-1,4 glycosidic bonds, cellulose has only β -D-1,4 glycosidic bonds as shown in Fig. 5.2. Due to these β -D-1,4 glycosidic bonds, the molecular chain of cellulose can extend quite linearly, making it a good fiber-forming polymer. In order to use cellulose for sizing purposes, it should be modified to shorten the molecular structure. The two most used cellulose derivatives are carboxymethyl cellulose (CMC) and hydroxyethyl cellulose (HEC).

Carboxymethyl cellulose (CMC) is manufactured with alkali cellulose and sodium chloroacetate. The hydrogen atoms of hydroxyl groups on C2



5.1 Chemical structure of amylopectin.



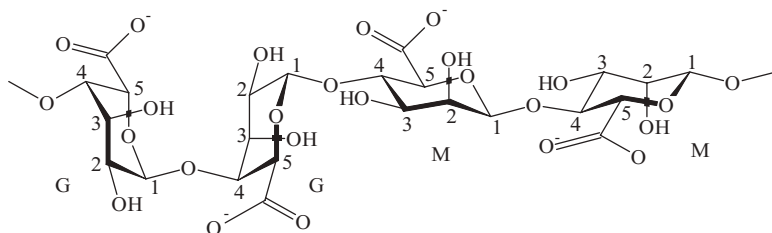
5.2 Chemical structure of cellulose.

and C6 are partially substituted with $-\text{CH}_2\text{COONa}$ or $-\text{CH}_2\text{COOH}$ depending on reaction conditions. The degree of substitution (DS) is usually between 0.2 and 1.5 (0.2 to 1.5 carboxymethyl groups ($-\text{CH}_2\text{COOH}$) per anhydroglucose unit). CMC with DS 1.2 and below is water soluble. The final product always contains sodium salt. A foaming test can distinguish sodium CMC from other cellulose ethers, alginates and natural gums.¹² Sodium CMC solution, after vigorous agitation, would not produce any foam layer. Uranyl nitrate can be used to detect the existence of CMC. A 4% uranyl nitrate is used to precipitate CMC between pH 3.5 and 4.¹³ A precipitate with off-white color indicates the presence of CMC. A 0.5% methylene blue methanol solution may also be used to detect CMC on fabric.⁷ After rinsing in distilled water and drying, the methylene blue treated sample may show a blue/purple color which confirms the existence of CMC or acrylic sizes. A separate extraction of the fabric with toluene can exclude the acrylic sizes from the test.

When the hydrogen atom of the hydroxyl group on C6 of cellulose is partially substituted with the hydroxyethyl ($-\text{CH}_2\text{CH}_2\text{OH}$) group in a reaction with ethylene oxide under alkaline condition, hydroxyethyl cellulose (HEC) is produced. So far there are no known testing methods for HEC detection. However, if one wants to distinguish CMC from HEC, an ion tolerance test can be conducted. CMC is anionic and can be precipitated from an aqueous solution with a cationic surfactant. Since HEC is non-ionic, its aqueous solution is compatible with cationic surfactants. Based on the same ionic tolerance principle, a high salt concentration can precipitate CMC, not HEC.

5.4.3 Alginates

Alginates are linear copolymers of randomly arranged β -D-1,4 mannuronic acid (M) and α -L-1,4 guluronic acid (G) blocks as represented in Fig. 5.3. Their chemical structure is similar to that of cellulose except that they have a carboxylic group on the C5 position instead of a methylol group in the case of cellulose. Alginates have good water solubility. Divalent and higher



5.3 Chemical structure of alginate.

valent metal ions, strong acids and bases can precipitate alginates out of its aqueous solutions.

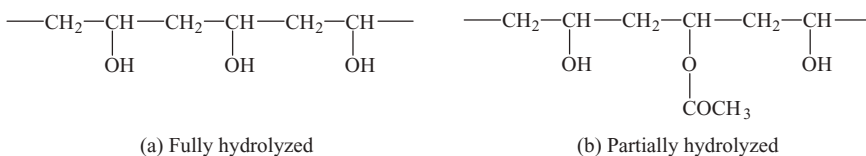
In order to distinguish alginates from other thickening agents, precipitation methods can be tried.¹² 2.5% CaCl_2 can cause 0.5% sodium alginate solution to precipitate. Aqueous solutions of gum arabic, sodium carboxymethyl cellulose, carrageenan, gelatin, gum ghatti, karaya gum, carob bean gum, methyl cellulose and tragacanth gum would not be affected. Saturated $(\text{NH}_4)_2\text{SO}_4$ would not precipitate 0.5% sodium alginate, but agar, sodium carboxymethyl cellulose, carrageenan, de-esterified pectin, gelatin, carob bean gum, methyl cellulose and starch would be affected. The existence of sodium alginate can be tested with acid $\text{Fe}_2(\text{SO}_4)_3$.¹² Five minutes after a sample is in contact with a ferric sulphate solution, a cherry red color appears and this gradually changes to a deep purple color. This confirms the presence of sodium alginate in the sample.

5.5 Synthetic sizing agents

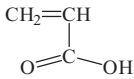
5.5.1 Polyvinyl alcohol

Polyvinyl alcohol (PVA) is the hydrolysis product of polyvinyl acetate. Depending on the hydrolysis conditions, there are fully hydrolyzed PVA and partially hydrolyzed PVA as shown in Fig. 5.4(a) and (b) respectively. Fully hydrolyzed PVA usually has a degree of hydrolysis (DS) of 98% to 99.8%, and can dissolve in water only at $>80^\circ\text{C}$. The solubility of partially hydrolyzed PVA with a DS between 85% and 90% is dependent upon its molecular weight. The one with high molecular weight needs to have high temperature for dissolving.

Specific detection of PVA on fabrics can be achieved using potassium dichromate ($\text{K}_2\text{Cr}_2\text{O}_7$).¹⁴ Two solutions are used. Solution A consists of 11.88 g $\text{K}_2\text{Cr}_2\text{O}_7$ and 25 ml concentrated H_2SO_4 in 50 ml distilled water. Solution B contains 30 g NaOH in 70 ml distilled water. After solutions A and B are applied to a white fabric sample sequentially, a brown color developing after rubbing the spotted area for a complete reaction indicates the existence of PVA. A yellow-green color can be triggered by unsized



5.4 Chemical structures of PVA.



5.5 Chemical structure of acrylic acid.

goods, potato starch, styrene–maleic anhydride copolymer, alginates, guar, gelatin or CMC.

5.5.2 Acrylics

Acrylic is a generic term for a large group of homopolymers and copolymers derived from acrylic acid shown in Fig. 5.5. Since the hydrogen atoms of the carboxylic group and the vinyl group can be substituted with many different chemical groups, a huge variety of polyacrylic acid and polyacrylates are currently available for many different applications. Most of them are used as an emulsion.

The analysis of acrylics is almost impossible without using sophisticated instruments. There are no known simple methods for the tests to be done with wet chemistry, which could be because (1) the analysis with wet chemistry is too complicated; (2) the analysis has to deal with too many different types of polymers; (3) the analysis involves the use of many toxic organic solvents. If the analysis is needed, it is recommended to use either FTIR or GC to get the results quickly and accurately. FTIR analysis of acrylics can show very distinctive absorption peaks between 1100 and 1150 cm^{-1} for the alkyl C—O—C stretching band and at 1750 cm^{-1} for the C=O stretching band. If the acrylic polymer system contains some vinyl monomers, a broad peak at 3020 cm^{-1} and a strong peak at 1660 cm^{-1} indicate the stretching bands of C—H and C=C in CH=CH structure respectively.¹⁵ With GC analysis, acrylic acid, ethyl methacrylate, *n*-butyl acrylate, 2-ethylhexyl acrylate, isobutyl acrylate, methyl methacrylate, ethyl acrylate and methyl acrylate can all be detected and quantitatively determined.¹⁶ ASTM Test Method D3362¹⁷ is a standardized method for the purity analysis of acrylate. It is certain that more types of acrylates can be successfully analyzed nowadays with modern instruments.

5.6 Surfactants

The detection of surfactants on fabrics requires extraction of the surfactants from the fabric sample. First, agitate a fabric sample in water at a low liquor ratio (<1:20) overnight at room temperature, then remove the sample and concentrate the solution containing surfactants for testing using the following methods at room temperature. Any colors, especially the ionic dyes,

removed during the agitation may interfere. The following methods can also be used to detect the ionic type of the surfactants concerned.

5.6.1 Anionic surfactants

*Acidic methylene blue test*¹⁸

Methylene blue is a cationic dye soluble in water and insoluble in chloroform. It can form with anionic surfactants a blue compound which is soluble in chloroform.

Acidic methylene blue solution: Slowly add 12 g H_2SO_4 to 50 ml water; after cooling down, add 0.03 g methylene blue and 50 g Na_2SO_4 anhydrate; dilute the whole solution to 1 liter.

Test: Add 5 ml of 1% sample surfactant solution into a mixture of 10 ml methylene blue solution and 5 ml chloroform in a test tube; shake vigorously, then allow it to stand until two layers are formed. If the chloroform layer (bottom layer) shows blue, add another 2–3 ml of the surfactant solution. Shake well and leave for layers to form. The chloroform would show dark blue and the water layer would be almost colorless. This is a positive result for the existence of anionic surfactant in the sample solution. This test is suitable for alkylsulfate and alkylbenzolsulfonate surfactants. Soap cannot be tested because it would precipitate in the strong acidic medium.

*Basic methylene blue test*¹⁹

Add one drop of 5% sample solution to a mixture of 5 ml 0.1% methylene blue solution, 1 ml 1N NaOH solution and 5 ml chloroform. Shake well and observe the color of the chloroform layer. If a blue-purple color is shown, there exists an anionic surfactant in the sample. This test is suitable for any type of anionic surfactants.

*Thymol blue test*²⁰

Thymol blue solution: Add three drops of 0.1% thymol blue to every 5 ml of 0.005N HCl solution.

Test: Add 5 ml neutralized sample solution to 5 ml thymol blue solution. Shake well and observe the color of the mixture. A reddish-purple color is the evidence of existence of anionic surfactants in the sample solution.

*Precipitation test*²¹

A few drops of sample solution are added into 5 ml of 5% *p*-toluidine hydrochloride aqueous solution. If a white precipitate appears, there is anionic surfactant in the sample solution.

5.6.2 Cationic surfactants

Methylene blue test

Cationic surfactants can also be tested using methylene blue solution. First add two drops of a known anionic surfactant solution to a mixture of 5 ml methylene blue solution and 5 ml chloroform, shake well and leave it to stand for the chloroform layer to show blue. Then add a few drops of the sample solution, shake well and leave it for layers to form. If the blue color in the chloroform layer becomes lighter or colorless, the existence of cationic surfactants in the sample solution can be confirmed.

*Bromophenol blue test*²²

Bromophenol blue solution: Add 20 ml of 0.1% bromophenol blue in 96% ethanol to a mixture of 75 ml 0.2*N* sodium acetate and 925 ml 0.2*N* acetic acid. Adjust the pH of the solution to 3.6–3.9.

Test: Add 2–5 drops of a neutralized sample solution to 10 ml of bromophenol blue solution. Shake well and observe the color of the mixture. If a blue color is shown, the existence of a cationic surfactant is confirmed.

Alternatively, add one drop of 5% sample solution to a mixture of 5 ml chloroform, 5 ml 0.1% bromophenol blue dilute ethanol solution and 1 ml 6*N* HCl. Shake well and observe the color of the chloroform layer. If a yellow color appears, there exists a cationic surfactant in the sample.

*Precipitation test*²⁰

A diluted aqueous solution of either sodium salicylate, sodium benzoate, or sodium succinate can precipitate cationic surfactants.

5.6.3 Non-ionic surfactants

Methylene blue test

This test is conducted as on page 136. If the aqueous layer is emulsified to a milk-like state, or both layers have the same color, the existence of non-ionic surfactants can be confirmed.

*Cloud point test*²³

The solubility of polyoxyethylene surfactants is dependent on their hydrogen bonding with water. At a high temperature, the hydrogen bonds of the surfactants would be dissociated, leading to lower solubility of the surfactant. Therefore, the solution of the surfactant becomes cloudy at the high

temperature. Based on this principle, the polyoxyethylene surfactants can be detected.

A 1% sample solution is gradually heated with a thermometer in the solution to monitor its temperature. When the solution becomes cloudy, stop heating. Let the solution cool down slowly. The cloud point is reached when the solution turns to clear.

*Amphoteric surfactants*¹⁹

Amphoteric surfactants contain both anions and cations. They should show positive results when tested with either the basic methylene blue test for anionic surfactants or the alternative bromophenol blue test for cationic surfactants.

A saturated bromine aqueous solution can also be used to determine the type of amphoteric surfactants. Add 5 ml of 1% sample solution to 1.5 ml saturated bromine aqueous solution. Observe the color of the precipitate. Heat the mixture and observe the change of the precipitate. If the precipitate is yellow to yellow-orange and is dissolved to form a yellow solution after heating, the sample is imidazoline or alanine types of amphoteric surfactants. If the precipitate is white to yellow and insoluble after heating, the sample is the other types of amphoteric surfactants.

5.7 Fluorescent whitening agents

Fluorescent whitening agents (FWAs) are a special type of chemicals that can significantly increase the apparent whiteness of treated fabrics. They absorb UV radiation and re-emit the absorbed energy in the blue visible light range, which makes the treated fabrics appear whiter complementary with the yellow color. The detection of the presence of FWAs on fabrics is simply a visual examination under UV light in a dark room. An FWA-treated fabric fluoresces under the UV light.

5.8 Colorants testing

Before conducting any testing listed in this section, it is necessary to positively identify the fiber first. Care should be taken to separate blend fibers carefully. A burning test of the fiber samples can often help distinguish from main fiber types. If a cellulosic sample is resin finished, treat the sample with 1% hydrochloric acid at 75°C for 20 minutes, then wash with hot water, 0.1% ammonia solution, and cold water in succession; finally dry.

5.8.1 Azoic, vat and sulfur dyes¹

Boil the sample in sodium formaldehyde sulfoxylate (Formosul, C. I. Reducing Agent 2) solution at pH 11 for a few minutes. If vat and sulfur

dye are present, discoloration happens. However, the original color is usually restored by exposing the rinsed sample to air. The color of azoic dyes changes permanently and cannot be restored.

Sulfur dyes can be confirmed^{24,25} by boiling the sample in 16% hydrochloric acid for 30 seconds in a test tube. Cool and add 3 mg pure zinc dust and warm for 2–3 minutes. A filter paper wetted with a solution of 5% lead acetate and 25% glycerol shows a brown or black stain when placed on the test tube, and vapors give smell of hydrogen sulfide. Other dyes containing sulfur element may give a positive reaction.

5.8.2 Ionic dyes²⁵

Boil 0.5 g cellulosic fabric sample for 2 minutes in a 5% sodium hydroxide solution (stripping). Add a small piece of bleached cotton fabric to the warm stripping solution. If the bleached cotton fabric is deeply stained, direct dye is confirmed. Reactive dye is confirmed when little or no staining happens to the bleached cotton fabric.

Boil a protein fiber/fabric or nylon fiber/fabric in dimethylformamide for 2–4 minutes. Acid dyes bleed off except some supermilling acid dyes which are difficult to distinguish from reactive dyes. Metal-complex acid dyes may bleed slightly, and mordant acid dyes do not bleed at all. Acid dyes can be stripped in 2% ammonia solution and can redye white wool in acidified solution except the acid dyes with high wet fastness.

Boil an acrylic sample in 85% formic acid for 2 minutes (stripping) and dilute with an equal amount of water after removal of the stripped sample. The stripped basic dye can be transferred to an undyed acrylic (Orlan) sample by boiling.

5.8.3 Disperse dyes^{24,25}

Boil a nylon/polyester/acetate sample in ethanol for 2 minutes. Some dye can be stripped and transferred to undyed secondary acetate in the same solution.

Treat an acrylic sample in liquid paraffin at 160°C for 5–10 minutes in a glycerol bath. Disperse dyes can be partially stripped and then partially transferred to undyed secondary acetate.

5.8.4 Pigments^{24,25}

Pigments can be identified using a microscope when the fiber sample is immersed in ethyl salicylate as an optical solvent. If the fibers are mass-pigmented, pigment particles are visible within the fiber. If the fibers are binder-bonded to the pigments in full depths, the particles are visible on the surface of the fiber. For pale depths, the test method listed in Section 5.8.5 can help.

Table 5.4 Dye test using *N*-methyl-2-pyrrolidone (NMP)

	Water layer	Toluene layer
Acid and direct dyes	Strongly colored	Colorless
Basic dyes	Colored	Colored
Disperse dyes	Colorless to slightly tinted	Colored similarly to the original dyeing
Azoic dyes	Colorless to slightly tinted	Colored darker than the water layer
Vat dyes	Colorless to slightly tinted	Colorless to slightly tinted

Azoic and vat types of pigments can be tested using the test methods mentioned above for the corresponding types of dyes. Phthalocyanine pigments show a bright green tone when spotted with concentrated nitric acid.

5.8.5 *N*-methyl-2-pyrrolidone extraction test²⁶

Boil a 2.5 × 2.5 cm (1 × 1 inch) sample in 5 ml of 25% *N*-methyl-2-pyrrolidone (NMP) in a test tube immersed in a water bath for 20–40 seconds. Take the test tube out of the water bath, remove the sample, and add 5 ml toluene and 25 ml of water. Shake well, record the color of each layer after standing for 30 minutes or until settling, and check against the results shown in Table 5.4.

5.9 Finishes testing

5.9.1 Formaldehyde

*Spot test*²⁷

Place one drop of 1% phenylhydrazine in 40% sulfuric acid on a white or pale colored fabric sample and let it sit for 30 seconds. Apply a drop of 10% ferric chloride solution. Within 30 seconds, a pink, red, or brown color shown indicates the presence of formaldehyde.

*Free formaldehyde detection using cold sulfite*²⁸

Weigh a 1.5 g fabric sample accurately, cut it into small pieces, place them into a conical flask with 50 ml water at <5°C, and add 1 ml 2*N* sodium sulfite solution and four drops of thymolphthalein indicator. If the mixture shows no color, add 2*N* sodium carbonate slowly until a blue color is shown. The

mixture is then neutralized to colorless with 0.3N hydrochloric acid and stood in an ice bath for 7 minutes. Add 5 ml ice-cold 1N acetic acid and a few drops of starch indicator. Titrate the excess sulfite using 0.01N iodine solution to the blue end point. Then:

$$\text{Free formaldehyde \%} = \frac{\text{volume of iodine} \times N \text{ of iodine} \times 1.5}{\text{weight of sample, g}} \times 100\%$$

*Free and released formaldehyde in a sealed jar*²⁹

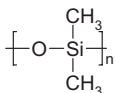
Suspend 1 g fabric sample in a sealed jar with 50 ml water. The jar is kept in an oven at 49°C for 20 hours or alternatively at 65°C for 4 hours. The free and released formaldehyde is absorbed in water and reacted with NASH reagent, which consists of 150 g of ammonia acetate, 3 ml of acetic acid, and 2 ml of acetylacetone and deionized water totaling to 1000 ml, at 58°C for 6 minutes. The amount of formaldehyde (µg/ml) is determined colorimetrically using the absorbance measured at 412 nm against a prepared calibration curve.

5.9.2 Silicones

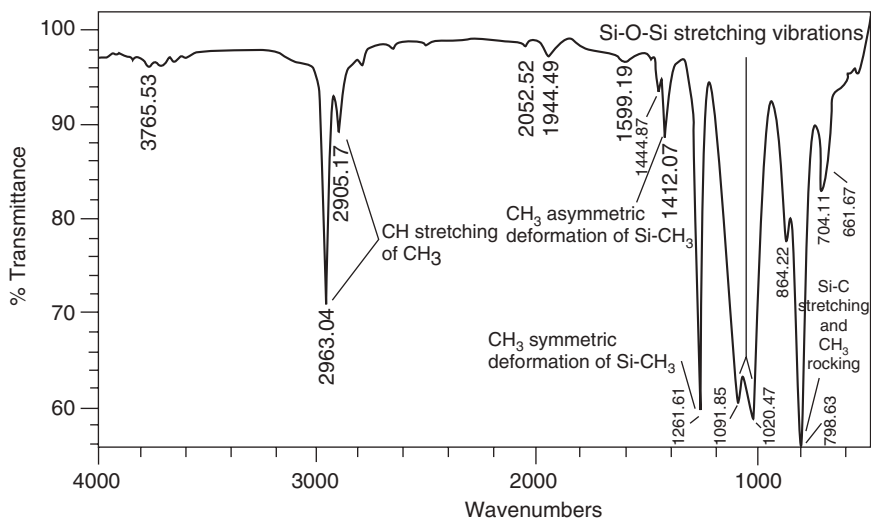
Silicones are used widely as softeners and lubricants in textile finishes. The most common silicone is polydimethylsiloxane as shown in Fig. 5.6.

It was reported³⁰ that using a carefully selected fluorescent dye, the silicone finish on the dye-specific fiber can be detected by microscopy. To achieve the best results, Rhodamine B was selected for cellulose, polyester, and polypropylene fibers and Phloxin B for nylon fibers. Auramine can be used in some cases, but the fluorescence from the delustering agent such as TiO₂ used in the synthetic and regenerated fibers can interfere.

Silicones can be easily detected using FTIR ATR analysis. The representative IR spectrum is shown in Fig. 5.7.³¹ Alternatively, silicone can be extracted using pentane in a Soxhlet extractor. The pentane is then evaporated and the residue taken up in carbon disulfide is ready for IR analysis.³² The IR absorption peak at 1262 cm⁻¹, which represents the CH₃ symmetrical deformation of Si-CH₃, is the most characteristic absorption for organosilicon compounds. This band is intense and sharp and always occurs at 1262 ± 5 cm⁻¹. Therefore, it can also be used for quantitative analysis of silicones.³³



5.6 Chemical structure of polydimethylsiloxane.



5.7 IR spectrum and peak assignments of polydimethylsiloxane.

5.9.3 Halogens³⁴

Boil the fabric sample in deionized water to extract the halogen. Concentrate the water solution. Add a few drops of 1% silver nitrate into the concentrated extraction solution. The presence of a halogen is indicated by a white turbidity.

5.9.4 Hypochlorite³⁴

Agitate a fabric sample in water at a low liquor ratio (<1:20) overnight at room temperature, then remove the sample. Test the extraction solution with 4% alkaline solution of thallosulfate. A brown precipitate indicates the presence of hypochlorite.

5.9.5 Silicate³⁴

Agitate a fabric sample in water at a low liquor ratio (<1:20) overnight at room temperature, then remove the sample. A drop of the extraction solution and a drop of ammonium molybdate solution (5 g ammonium molybdate in 100 ml of cold water poured into 35 ml of nitric acid) are placed on a filter paper and warmed gently over a hot plate. A drop of benzidine solution (0.5 g of benzidine dissolved in 10 ml of acetic acid and diluted with water to 100 ml) is added and the paper suspended over ammonia show a blue color indicating the presence of silicate.

Alternatively,⁷ ash 5 g of a fabric sample in a crucible. After cooling, mix with five times the amount of 50/50 w/w mixture of sodium carbonate and potassium carbonate and heat until a clear melt is formed. Cooling down again, dissolve the solid in distilled water, mix with solid ammonium molybdate, and acidify with 20% nitric acid. An intense yellow color or a yellow precipitate indicates the presence of silicate.

5.10 Degradation testing

5.10.1 Oxidative damage to cellulose

Cellulose can be oxidized in the bleaching operation, generating many carboxylic groups that can bind basic dyes under acidic conditions. Two undyed fabric samples are dyed with methylene blue for 1 minute at boil at neutral and acidic pH, respectively. The oxidatively damaged cellulose shows a darker color with the acidic pH than that at neutral.³⁵ It was reported³⁶ that a test dye, Oxycarmine, can be four times as sensitive as methylene blue, and is specific for oxycellulose.

The other qualitative staining tests⁷ for the evaluation of damage to cellulose due to the formation of oxycellulose and hydrocellulose are the Fehling's solution (brownish red color), Nessler's reagent (yellow then gray color), Schiff's reagent (red color), alkaline silver nitrate (gray to black color), and stannous chloride and gold chloride (purple color).

5.10.2 Alkali damage to wool³⁴

The cystine disulfide link ($-\text{CH}_2-\text{S}-\text{S}-\text{CH}_2-$) in wool can be attacked by alkali and converted to a lanthionine sulfide link ($-\text{CH}_2-\text{S}-\text{CH}_2-$). Due to the variation in the sources and fineness of the wool, the absolute content of the cystine group in wool samples is variable. Therefore the damage analysis of wool fibers based on chemical principles requires the undamaged wool sample as a comparison reference. Otherwise, the test cannot give quantitative results.

A common test for estimating the alkaline damage of wool is the urea/bisulfite solubility test. Urea can cleave the hydrogen bonds and bisulfite the bisulfide bonds. The testing solution contains 50 g urea, 3 g sodium metabisulfite and 2 ml of 5*N* sodium hydroxide per 100 ml. The alkaline-damaged wool shows only <10% weight loss in the test due to the reduced amount of cystine disulfide links after the alkaline attack. The undamaged wool can have 40–50% weight loss, while the acid-damaged wool can have a weight loss of more than 80%.³⁵

Alternatively,³⁷ Kiton Red G dye (C. I. Acid Red 1) can be used to test the damaged wool. Mix 1 g of wool fiber for 10 minutes with 100 ml of 0.1%

Kiton Red G acidified with 5 ml of 0.1*N* HCl. Undamaged wool shows mainly as uncolored, while damaged or chlorinated wool shows a red color, of which the intensity is proportional to the degree of the damage or chlorination up to 50%. A well-chlorinated sample can show 25–35% damage.

5.10.3 Damage to elastane (spandex)

The most common damage to elastane fibers is due to heat at temperatures above 170°C and chlorine attack. The result of such damage is loss of elasticity as well as strength reduction. Therefore the damage analysis of elastane fibers can be performed using a universal material tester, such as the Instron tester. The following methods can be adopted to evaluate damage to textile materials with elastane components:

- Stress (strength)–strain (elongation) curve of the elastane fiber: ASTM D2653-07, Standard Test Method for Tensile Properties of Elastomeric Yarns (CRE Type Tensile Testing Machines)
- Elastic properties test of the elastic yarns: ASTM D2731-07, Standard Test Method for Elastic Properties of Elastomeric Yarns (CRE Type Tensile Testing Machines)
- Stretch properties of fabrics: ASTM D3107-07, Standard Test Methods for Stretch Properties of Fabrics Woven from Stretch Yarns.³⁸

5.11 Conclusions

Fabric chemical testing is a task requiring a good understanding of chemistry as well as of textiles. Because many textile chemicals are applied to substrates based on the affinities between the textile material and the chemical, conducting a fiber identification first can often provide a good direction towards the following dye/chemical analysis. However, it is not the intention of this chapter that the test methods presented can be applied directly without further reading the details listed in the references. Instead, this chapter serves only as an introduction to the test methods, and to give guidance to anyone who wants to perform the test what could be done to start with. It is also worth mentioning that this chapter in no way delivers an exhaustive chemical test list for textiles, though some of the tests are equally applicable to fabrics, yarns, and fibers. Therefore, readers are greatly encouraged to access the further reading and references to find out more (and current) developments in the field of textile chemical testing.

With the advent of more and more affordable computer technologies, many traditional wet chemical testing methods are being replaced by instrumental analyses. Some of the testing methods presented may well be conducted using the newly developed instruments. In addition, the principles and chemistry of testing textiles can also be different from those

presented. The latest research and development in nanotechnologies for textiles has challenged current testing methods with regard to how textiles processed with nanotechnology can be effectively tested in terms of quality, performance, and safety. The most critical issues would be the environmental, health and safety (EHS) concerns. The US government has just released a research strategy on the topic,³⁹ stating that ‘EHS research is focused in particular on understanding general mechanisms of biological interaction with nanomaterials and on developing broadly useful tools and tests for characterizing and measuring nanomaterials in various environments, including in the body’. Therefore, it is envisioned that related testing methods will come to the market following the strengthened research efforts in this area. Readers concerned with textile ecology should read the Oeko-Tex Standard 100⁴⁰ revised in January 2008 to understand how ecological issues are addressed in textile chemical testing. Oeko-Tex Standard 100 tests for harmful substances such as formaldehyde, heavy metals, pesticides, chlorinated phenols, allergic dyes, flame retardants, biologically active products, volatile organic compounds, etc., as well as for skin-friendly pH (4 to 7.5) on four classes of textiles: baby; direct skin contact; non-direct skin contact; and decoration. After a textile product has successfully passed all Oeko-Tex Standard 100 tests, the certified lab which conducted the conformity tests can issue the Oeko-Tex 100 label that can then be placed on the product, showing the eco-friendly nature of the textile goods.

5.12 Sources of further information and advice

For more detailed information and testing methods as well as for further developments of new and updated tests and standards, readers should access the following:

- AATCC, American Association of Textile Chemists and Colorists, *AATCC Technical Manual*, updated annually, <http://www.aatcc.org/>
- ASTM, American Society for Testing and Materials, *Annual Book of ASTM Standards, Section Seven, Textiles*, <http://www.astm.org>
- BSI, British Standards Institution, <http://www.bsi-global.com/en/Standards-and-Publications/>
- C.I., Color Index, jointly published by the Society of Dyers and Colourists (SDC, UK) and the American Association of Textile Chemists and Colorists (AATCC, USA), <http://www.colour-index.org/>
- EN, European Standards, <http://www.cen.eu/catweb/cwen.htm>
- ISO, International Organization for Standardization, TC 38: *Textiles*, and ICS 59: *Textile and Leather Technology*, <http://www.iso.org/>
- JIS, Japanese Industrial Standards, <http://www.webstore.jisa.or.jp/webstore/JIS/SearchEn.jsp?lang=en>

- Oeko-Tex Standard 100, <http://www.oeko-tex.com/en/main.html>
- Textile journals: *AATCC Review*, *Coloration Technology*, *Melliand Textilberichte*, *Textile Research Journal*, *Journal of the Textile Institute*, *Dyes and Pigments*, etc.
- Textbooks on analytical chemistry, inorganic chemistry, organic chemistry, polymer chemistry, instrumental analysis, etc.

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Abstract: Fabric appearance is always considered to be one of the most important aspects of fabric quality. Testing for fabric appearance is the process of inspecting, measuring and evaluating characteristics and properties of a fabric surface; the purpose of testing and evaluation is to assess the performance of a fabric or predicate its performance in conjunction with its end use. It can be performed according to well-defined test methods by industry-wide organizations. There are many aspects of fabric appearance that can contribute to a woven or knit fabric's overall value and consumer satisfaction. In this chapter, an attempt has been made to explain the testing methods for assessing various fabric appearance attributes.

Key words: fabric appearance, pilling evaluation, wrinkling testing, seam puckering, dimensional stability, light reflectance, objective evaluation of fabric appearance.

6.1 Introduction

Fabric appearance is always considered to be one of the most important aspects of fabric quality. However, the definition of fabric appearance is quite complicated; it is a general term including the visible properties of fabric material universally, which is related to many factors, such as structure, material properties, surface morphology and reflectance properties. Usually, fabric appearance can be described separately in terms of different attributes: pilling, wrinkling, seam puckering, fuzziness, dimensional change and luster. These kinds of typical attributes are always happening and observed during the daily wearing or washing of fabric products.

Fabric appearance testing is the process of inspecting, measuring and evaluating characteristics and properties of a fabric surface; the purpose of testing and evaluation is to assess the performance of a fabric or predicate its performance in conjunction with its end use. Fabric appearance testing can be performed according to well-defined test methods by industry-wide organizations, such as AATCC, ASYM, ISO, etc. The testing methods can be divided into two main types: subjective and objective. The differences between these two types of methods rely on whether they are based on visual assessment or on digital assessment with the aid of testing machines. Subjective methods have the advantages of simplicity and low cost of equip-

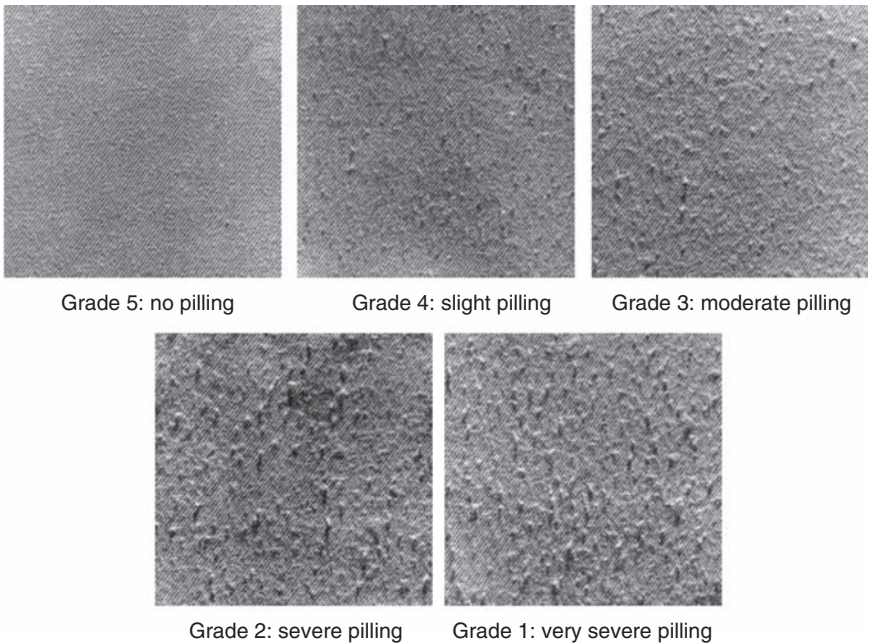
ment; however, they tend to be time consuming, inconsistent and labor-intensive. Although objective methods could avoid these disadvantages, they are not widely used in practice in the industry.

In some cases, woven fabrics and knitted fabrics might have different standards for the evaluation of appearance in view of their different material properties and internal structures. There are many aspects of fabric appearance that can contribute to a knit fabric's overall value and consumer satisfaction. For woven fabrics, wrinkling and seam puckering evaluation seems to be considered much more than other factors; for knitted fabrics, usually there are four key factors: facing-up, wrinkling/surface smoothness, cockling/loop distortion in knits, and spirality. In this chapter, we will give a brief introduction to these testing methods for assessing fabric appearance in terms of those attributes.

6.2 Appearance testing: pilling testing and evaluation

Pilling is a phenomenon of fiber movement or slipping out of yarns, which is usually happening on the fabric surface during abrasion and wear. The development of pilling could be divided into four stages: fuzz formation, entanglement, growth, and wear-off. The formation of fuzz and pills suspended on the fabric surface could affect the fabric aesthetics and its ultimate acceptance by customers. Many researchers are investigating how to improve the pilling resistance ability of cloth, including the optimization of fiber manufacture, yarn manufacture and fabric manufacture. In this case, the standards and testing methods for evaluating the pilling grade of cloth are very important in guiding the technology of pilling resistance optimization. The photographs in [Fig. 6.1](#) show standard pilling images of woven fabrics from grade 1 to grade 5 (see [Table 6.1](#)).

Facing-up [1] can be defined as the generation of unwanted surface fibers leading to a change in the appearance of the garment, as illustrated in [Fig. 6.2](#). Facing-up is one kind of surface change which is less serious than pilling. Facing-up is normally associated with knitted yarns made from worsted and possessing a clean surface. Fabrics and knit made from wool spun yarns generally are finished to create a fuzzy or hairy surface and during wear/abrasion the reverse effect is sometimes an issue. Facing-up can occur all over a garment or in localized areas. It is caused by the gradual withdrawal of fibers from the surface layer of yarns (migration) and can in many cases lead to pilling. The migration of surface fibers from the body of the fabric to the surface is due to frictional forces applied to the fibers on contact with other surfaces, which might also include the same fabric. Consequently, facing-up tends to occur when surface abrasion forces are high such as during tumble drying.



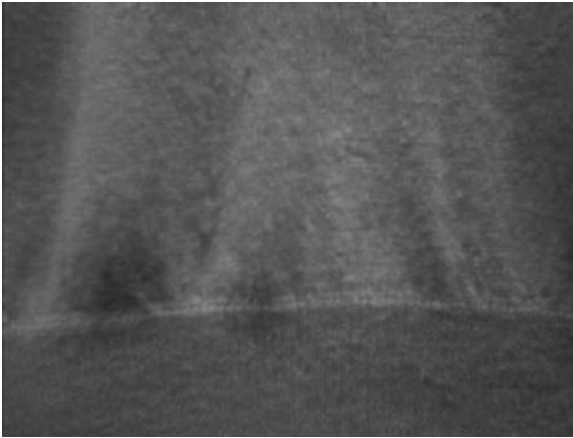
6.1 Pilling standards of woven fabrics.

Table 6.1 Visual assessment of pilling

Grade	Description
5	No change
4	Slight surface fuzzing and/or partially formed pills
3	Moderate surface fuzzing and/or moderate pilling. Pills of varying size and density partially covering the specimen surface
2	Distinct surface fuzzing and/or distinct pilling. Pills of varying size and density covering a large proportion of the specimen surface
1	Dense surface fuzzing and/or severe pilling. Pills of varying size and density covering the whole of the specimen surface

6.2.1 Fabric pilling: standards

Fabric pilling or related surface change is commonly tested in the laboratory using specific machines by generating pilling on the fabric by simulating wear. A sample of the original fabric is fixed in the machine and wear is simulated by the action of abrasive materials. Generally, the machines are supplied with a standard reference consisting of photographs of samples



6.2 Facing-up of wool knits.

with different degrees of pilling. The abraded fabric is then compared with standard photographs that have been developed by the standards institutions such as ASTM, AATCC, IWS, BIS, JIS, etc., and a degree of pilling is assigned accordingly.

6.2.2 Fabric pilling: instruments

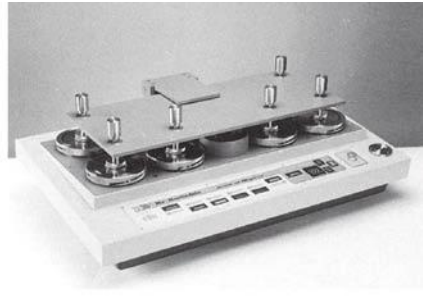
The most popular abrasion machines (Fig. 6.3) to simulate wear conditions in the market are the ICI pilling box tester, the Martindale tester, and the random tumble pilling tester. The methods of abrasion differ in the following ways.

- *ICI pilling box tester.* Specimens are mounted on the polyurethane tubes and tumbled randomly in a cork-lined box for a certain time.
- *Martindale tester.* Flat abrasion as specified in the ASTM D4970 pilling test. The instrument subjects specimens to a rubbing motion in a straight line that widens into an ellipse and gradually changes into a straight line in the opposite direction. This pattern of rubbing is repeated until fabric threads are broken or until a shade change occurs in the fabric being tested.
- *Random tumble pilling tester.* The specimen is placed in a cylindrical chamber and tumbled around within the chamber which is lined with mildly abrasive materials to brush the specimens to free fiber ends.

The method of abrasion has a significant effect on the pilling appearance. In comparing abrasion instruments, it was noted that the test results could be affected by instrument type, as well as instrument settings. Therefore, the



ICI pilling box



Martindale tester



Random tumble pilling tester

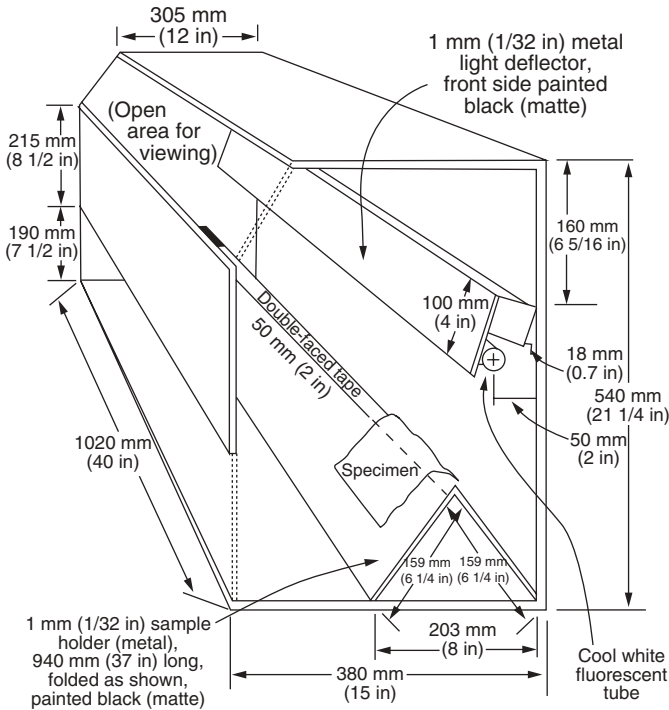
6.3 Pilling testers.

choice of pilling tester should depend on the consideration of material properties and the end-use of products.

6.2.3 Fabric pilling: evaluation

Subjective evaluation

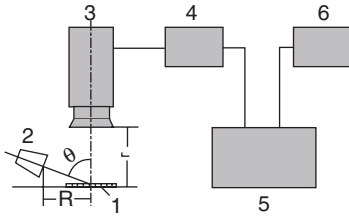
Once the fabric has been subjected to abrasive action of some kind, subjective or objective evaluation can be carried out to assess the degree of fabric pilling. Subjective evaluation is performed by comparing the tested specimens with visual standards, which may be actual fabrics or photographs of fabrics, showing a range of pilling resistance. The observed resistance to pilling is reported on an arbitrary scale ranging from 5 (no pilling) to 1 (very severe pilling) (see [Table 6.1](#)). The viewing condition is shown in [Fig. 6.4](#); it is a sketch map of apparatus for fabric appearance evaluation, also adopted for other appearance evaluation.



6.4 Apparatus for fabric evaluation (ASTM 3514-02).

Objective evaluation

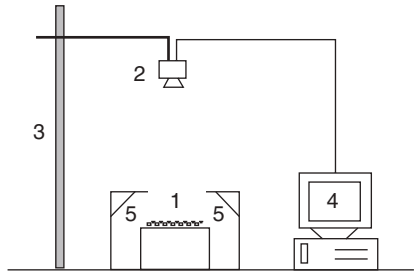
Considerable research has been undertaken on the objective evaluation of fabric pilling. These methods are mainly based on digital technologies, such as digital image analysis or the laser scanning method. The laser scanning system applies the laser triangulation technique to measure the 3-D height field of the fabric surface and to identify pills or fuzzes through the variation of its height; or a 2-D CCD/CMOS imaging system can be used to digitalize the reflectance properties under a certain illumination by using the intensity of image pixels, and some algorithms are then developed to characterize the pills or fuzzes to distinguish them from the common texture. In the latter case, the algorithms rely greatly on the design of the imaging style and the setting of the imaging condition. In comparison with laser scanning, the CCD/CMOS imaging system is simple, easy to implement and low-cost; however, it is much more sensitive to the color and texture of fabric samples. Konda *et al.* [2] first attempted to use image processing techniques to evaluate fabric pilling (Fig. 6.5); Xu [3] developed an image analysis system that aims at characterizing and rating fabric pilling appearance using Fast Fourier Transform (FFT) and other related image-processing techniques; Hsi *et al.*



Key

- | | |
|----------------|-------------------|
| 1 Sample | 2 Light source |
| 3 Video camera | 4 Graphic display |
| 5 Computer | 4 Printer |

6.5 Two-dimensional image analysis system for fabric pilling evaluation (from Ref. 2).



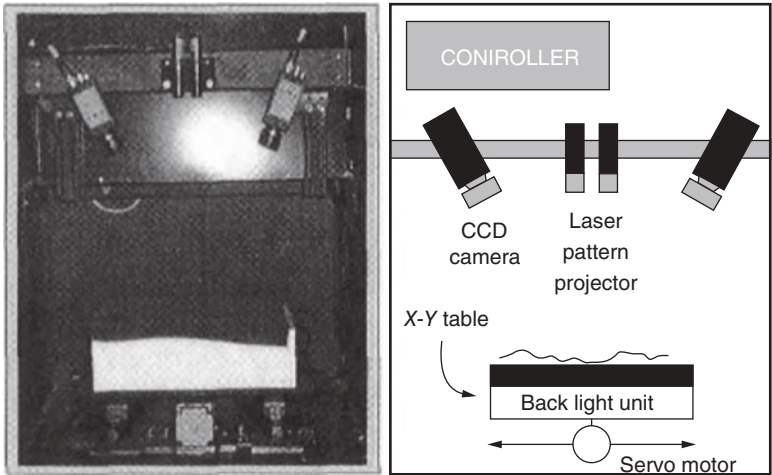
- Key
- | |
|----------------------------|
| 1 Lighting system |
| 2 Digital camera |
| 3 Frame |
| 4 Computer |
| 5 Parallel lighting source |

6.6 Two-dimensional image capturing system.

[4] developed a hardware device and software based on image analysis techniques to detect and describe fuzz on fabric surfaces; and Kang *et al.* [5] developed a non-contact 3-D measurement method for the objective evaluation of fabric pilling based on stereovision.

6.2.4 Image capturing

The 2-D image capturing system used for pilling evaluation is illustrated in Fig. 6.6 and the 3-D surface reconstruction system based on stereovision is illustrated in Fig. 6.7. The lighting box is designed to illuminate fabric samples uniformly, simulating daily lighting conditions. Each fabric sample was cut into lengths of approximately 105 mm, and put on the testing platform of the imaging system for the purpose of digitalization.



6.7 Stereovision system for fabric pilling evaluation (from Ref. 4).

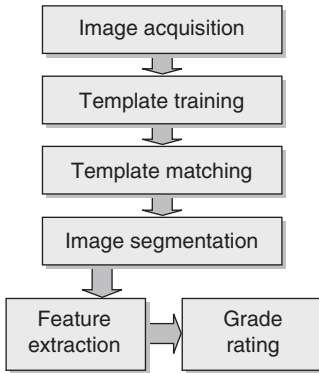
The principle of the two-dimensional image capturing system is very simple. The image of the cloth surface is digitalized by a kind of photoelectric sensor called a CCD (charge coupled device). However, the principle of 3-D reconstruction is a little more complex and the hardware is also more expensive than for a 2-D imaging system; stereovision is based on the geometry of the camera and can calculate the 3-D coordinate of each surface point accurately. In this chapter, we introduce the objective evaluation method based on 2-D image analysis technology.

6.2.5 Method for pilling evaluation

After an image is acquired by hardware, two major functions are implemented by the algorithms of software, including the identification of pills/fuzzes and the measurement of their features. A general scheme of the image analysis procedure is presented in Fig. 6.8, where the processing steps are integrated in blocks.

Pill template training

The remarkably varied structure of fabrics creates a challenge for detecting pills if a wide variety of fabrics is considered. However, pills are spaced and distributed relatively far apart and are elevated compared with the yarn body in fabrics. By illuminating fabrics at an oblique angle, pills are much brighter than the ground of a fabric. For image analysis, pills can be regarded as elliptical or circular objects that contain a centered white circle



6.8 Flow diagram of pilling evaluation.

surrounded by black pixels. In this case, a two-dimensional Gaussian function should be the most suitable template for pill detection.

Template training

Actual pill images from fabric images were used for the parameter estimation of the Gaussian function; σ_x and σ_y are the most important parameters to generate the pill template. As a criterion of optimality, the mean square error (MSE) is used to describe the estimation reliability. Here,

$$\text{MSE} = \sqrt{\frac{\sum_{i=1}^n (z_e - z_i)^2}{n-1}}$$

where z_e is the estimated function and z_i is the original data. When σ_x is equal to σ_y , the shape of the pill template will be circular, otherwise the shape will be elliptical. It is found that the value of σ_x and σ_y influences the contrast of the pill template: the lower it is, the more contrast there will be.

Template matching

Template matching is the process of moving the template over the entire image and calculating the similarity between the template and the covered window on the image. Template matching is implemented through two-dimensional convolution. In convolution, the value of an output pixel is computed by multiplying elements of two matrices and summing the results. One of these matrices represents the image itself, while the other matrix is the template, which is known as a convolution kernel.

If the original image and the template are denoted $f(x, y)$ and $t(x, y)$, and the enhanced image after convolution is denoted $g(x, y)$, the convolution may be abbreviated by:

$$g(x, y) = f(x, y) \circ t(x, y) \quad 6.1$$

where \circ is used to indicate the convolution of two functions. Discrete convolution is given by

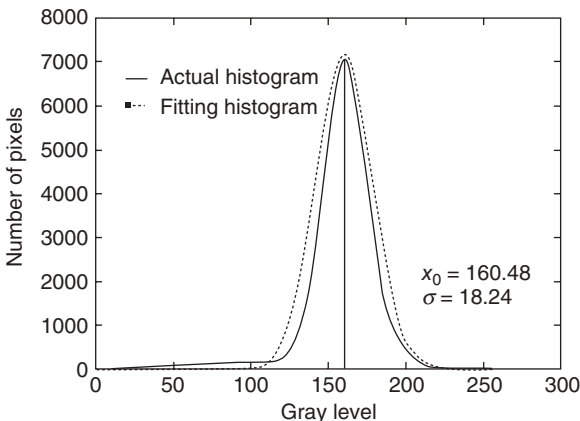
$$g(i, j) = \sum_{m=1}^M \sum_{n=1}^N t(m, n) \cdot f(i-m, j-n) \quad 6.2$$

where M, N is the size of the template.

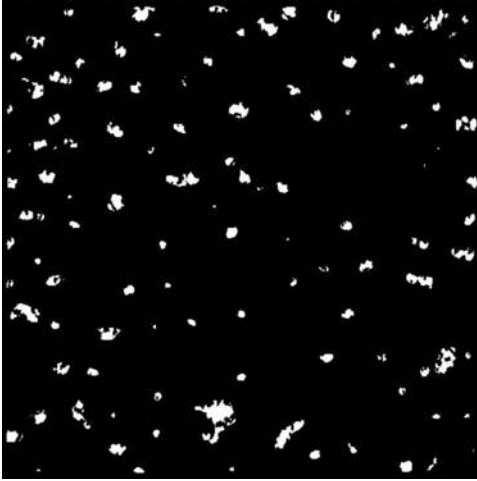
Image segmentation

After template matching, an enhanced fabric image is generated for pill evaluation: The bright areas in the filtered image indicate pill locations; most of the pixels of the filtered image are of low gray level and belong to the background. In this step, we intend to segment pills from the background in order to obtain a binary image with white pixels (pills) on a black background. Choosing a suitable threshold is the key problem for image segmentation.

If we examine the histogram of the filtered image after template matching, as shown in Fig. 6.9, a single peak corresponding to the background can be observed in the center of the histogram (solid line). We model the histogram curve with a 1-D Gaussian distribution (dashed line); x_0 is the position of the peak center and σ is the standard deviation of the Gaussian function. We calculate the threshold t according to the formula:



6.9 Histogram of the filtered image and its fitting curve.



6.10 The binary image after a global binarization.

$$t = x_0 + \lambda \cdot \sigma \quad 6.3$$

where λ is the coefficient which determines the threshold. Consider a normal population with mean x_0 and standard deviation σ ; the interval $[x_0 - 3\sigma, x_0 + 3\sigma]$ contains 99.73% of the population values, so $\lambda = 3$ in this chapter. The result obtained by applying the threshold defined by the above formula is shown in Fig. 6.10.

Feature extraction

In subjective evaluation, judges tend to rate the pilling appearance of a fabric by comparing pill properties such as number, area (size), contrast and density. All these properties can be measured in the binary fabric images objectively using image analysis techniques.

Number

Pill number n is an important factor influencing pilling appearance. It can be measured by counting the number of white objects in the binary image. Note that very small objects with area less than 4 pixels should be removed, as these are considered to be noise objects.

Area (size)

The area s_i of one pill is expressed in terms of the number of pixels with 255 gray values that make up this pill, where i is the label number of the pill. Then if \bar{s} is the mean area of the pills, the total area S can be calculated

as the product of the pill number n and the mean area \bar{s} . The size of one pill d_i is expressed in terms of its equivalent diameter in pixels, and \bar{d} is the mean size of pills. Since d_i has a good correlation with s_i , both can be used to describe both big and small pills.

Contrast

Pill contrast is a measure of how much the gray level of a pill differs from the gray level of the base fabric in the fabric image. It is calculated by the following expression:

$$C_i = \frac{g_{p-i}}{g_b} \quad 6.4$$

where g_{p-i} is the mean gray level of pill i , and g_b is the mean gray level of the background. \bar{C} is the mean value of C_i .

Density

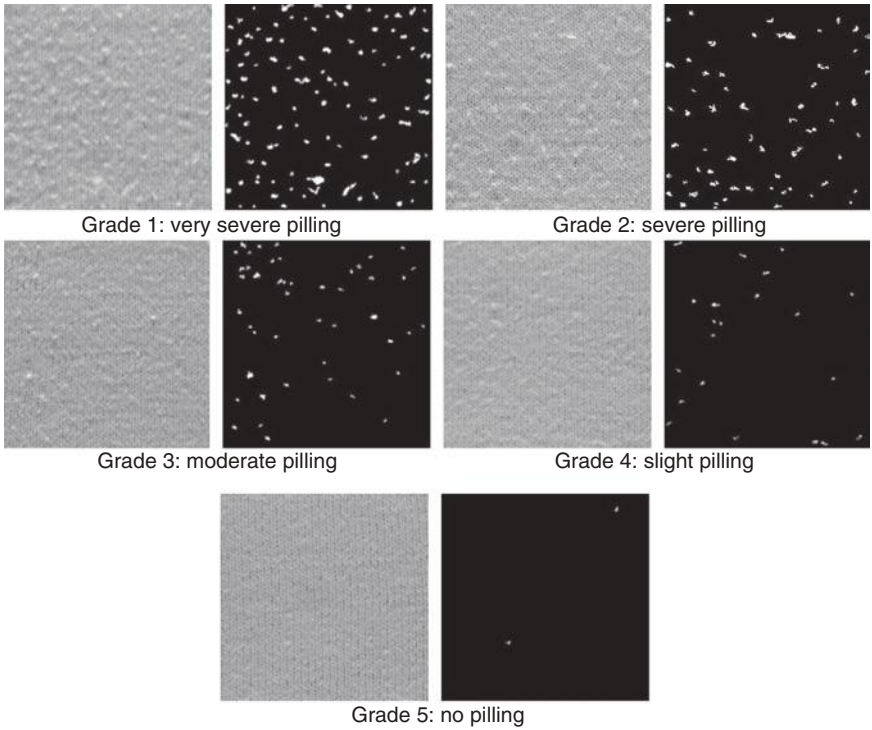
Pill density is another important factor influencing pilling appearance; a reasonable estimator of pill density has been introduced in Ref. [3]. First, a number of points were randomly generated inside the binary image. At each of these points i , a pill closest to the point was searched and the distance r_i between this pill and the point can be calculated. Then another pill nearest this point was found and the distance between these two pills x_i can also be calculated. After n random points have been counted, the population-density estimator D can be determined by the following equation:

$$D = \frac{\sqrt{2n}}{\pi \sqrt{\sum (r_i^2) \sum (x_i^2)}} \quad 6.5$$

This estimator is insensitive to the clumping pilling, while the density estimated by the number of pills in a unit area is sensitive to it.

Grade rating

In order to make the rating result by the image analysis techniques consistent with the visual standards, five samples are selected as the initialization of system training, which are subject to different grades (from grade 1 to grade 5) according to ASTM standards. Since the pilling of textile fabrics is affected by many factors, such as type of fiber or blends, fiber dimensions, yarn and fabric construction, and fabric-finishing treatments, it is better to select the same fabric as the standard image to make the correlation between the objective evaluation and subjective evaluation. [Figure 6.11](#) shows the images of five grades and their binary images after image segmentation. [Table 6.2](#) shows the parameters extracted from these images.



6.11 Standard pilling images.

Table 6.2 Pill parameters of standard pilling images

Image no.	n	\bar{s} (pixel)	S (pixel)	\bar{C}	D (1/pixel ²)
1	109	93.3395	10 174	1.2926	0.000029
2	57	63.7368	3633	1.26858	0.000015
3	46	54.2609	2496	1.27377	0.000012
4	21	48.6667	1022	1.20683	0.000004
5	2	45.5	91	1.29234	0.000000

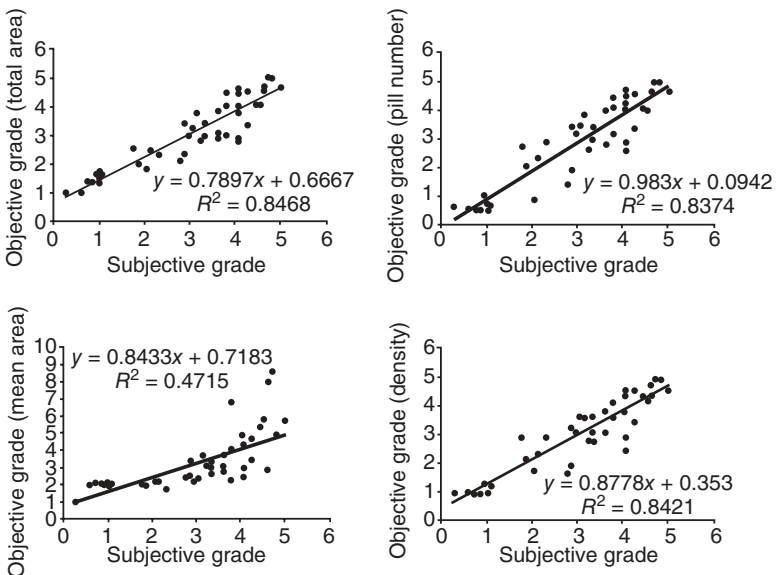
From Table 6.2, it is easily found that pill number n , mean area \bar{s} , total area S and density D decrease with subjective grade decrease, while mean contrast \bar{C} has no correlation with subjective grade. In this case, the empirical rating equations for the pilling grade are established for these four image features by using the linear regression method. Among them, the pill total area S is the highest, so for simple calculation, S can be chosen in our research to build the rating formula, which is

$$y = -7E - 12x^3 + 2E - 07x^2 - 0.0012x + 5.0904$$

where x is the pill total area of the image, and y is the objective pilling grade.

Having established the relationship between pilling grade and objective parameters, the objective parameters of the other 40 samples used in our experiment were measured. In order to identify the efficiency of objective evaluation, the grade values using the four rating formulas were compared with the subjective grade, and satisfactory agreement can be achieved in our experiment, as shown in Fig. 6.12. There are four objective grade values for each sample calculated by different rating formulas, for total area, pill number, mean area and density. Three have good correlation with the subjective grade (0.8468, 0.8374, 0.8421), except the objective grade from mean area (0.4715). It is an interesting finding that the parameter mean area has a good correlation with the standard grade (0.9993) but a poor correlation with the practical grade from judges (0.4715). This proves that judges are insensitive to the mean area of pills, and more sensitive to pill number, total area and density; the pill number and total area are more important factors for subjective evaluation, so is the distribution density of pills.

Although much valuable research work has been done in recent years, the objective evaluation of pilling appearance is still at the stage of academic research; although some commercial prototypes have been developed, the algorithms to eliminate the color and pattern effects and improve the system reliability should be optimized in the future.



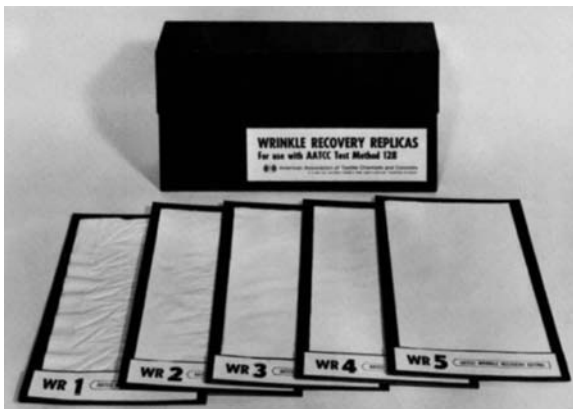
6.12 Relationships between objective grade and subjective grade.

6.3 Fabric wrinkling testing and evaluation

Wrinkles are three-dimensional versions of creases, and form when fabrics are forced to develop high levels of double curvature, which result in some degree of permanent in-plane and out-of-plane deformations. Most fabric will generate some wrinkles after laundering, dressing, and folding. These wrinkles seriously compromise the cloth's acceptability. For example, for most customers it is an unpleasant feeling to be wearing a wrinkled shirt while attending some social activities. The photographs in Fig. 6.13 show standard wrinkling images of fabrics from grade 1 to grade 5.

6.3.1 Fabric wrinkling: standards

The method most often used in the laboratory to evaluate the wrinkle recovery of a fabric is AATCC test method 128, 'Wrinkle recovery of fabrics: appearance method'. The principle of this method is to induce wrinkles in the fabric under standard atmospheric conditions in a standard wrinkle device under a predetermined load for a certain period of time. Then the specimen is rated by comparing it with AATCC wrinkle replicas. AATCC test method 66, 'Wrinkle recovery of woven fabrics: recovery angle', is used to determine the wrinkle recovery of woven fabrics. It is applicable to fabrics made from any fiber, or combination of fibers. The principle is to fold the specimen and compress it under controlled conditions of time and force to create a folded wrinkle. The test specimen is then suspended in a test instrument for a controlled recovery period, after which the recovery angle is recorded. Usually, AATCC test method 128 is used to evaluate the wrinkling appearance of fabrics.



6.13 AATCC wrinkle replicas for gradings.



6.14 AATCC Wrinkle Tester.

6.3.2 Fabric wrinkling: instruments

The AATCC Wrinkle Tester illustrated in Fig. 6.14 is designed to introduce wrinkles in the test specimen under controlled conditions. This apparatus is based on a development of ENKA/AKU Research.

6.3.3 Fabric wrinkling: evaluation

Subjective evaluation

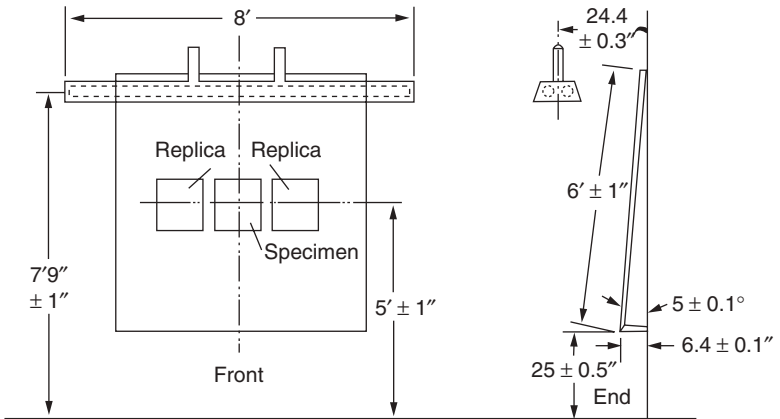
Once the fabric has been induced to be wrinkled under a certain load for a standard period of time, subjective or objective evaluation can be performed to assess the degree of fabric wrinkling. Subjective evaluation compares the tested specimens with wrinkle replicas, showing a range of wrinkling status. The observed wrinkling is reported on an arbitrary scale ranging from 5 (no wrinkling) to 1 (very severe wrinkling). The viewing conditions are shown in Fig. 6.15.

Objective evaluation

Objective evaluation of fabric wrinkling is also an interesting application of digital technology to the textile field. According to the way in which the wrinkled appearance is detected and measured, these evaluation methods could be classified into three main categories: the contact, laser scanning and image processing methods.

Contact method

A contact method-based instrument like the 'Wrinklemeter' [6] consists of a movable platform, a speed-controlled motor, a small probe linked to a



6.15 Apparatus for fabric evaluation (AATCC test method 128).

shutter, a light source, a photovoltaic cell and a signal recorder. The principle of this method is to record the surface profile of wrinkled fabric on the recorder paper, and calculate the mean wrinkle height of the fabric to characterize the degree of wrinkling. The wrinkled surface of a fabric could be regarded as a random rigid surface; for a particular cross-section of the 3-D surface profile, four parameters could be defined to describe the severity of wrinkling quantitatively: wrinkle height, wrinkle slope, density of zero points and density of extreme points [7]. However, this method is based on contact with the fabric surface; it might flatten the wrinkled surface under a certain pressure, in which case it could result in an error in the assessment of fabric wrinkle.

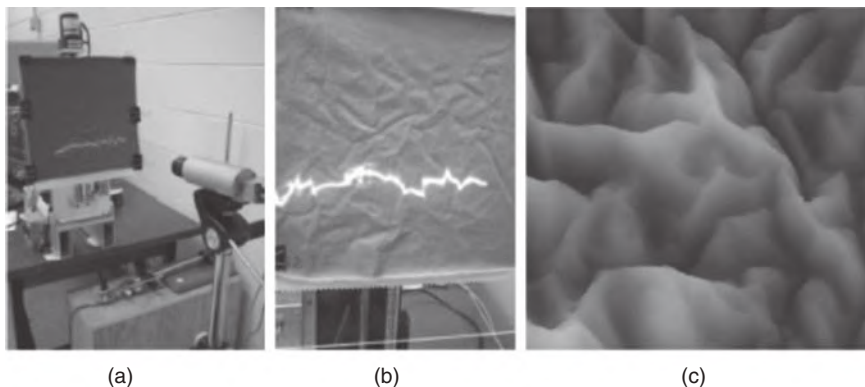
Laser scanning method

The laser scanning method is based on the laser triangulation or stereovision technique. It is accomplished by projecting a laser line or point on an object and then capturing its reflection with a sensor located at a known distance from the laser's source. The resulting reflectance angle can be interpreted to yield 3-D measurements of the part. Ramgulam *et al.* [8] used a laser scanning system to measure the 3-D surface profile of a wrinkled surface. The sample was placed and fixed on a platform of an X - Y table driven by step motors to do the laser scanning. Amirbayat and Alagha [9] applied the same 3-D laser scan method to measure the wrinkle replicate standards and extracted certain geometrical features – surface area, average surface length in X and Y directions, covering volume, average curvature and average maximum skewness – to characterize the fabric wrinkle status. In their research, the last two parameters could describe the wrinkle status reasonably, and the relationship between this method and standards could

achieve 0.984. This method is not affected by color and pattern; however, the scanning speed is a little slow.

The three-dimensional scanning device developed by Park and Kang [10] to measure wrinkle degree also consists of a laser scanner to detect the magnitude of a wrinkle. On the basis of hardware, Kang and Lee [11] proposed a method based on fractal dimensions to characterize the severity of the fabric surface wrinkles. The surface contours of wrinkled fabrics or puckered seams were scanned using a laser scanning system, and the fractal dimensions of the surface were then counted using a box-counting method. Neural networks were applied by Kim [12] to judge the wrinkling grade based on 64×64 points of sampling data using a similar scanning system. The study revealed a linear relationship between objective evaluation and subjective evaluation results. Turner *et al.* [13] also proposed a laser-based surface profiling system that utilizes a smart camera to sense the 3-D topography of fabric specimens (see Fig. 6.16). The system incorporates methods based on anisotropic diffusion and the facet model for characterizing edge information that ultimately relate to a specimen's degree of wrinkling. It is reported that this system is as good as the current American Association of Textile Chemists and Colorists (AATCC) smoothness grading system.

Xu *et al.* [14] combined laser triangulation and image processing techniques to develop a laser profilometer for assessing fabric smoothness appearance. The profilometer consists of a laser line projector, CCD camera, rotating stage, computer and special software. They introduced the basic principle of laser triangulation, image processing techniques for extracting surface profiles, wrinkle characterization methods, and the results of a trial



6.16 (a) Overall view of the laser acquisition system; (b) laser line being projected onto a sample fabric; (c) sample range image (from Ref. 13).

test. The profilometer can generate results that are consistent with those of human observers, and the patterns and colors of the fabric do not affect the measurements. In addition, the profilometer is essentially insensitive to patterns of wrinkle orientations. This new evaluation method also solves a problem encountered in research on other instrumental evaluation techniques – the ability to discriminate differences in fabrics whose smoothness appearance falls between AATCC test method 124 replicas SA-3 and SA-3.5. This method is faster than Amirbayat and Alagha's laser scanning [9], but the resolution is so high that it does not give 3-D recovery for the whole fabric surface.

Image processing method

Image analysis is another objective evaluation method for the evaluation of fabric wrinkling; the low cost of image digitalization makes it easily acceptable by the textile industry. There has been much valuable research work on this kind of method. For example, Xu and Reed [15] digitalized the standard wrinkle images using a panel scanner and defined two variables – surface ratio and shade ratio – to quantify wrinkled appearance, then studied the correlation between these two parameters and subjective grades using a non-linear regression method to generate the objective evaluation judging grade. Na and Pourdeyhimi [16] analyzed the AATCC replicate standards using a combination of texture and profile analysis techniques. Their research shows that wrinkling can be reliably measured using gray level and surface statistics, co-occurrence analysis and power spectral density of image profiles. However, previous methods cannot work well when fabrics have different colors and irregular patterns, because 2-D gray images cannot describe the 3-D status of fabric surfaces and can confuse some color or pattern shades with surface height information. Fazekas *et al.* [17] designed some special illumination for fabric image capture (bi-illumination, *Y*-illumination and *X*-illumination). After pre-processing (intensity adjustment, image filter, histogram stretching), depth information for the fabric surface was calculated and good correlation between the experimental results and subjective evaluation could be achieved. Chen *et al.* [18] also digitalized fabric wrinkle images using a panel scanner, and applied a box-counting method to calculate the fractal dimension of gray level surface and the fractal dimension of wrinkle block area, both of which could be used for wrinkle evaluation.

Hu *et al.* [19] proposed a new method for measuring fabric wrinkle based on integrating photometric stereo and image analysis techniques. The photometric stereo method was used for the first time to extract 3-D surface profiles of fabrics and successfully eliminate the influence of color and pattern. Image analysis techniques were developed further to extract wrinkling features of these reconstructed 3-D images, and there was good cor-

relation between objective parameters and subjective AATCC grades. Yang and Huang [20] proposed a similar approach to reconstruct the fabric 3-D surface profile from multi-illuminated images based on the photometric stereo method; they measured the wrinkling degree using four index values to indicate the variation of surface height.

Wrinkle characterization

No matter which method is used to digitalize the wrinkled surface, certain features are essential to characterize the wrinkling status of a fabric surface. According to the type of feature definition, wrinkle features can be divided into two major categories: geometrical features and textural features.

Geometrical features

Common geometrical features can be defined in terms of height, area, volume and its variance or statistical parameters:

- Wrinkle height and its variance is a measure of the height of wrinkles.
- Mean length of the paths over the wrinkled surface along the X and Y directions.
- Surface area and volume under the surface.
- Mean principal curvature.
- Mean maximum twist.
- Wrinkle roughness is a measure of the size of wrinkles, with no consideration of their shape, and is characterized by four different quantitative measures [14].
 - Arithmetic average roughness:

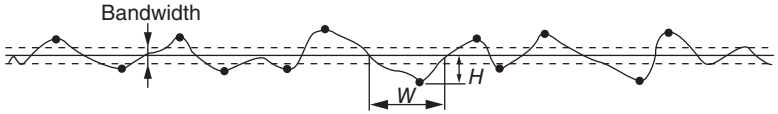
$$R_a = \frac{1}{n} \sum |Z_i - m| \quad 6.6$$

- Root mean square roughness:

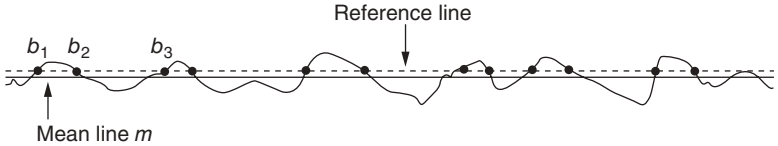
$$R_a = \sqrt{\frac{1}{n} \sum (Z_i - m)^2} \quad 6.7$$

In these two equations, Z_i is the height of the profile at the i th point, n is the number of points selected, and m is the height of the mean line which fits in the middle of the profile. Both these measures compute the average height of the wrinkles from the mean middle line.

- Ten-point height R_z : the average distance between the five height peaks and the five lowest valleys on the curve.
- Bearing length ratio t_p : a measure obtained by establishing a reference line parallel to the mean line at a predetermined height between the highest peak and the lowest valley of the profile. The line intersects the profile, generating one or more subtended lengths; t_p is the



6.17 Illustration of bearing length ratio.



6.18 Illustration of sharpness and peak-and-valley count.

ratio of the sum of the subtended length to the sampling length of the curve as illustrated in Fig. 6.17.

- Wrinkle sharpness k represents the shape of the wrinkle, describing the point of the wrinkle which forms a definite peak as illustrated in Fig. 6.18. The ratio of the height to the width of the wrinkle is used to quantify sharpness.
- Wrinkle density can be quantified by the peak and valley count, which is the number of peaks and valleys along the selected bandwidth symmetrical to the mean line of the profile. The selection of bandwidth is important to avoid tiny peaks and valleys which may correspond to noise signals.

Textural features

Usually the co-occurrence matrix and fractal dimension are used to describe the textural properties. The co-occurrence matrix $M(d, \theta)$ consists of probability $P_\delta(i, j)$, in which the pixel of gray level i appears separated a distance $\delta = (d, \theta)$ from the pixel of gray level j , where the parameters d and θ are the distance and positional angle between the gray level pair i, j . The four parameters and the fractal dimension D are defined as follows [21]:

- Angular second moment (ASM), which is the parameter for the evenness distribution degree of the texture:

$$ASM = \sum_{i=0}^{n-1} \sum_{j=0}^{n-1} \{P_\theta(i, j)\}^2, i = 1, 2, \dots, n-1; j = 1, 2, \dots, n-1 \quad 6.8$$

- Contrast (CON), which is a measure of the gray level contrast:

$$CON = \sum_{k=0}^{n-1} k^2 P_{x-y}(k), |i - j| = k, k = 1, 2, \dots, n-1 \quad 6.9$$

- Correlation (COR), which is a measure of gray-tone linear dependencies:

$$\text{COR} = \frac{\sum_{i=0}^{n-1} \sum_{j=0}^{n-1} i \cdot j \cdot P_{\delta}(i, j) - u_x u_y}{\sigma_x \sigma_y} \quad 6.10$$

- Entropy (ENT), which is a measure of the complex degree of the texture:

$$\text{ENT} = - \sum_{i=0}^{n-1} \sum_{j=0}^{n-1} P_{\delta}(i, j) \cdot \log \{P_{\delta}(i, j)\} \quad 6.11$$

- Fractal dimension D :

$$D = \frac{\log(c) - \log(N(r))}{\log(r)} \quad 6.12$$

where $P_x(i) = \sum_{i=0}^{n-1} P_{\delta}(i, j)$, $P_y(j) = \sum_{j=0}^{n-1} P_{\delta}(i, j)$, $P_{x-y}(k) = \sum_{i=0}^{n-1} \sum_{j=0}^{n-1} P_{\delta}(i, j)$, u_x, u_y, σ_x

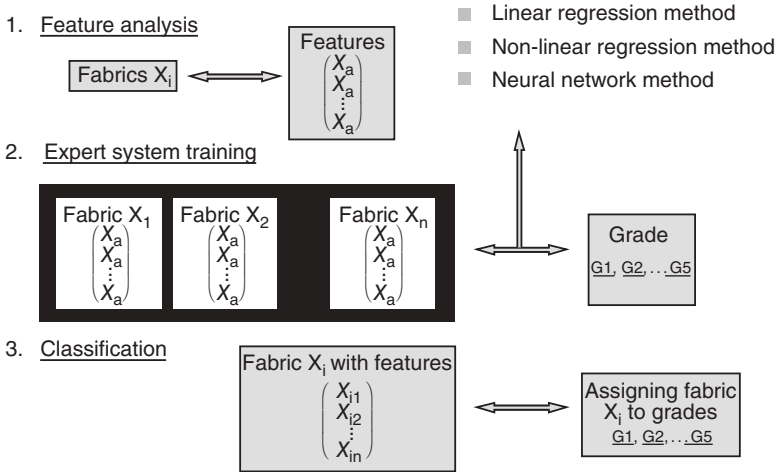
and σ_y are the means and standard deviations of $P_x(i), P_y(j)$, c is a positive constant, r is the side length of the cube and $N(r)$ is the number of cubes which cover the images.

Grading model

Generally speaking, the grading model establishes the relationship between the final wrinkling degree and those essential features defined previously to characterize the wrinkling status objectively. Linear regression, non-linear regression and neural networks are the three main methods to model this kind of relationship, as illustrated in Fig. 6.19.

Let $X = [x_1, x_2, \dots, x_n]$ represent the vector of wrinkling features and G represent the final wrinkle degree; then after feature extraction using previous digital technology, including both contact and non-contact methods, one set of standard wrinkle replicas or specimens is needed to estimate the parameters of the grading model; this step is called training of the grading model. Linear regression, non-linear regression and neural network or another related non-linear fuzzy-logic method could be selected to model the relationship between X and G . Xu *et al.* [14] used the logarithmic equations corresponding to each wrinkling feature to establish the grading model in the form $G = a(\log x_i - b)$. This method is simple and effective, and can determine and correlate the essential features very easily.

Artificial neural network models or simple neural nets are known by different names such as connectionist models, parallel distributed models, and neuromorphic systems. They can be viewed as circuits of highly interconnected parallel processing units called neurons. The network is a directed



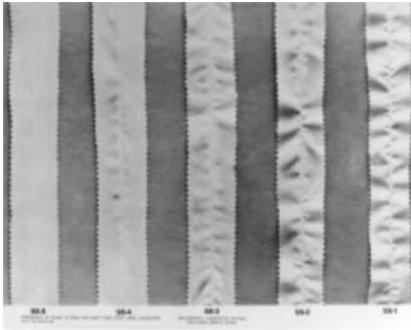
6.19 General flowchart of objective evaluation system.

graph consisting of nodes and edges. An artificial neural network (or neuro-computing) is based on the mathematical modeling that simplifies biological neurons and their connections. Neural networks have been widely used in the objective evaluation of fabric wrinkling [12, 21].

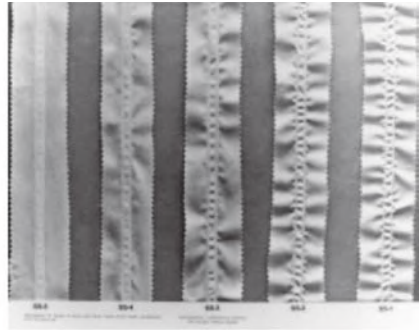
6.4 Seam puckering evaluation

Seam puckering consists of ridge, wrinkle or corrugation of the material, or a number of small wrinkles running across and into one another, which appear on sewing together two pieces of fabric. Seam pucker is regarded as a matter of primary concern in garment manufacture. When the sewing parameters are not appropriate to the material selected, puckering occurs along the garment seams, and the aesthetic appeal of the garment deteriorates. AATCC 88B from the American Association of Textile Chemists and Colorists establishes a set of photographic replicas for the subjective evaluation of seam puckering, as shown in Fig. 6.20.

There are two standard photographic replicas for seam puckering evaluation, one for single needle seams and the other for double needle seams. Seamed fabric specimens are subjected to standard home laundering practices. A choice is provided of hand or machine washing, alternative machine wash cycles and temperatures and alternative drying procedures. The test specimen is mounted on the viewing board with the appropriate photographic standard placed alongside. Evaluation is performed using a standard lighting and viewing area by rating the appearance of specimens in comparison with appropriate reference standards.



(a) For single needle seams



(b) For double needle seams

6.20 AATCC sample for seam gradings 5 down to 1.

6.4.1 Objective evaluation methods

The evaluation of seam puckering is quite similar to wrinkling evaluation in terms of surface profiling and digitalization. Techniques for the objective characterization of seam pucker may be classified into two categories: contact and non-contact methods, in which the non-contact tests could be further divided into laser scanning methods and image analysis methods. Since the non-contact type of testing has the advantage of accuracy, speed and reproducibility, our introduction will focus on it.

6.4.2 Laser scanning method

The principle of laser scanning was introduced in Section 6.3. Many researchers have also applied this method to evaluate seam puckering appearance. Among them, Kawabata *et al.* [22] used the laser scanning method to measure seam pucker and analyzed the sensory evaluation of seam pucker using the Weber–Fechner law. From the height signal, they calculated a surface roughness parameter and found that sensory evaluation of seam pucker follows the Weber–Fechner law, which states that a sensory value is proportional to the logarithm of the magnitude of the quality of the physical stimulation. Based on the above theory, they developed an equation for the objective evaluation of seam pucker which shows an almost linear relationship between the subjective seam pucker grade and physical quantity.

Park and Kang [10] also applied the laser scanning method to profile the seam puckering surface and evaluate it using artificial intelligence. Their scanning system (a displacement meter), consisting of a laser diode, could reconstruct the surface profile of the seams with little influence from color and texture. FFT was applied to calculate the specific features for the neural network modeling in order to simulate the judging behavior of the human experts by comparing AATCC rating standards with testing samples. Their

research shows that it is possible to predict and optimize the quality of seam pucker from material properties and processing parameters.

Fan and his co-workers [23, 24] developed an objective method for the evaluation of seams on a 3-D garment surface through the application of laser scanning technology. A commercial 3-D laser scanning system, consisting of a laser scanning head, robot arm, computer and some special software for data acquisition, was used to scan garment seams. They used 2-D filters to obtain 3-D pucker profiles by removing the high frequency components in the seam profiles that might have been contributed to by the individual threads of the fabric or noise, as well as the lower frequency components that might have been contributed to by the smooth garment surface. They defined four geometrical parameters to characterize the seam puckering profile: average displacement, its variance, the skewness of the height distribution, and the kurtosis of the height distribution. It was found that the logarithm of the average displacement from the mean magnitude and its variance were linearly related to the severity of seam puckering. The addition of the logarithm of the skewness and kurtosis of the height distribution hardly improved the correlation, so that the first two parameters were selected as the objective measures of seam puckering.

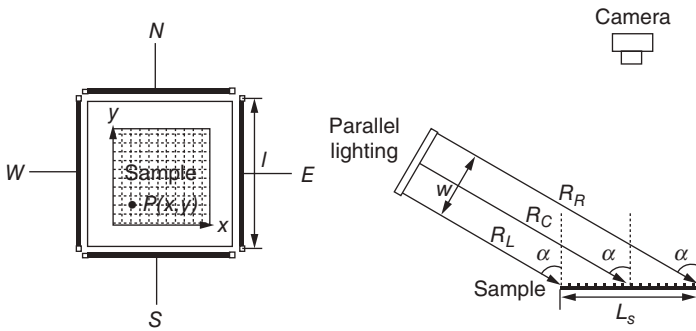
In their research, Fan and Liu [24] used 10 men's shirts, made from different fabrics of similar weight and density, one white polyester/cotton and the other red and white cotton check, as samples. They found a relationship between the logarithm of variance and the subjective grade of seam pucker close to four regions on the sample garment – yoke seam, pocket seam, placket seam and armhole seam. Although this proved that their method is effective on the objective evaluation of seam puckering, further efforts are needed to reduce the cost of the system and make it more robust for industrial use.

6.4.3 Image analysis method

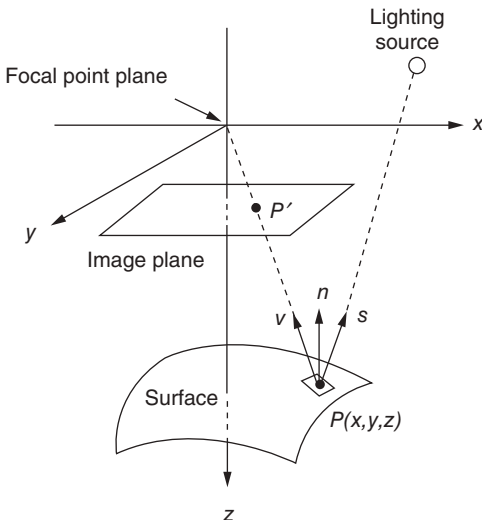
Some researchers have also investigated the objective evaluation of seam puckering based on image analysis methods. For example, Stylios and Sotomi [25] developed a so-called Pucker Vision System, consisting of a CCD camera to capture the surface image of seam pucker instead of human eyes, and a software program used to evaluate the image features. The system was designed to capture the images of two groups of seam stripes produced from the same fabric, one the unstitched seams and the other sewn with puckers. Using the mean reflection of the unstitched seams as a reference, the system assessed the configuration of the pucker by identifying the pucker wavelength and pucker amplitude to develop a pucker severity index. The consistency of the light source and the influence of the pattern and color of the fabric were the major limitations of the system.

Richard [26] developed a computer-based seam pucker measurement system to quantify seam surface irregularities using digital image analysis. A video camera was used to capture seams in the immediate vicinity of the seam formation area. The measurement of the pucker index on a scale of 1 to 5 was very rapid and the results were incorporated into a fabric sewability report, together with the measurement of the dynamic force of the sewing process.

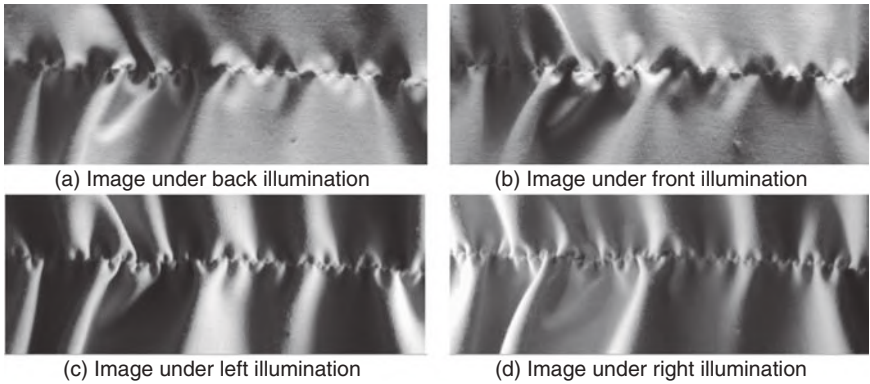
In our previous research [19], a special lighting box was designed to illuminate the testing sample from four different directions, and one digital camera was located on top of this lighting box to capture one image group, which includes the four images with the same imaging geometry, though with different illumination. The four-directional illumination and imaging geometry are illustrated in Figs 6.21 and 6.22. In our research, 29 samples



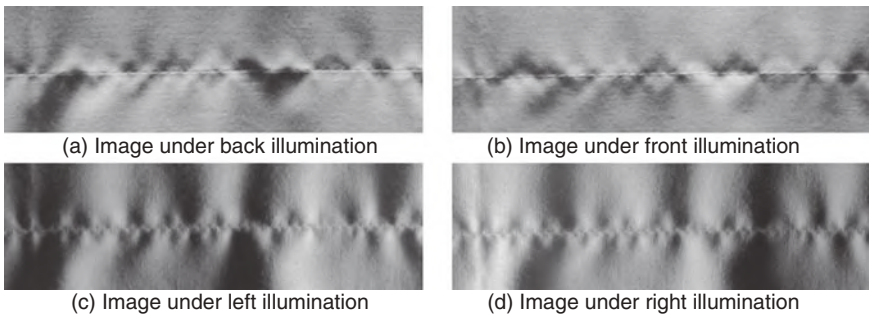
6.21 Lighting system.



6.22 Surface model and observation system.



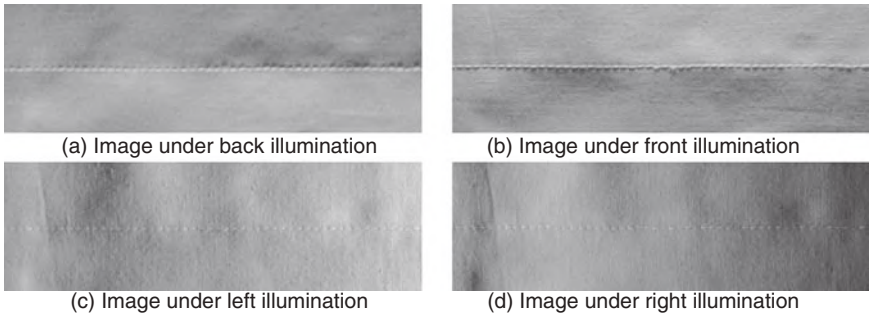
6.23 Image group of four images under different illuminations (Grade 1).



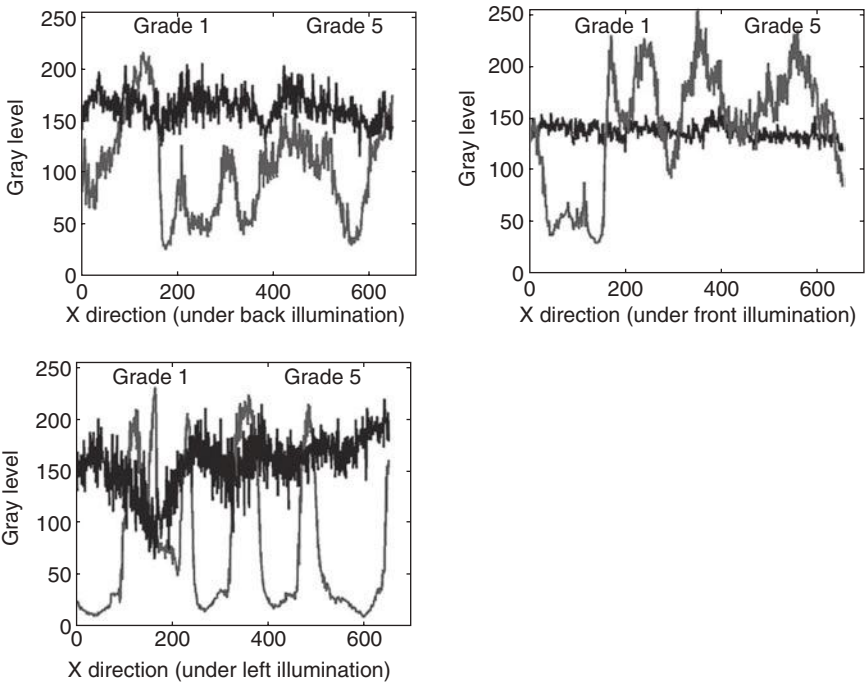
6.24 Image group of four images under different illuminations (Grade 2.5).

were sewn from gray cotton woven fabrics with different setting parameters to achieve different seam puckering grades. Each fabric specimen was cut into 380 mm × 120 mm sections, and given varying grades of seam puckering by adjusting sewing conditions as illustrated in Fig. 6.23. Four images of each sample were captured at a resolution of 640 × 480 pixels under four different illuminating directions. The region of the image was set at 300 × 300 pixels for all the samples, and the sample surface to be captured was 150 mm × 150 mm, thus making the image resolution 50.8 dpi. Each pixel was assigned a gray-level value from 0 for black to 255 for white.

From the comparison of Fig. 6.23 (Grade 1), Fig. 6.24 (Grade 2.5) and Fig. 6.25 (Grade 5), it is found that the seam puckering appearance with different puckering severity demonstrates different changes under different illumination. The seam puckering appearance with a rough surface profile has a quite different image intensity at the same position under different illuminations; however, the seam puckering appearance with a smooth and flat surface profile has a similar image intensity at the same position even



6.25 Image group of four images under different illuminations (Grade 5).



6.26 Comparison of three image profiles under different illuminations (Grade 5 and Grade 1).

under different illuminations as illustrated in Fig. 6.26. In this case, this phenomenon could be used to characterize the seam puckering.

Seam puckering characterization

In this chapter, three line profiles along the seam direction were selected to characterize the severity of seam puckering; one is the central line of seam puckering, the other two are symmetrical to this central line at a

certain distance from it. The fractal dimension of these three line profiles can then be calculated according to the following equation:

$$D = \frac{\log(c) - \log(N(r))}{\log(r)} \quad 6.13$$

where c is a positive constant, r is the side length of the cube and $N(r)$ is the number of blocks which cover the profile. Since four images were captured under four different illuminations, in this case a feature vector $\vec{V} = [D_{Li}, D_{Ri}, D_{Fi}, D_{Bi}]$, $i = 1, 2, 3$, could be defined to characterize the seam puckering properties.

System training and grade classification

We used the five standard seam puckering specimens from grade 1 to grade 5 for system training, and the other 19 specimens for testing. The system training procedure is that of calculating the feature vector of these five standard specimens and establishing a feature space according to the values of their features. To account for the distance between one specimen and five grade clusters, we used a simplified Bayes distance as the metric to determine 'closeness'. Under the conditions that the features are independent and Gaussian, the Bayes distance provides the maximum likelihood (ML) classification. Under these assumptions, the likelihood function for a feature vector \vec{v} belonging in fabric appearance grade l is

$$p(\vec{V} = \vec{v} | \vec{L} = \vec{l}) = \prod_{i=1}^n \frac{1}{\sqrt{2\pi}\sigma_{i,l}} e^{-(v_i - u_{i,l})^2 / 2\sigma_{i,l}^2} \quad 6.14$$

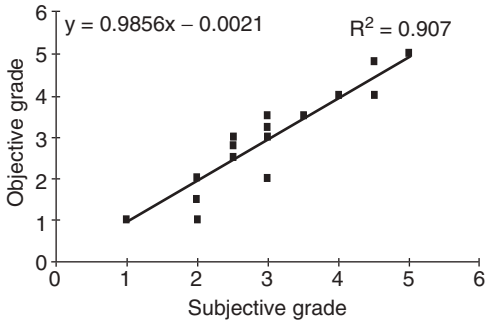
where v_i represent the elements of the feature vector, and n corresponds to the total number of features. The grade classification is achieved by choosing the grade l , which minimizes the simplified Bayes distance function:

$$d_l = \sum_{i=1}^n \left[2 \ln \sigma_{i,l} + \left(\frac{v_i - u_{i,l}}{\sigma_{i,l}} \right)^2 \right] \quad 6.15$$

In this chapter, we calculated 12 fractal dimensions under different illuminations to make up a fractal vector, and trained the system using five standard specimens from grade 1 to grade 5, each grade class having only one standard seam puckering sample as specimen, so we simplified the Bayes distance function as below:

$$d_l = \sum_{i=1}^n (v_i - u_{i,l})^2 \quad 6.16$$

Having calculated the fractal vectors of the 19 test specimens and the distances between the five standard clusters and the 19 test specimens, we can decide which grade class each test specimen should belong to. The prelimi-



6.27 Correlation between subjective and objective evaluation.

nary experimental results show that a good relationship between objective evaluation and subjective evaluation could be achieved based on this method, as illustrated in Fig. 6.27, which integrates the suitable choice of both the hardware design and the feature definition.

6.5 Fabric dimensional stability testing

Dimensional stability refers to a fabric's ability to resist a change in its dimensions. A fabric or garment may exhibit shrinkage in some dimensions or growth in other dimensions under conditions of washing, drying, steaming and pressing. Fabrics are often given shrinkage-resistant finishes to minimize dimensional change. Relaxation shrinkage, progressive shrinkage and thermal shrinkage are three major types of shrinkage that may occur when fabric is subjected to heat and/or moisture. Relaxation shrinkage results from the relaxation of stresses imposed during weaving or knitting of the fabric. Progressive shrinkage is dimensional change that continues through successive washings. Thermal shrinkage is limited to fabrics composed of thermoplastic fibers; upon imposition of heat to these fabrics, the polymer molecules in the fibers move and assume a random, non-linear form, shortening the fibers and causing the fabric to shrink and alter its shape.

For knitted fabrics, cockling has been defined as 'an irregular surface effect caused by loop distortion' [1]. In general it appears as localized groups of distorted knitted loops which have twisted out of the symmetrical configuration. The fault is usually found in the plain knit structure, which is relatively unstable, and especially in yarns spun from animal fibers such as wool or mohair. Wool knitwear made from worsted yarns is more prone to cockling/loop distortion because, unlike wool knitwear, no milling is carried out during finishing which helps to conceal faults under surface fuzz. There are three types of cockling: rib/plain interface cockling, panel-edge cockling,



(a) Rib/plain interface cockling



(b) Panel-edge cockling

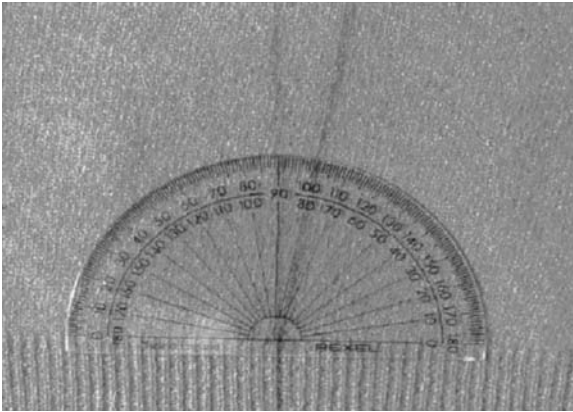


(c) Random overall cockling

6.28 Cockling of knit fabrics.

and random all-over cockling, as illustrated in Fig. 6.28. Rib/plain cockling is caused by a difference in the relaxed widths of the two structures. Panel-edge cockling is caused by a difference in the relaxed dimensions of neighboring structures. Panel edge loops are stretched in length when fashioning takes place and this tends to result in the contraction of the adjacent plain knit fabric, allowing cockling to take place. Random all-over cockling can almost always be assigned to using unsuitable yarn. Yarns which cause random all-over loop distortion also tend to cause rib/plain and panel edge cockling as well. Cockling could be considered as one type of three-dimensional change, similar to seam puckering. The testing method could be referred to as dimensional change and seam puckering evaluation. In some cases, manufacturer and buyer could make a specific standard according to their actual requirements.

Spirality is defined as angular displacement of filling yarns or knitted courses from a line perpendicular to the edge or side of a fabric or garment (see Fig. 6.29). Spirality in knitwear is caused by using an 'unbalanced' yarn, i.e. a single yarn or a two-fold yarn where the incorrect ratio of singles to folding twist has been used. When spirality occurs in a fabric there is little or nothing that can be done in finishing to alleviate it and usually the only option is to use replacement yarn having a balanced twist. However, sometimes spirality can be prevented by steam setting an unbalanced yarn when knitted in a single bed structure, and also some yarns which cause spirality



6.29 Spirality of knit fabrics.

can usually be knitted in a rib structure, since the skewing tendencies on the front and back beds should cancel out.

6.5.1 Fabric dimensional stability: standards

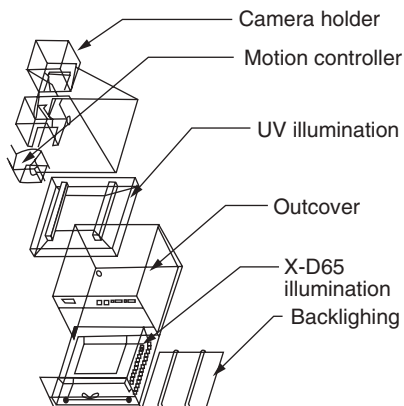
AATCC Test Method 135 details procedures for determining the dimensional stability of woven and knitted fabrics; this method provides the standard testing method for the measurement of dimensional change in home laundering. AATCC Test Method 96 specifies the use of a wash wheel to simulate commercial equipment for determining the stability of woven or knitted fabric in commercial laundering. AATCC Test Method 160 describes a procedure for applying dimensional restoration to textile items after a standard laundering procedure to simulate the stretching force or pressing they receive before or during use.

6.5.2 Fabric dimensional stability: evaluation

The basic procedure for testing fabric for dimensional change is measurement of length and width benchmarks before and after a selected refurbishing process. The benchmarks drawn with indelible ink are placed 25 cm apart, or 50 cm for better precision, in each direction. After a standard laundering or drycleaning method is applied, the marks are re-measured and dimensional change (DC) is calculated from:

$$DC(\%) = \frac{100(B - A)}{A} \quad 6.17$$

where A is the original dimension and B is the dimension after treatment. Length and width changes are calculated separately. Shrinkage is reported



6.30 Image analysis system for the measurement of dimensional stability.

as a negative number, while growth is reported as a positive percentage. Specimens are conditioned accordingly before each measurement.

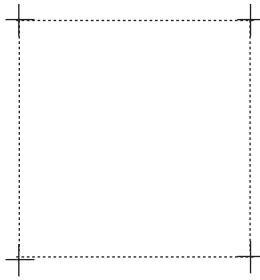
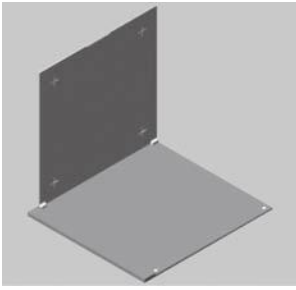
A digital imaging system may be used as a measuring device in place of the prescribed manual measurement devices if it is established that its accuracy is equivalent to that of the manual devices. Recently, a new image analysis system was developed to measure the dimensional change and spirality of woven/knitted fabric by HKRITA and PolyU. This digital imaging system, as illustrated in Fig. 6.30, consists of a lighting box with standard controlled illumination from four directions, a high resolution digital camera, and a set of software to control the digital camera and calculate the dimensional change and spirality of fabrics before and after home laundering or other industry finishing process. All the testing samples are marked with four cross-shaped markers using a specially designed marking template according to the standards, which cannot be washed during the finishing or laundering process, as illustrated in Fig. 6.31.

Image capturing module

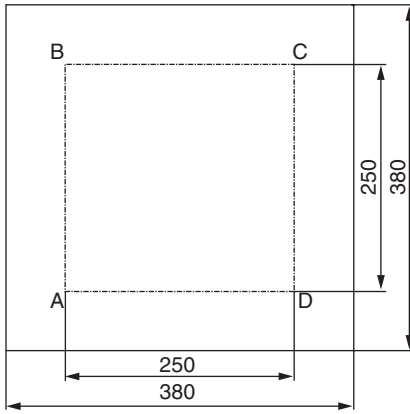
Samples were put on the testing platform after the marking; a digital camera was controlled by the software to capture the image of the fabrics (Fig. 6.32) under the standard illumination (D65), then the fabric images were transferred from the digital camera and recorded in the computer.

Feature analysis module

The major function of this module is to identify the markers and calculate their movement before and after the finishing or laundering process. An

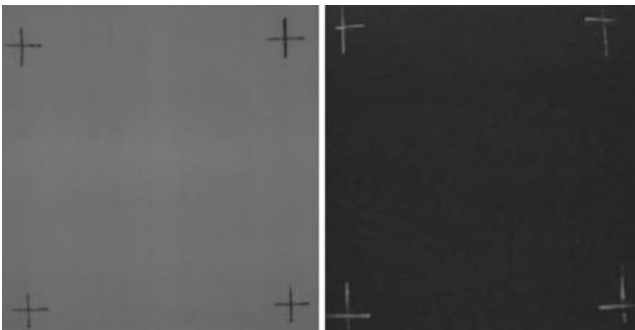


(a) Sample marker template (b) Markers on fabric surface

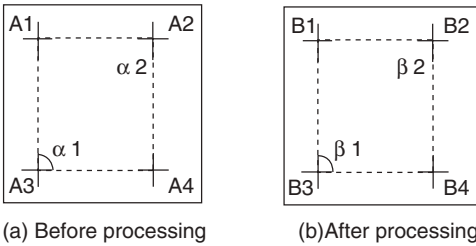


(c) Standard distance of markers (mm)

6.31 Benchmarking on fabric surface.



6.32 Fabric images captured.



6.33 Dimensional changes before and after processing.

automatic detector based on image analysis technology was developed to determine the image coordinates of these four markers, and three parameters (D_h , D_v , S) are defined to characterize the dimensional change and spirality as illustrated in Fig. 6.33.

D_h is the dimensional change along the horizontal direction:

$$D_h = \frac{\frac{d(B1, B2) + d(B3, B4)}{2} - \frac{d(A1, A2) + d(A3, A4)}{2}}{\frac{d(A1, A2) + d(A3, A4)}{2}} \times 100\% \quad 6.18$$

D_v is the dimensional change along the vertical direction:

$$D_v = \frac{\frac{d(B1, B3) + d(B2, B4)}{2} - \frac{d(A1, A3) + d(A2, A4)}{2}}{\frac{d(A1, A3) + d(A2, A4)}{2}} \times 100\% \quad 6.19$$

S is the spirality in terms of the changes of skewness angle:

$$S = \frac{\frac{\alpha_1 + \alpha_2}{2} - \frac{\beta_1 + \beta_2}{2}}{\frac{\alpha_1 + \alpha_2}{2}} \times 100\% \quad 6.20$$

The advantages of this digital imaging system for the purpose of dimensional change and spirality measurement lie in its speed, accuracy and use of digital technology. This system can also be used to evaluate other surface changes, such as hairiness evaluation.

6.6 Light reflectance of a fabric

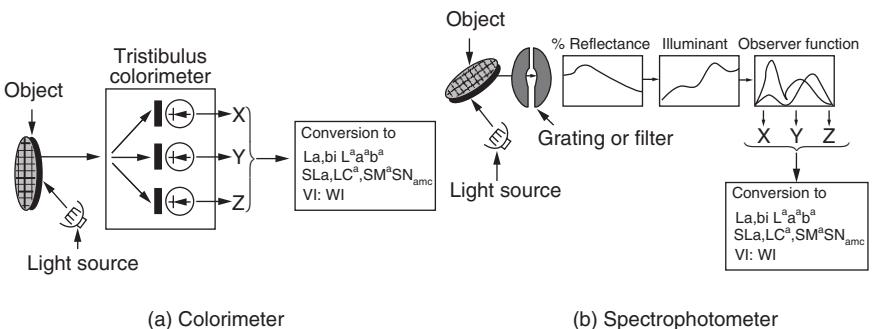
Light reflectance of a fabric mainly refers to the color and luster properties. Color is one of the most important factors in consumer acceptance of fabric materials. The color appearance of an object depends on the source of illumination, the object's interaction with light and the response of sensors in

the observer's eye to the light reflected from the object. Current technology offers the possibility of measuring color very precisely. Two theories – the tristimulus theory and the opponent theory – form the basis of instrumental color measurement.

The CIELAB color system is widely used in color measurement of textiles. The CIELAB values L , a and b are mathematically derived from the tristimulus color values X , Y and Z . CIELAB provides a method for quantifying color difference into a single term. The overall color difference between two specimens can be designated by the term ΔE .

6.6.1 Color measurement instruments

The instruments can be categorized according to their sophistication and precision in color measurement, how the measurements incorporate the components of color, the specimen viewing geometry and instrument portability. All include a light source, a port or opening onto which the specimen is placed, and a detector. The number of color sensors used in an instrument affects its accuracy in color measurement. There are three types of instruments: colorimeters, spectro-colorimeters, and spectrophotometers; the principles of colorimeters and spectrophotometers are illustrated in Fig. 6.34. Colorimeters evaluate the reflected color of a specimen using three sensors that respond to red, green and blue. Colorimeters are useful in color measurement, but they cannot detect metamerism. They should not be used for setting standards; they are the least accurate and least expensive of the three types. Spectro-colorimeters are more accurate because they have more color sensors that sense particular intervals of the spectrum. The accuracy depends on the number of sensors, which can be between three and 16. Spectro-colorimeters also offer more flexibility in the choice of illuminants than is possible in colorimeters. Spectrophotometers are the most accurate of the three levels of instruments and can safely be used to



6.34 Sketch maps of colorimeter and spectrophotometer.

set color standards. Spectrophotometers sense reflected color of a specimen at several individual wavelengths within the visible spectrum, at either 10 nm intervals or 20 nm intervals throughout the visible spectrum. The instruments are sometimes referred to as 16 point or 31 point instruments according to the number of measurement points across the visible spectrum, 400–700 nm.

6.6.2 Color measuring procedure

A proper procedure to perform the measurement of colors is important for industrial applications. A normal measurement procedure involves four major steps: instrument setup, calibration, verification, and sample preparation and measurement [27].

Instrument setup

The spectrophotometer has to be set up in the proper mode prior to color measurement, according to the instrument manufacturer's recommendations. For example, in the case of a sphere-type reflectance spectrophotometer, the possible list of parameters to be set up includes the spectral range, the polychromatic/monochromatic mode, the specular component in/out, the sample port size, and the selection of filters.

Instrument calibration

After the instrument has been properly set up, it has to be calibrated for its photometric scale with respect to the 100% line and the 0% line using a white and black standard template, respectively, in the case of a reflectance spectrophotometer. For a transmission spectrophotometer, a clear solution for the solution sample (or air for the color filter sample) is used to set up the 100% reference line, and the 0% reference line is normally established by blocking the illumination beam with an opaque sample. The calibration procedure establishes a set of correction factors at each wavelength and is applied to the subsequent spectral measurements to obtain absolute spectral data.

Instrument verification

The performance of the spectrophotometer in terms of precision and accuracy can be checked by the measurement of color standards with calibrated spectral data. Precision refers to how repeatable the measurements are for the same sample over a period of time, while accuracy refers to how close the measured reading of a sample is to its absolute true reading.

Sample preparation and measurement

The importance of the sample itself in providing reliable color measurement data should not be overlooked. There are a number of factors that may affect the measurement precision and accuracy. The following outlines the major items to be observed during the measurement of textile samples.

Sample temperature and moisture content

The temperature and moisture content of a textile sample could change its color appearance significantly and hence its measurements. It is therefore important to condition all textile samples in a room or chamber with controlled humidity and temperature for a suitable period prior to color measurement.

Sample format

A good technique of sample presentation for measurement is to ensure an identical format of presenting all the samples to be intercompared at the instrument sample port for color measurement. The textile usually is folded to complete opacity to avoid background influence during color measurement. Thus it is important that all samples to be intercompared are folded to the same number of layers. Yarn samples should be wound onto a rigid card uniformly with identical layers. Loose fibers should be placed into a transparent cup holder with identical thickness under identical pressure. Color measuring instruments are generally designed for measurement of flat samples to be placed at the sample port. If the sample extends inside the port or is displaced away from the port, different measured readings may result. If the textile sample flatness is difficult to achieve, due to surface texture, measurement behind glass will help. However, the measurement results must be corrected for effects of the cover glass, such as the Fresnel reflection.

Thermochromic and photochromic property

Some textiles have colorants that are sensitive to heat and light. Color change on exposure to heat and light is called thermochromism and photochromism respectively. Both the thermochromic effect and the photochromic effect can be eliminated or reduced by minimizing the time of sample exposure to the illuminating source during measurement.

In general, it is always good practice to average multiple measurements at different locations and orientations of the test sample to achieve repeatable measurement.

6.6.3 Color evaluation applications

The primary applications of color measuring systems in the textile industry include color fastness assessment, whiteness evaluation, yellow evaluation, luster evaluation, etc.

Color fastness assessment

Most methods in color fastness assessment of textile materials involve treating the dyed material in a standardized manner and then comparing the treated textile and the original untreated textile visually against a gray scale that carries a series of pairs of color chips with increasing color difference magnitude. There are two kinds of gray scales, one for the staining test and the other for change of shade. The obvious disadvantage of determining the color fastness rating by means of visual assessment is the poor reproducibility from observer to observer. Methods for instrumental assessment of staining and change of shade have been developed by various professional bodies: Textiles – Tests for colour fastness (ISO-105 standards) and Textiles – Tests for color fastness – Instrumental assessment of the degree of staining of adjacent fabrics (GB/T 6410-86).

Whiteness evaluation

White is a color of freshness, purity and cleanliness. It has been used as an indicator of qualities such as freedom from contamination. The determination of the degree of whiteness has been an interesting subject for many years. In principle, it can be measured by the amount of departure from the perfect white position in a three-dimensional color space. However, agreement on the perfect white has not been reached because of some problems. The major problem is that strong preferences in the concept of whiteness are governed by trade, nationality, habit and product. This problem is further enhanced by the introduction of fluorescent whitening agents, the conditions of observation, and the measurement accuracy. The principles of deriving a whiteness formula were described by Ganz [28]. In 1981, the CIE recommended field trials of a new whiteness formula, and the CIE whiteness formula was adopted by the AATCC in 1989 as AATCC Method 110-1989.

Yellow evaluation

The preferential absorption of white light in the short-wavelength region (380–440 nm) by the material usually causes an appearance of yellowness. Interest has developed in determining the degree of yellowness as it is considered to be associated with soiling, scorching and product degradation

by exposure to light, atmospheric gases, and other chemicals. Some yellowness standards have been developed over the years (ASTM D1925).

Luster evaluation

Some textile fabrics are finished with a lustrous appearance by means of a calendering process. The luster is the gloss appearance associated with the contrast between the specularly reflecting area of fabric and the surrounding diffusely reflecting area. Hunter [29] has developed a formula to express this relationship:

$$\text{Luster} = 100(1 - R_d/R_s) \quad 6.21$$

where R_d is the diffuse reflectance factor and R_s is the specular reflectance factor.

6.7 Conclusions

The testing methods and related standards for fabric appearance evaluation are reviewed in this chapter, including pilling, wrinkling, seam puckering, dimensional change and light reflectance. Some basic technologies related to these testing methods are also introduced briefly. Traditionally, fabric appearance evaluation relies to a large extent on subjective evaluation methods based on the perception of human eyes, but with the development of digital technologies, more and more testing standards are being replaced by new objective testing methods which have the advantages of speed, accuracy and repeatability. In this chapter, actual applications of digital evaluation methods on the evaluation of pilling, wrinkling, seam puckering and dimensional change are also reported. These methods could contribute to upgrading quality control in the textile industry. The aim of this chapter is to provide a simple but general background introduction to fabric appearance testing and evaluation.

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