HACKTEX VIRTUAL TRAINING MATERIALS

ADVANCED TEXTILES MANUFACTURING INDUSTRY
Learning unit 4
Lesson 2

Textile properties of smart textiles and their characterisation

HACKTEX
Innovative smart textiles & entrepreneurship

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Textile properties of smart textiles and their characterisation

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Content

Introduction

This lesson 2 about Textile properties of smart textiles and their characterisation is enclosed in the Learning Unit 4, which corresponds to Standards and characterization of functional and smart textiles.

In this lesson, you will learn about the most common tests used to determine the textile properties of smart textiles. The strength related properties, which give a measure of the behaviour of the material under tensile, tearing and friction forces determined with tensile, tearing, abrasion and pilling tests will be described. The haptic properties, related to the tailorability of the material as well as with the wearing durability of the material will be following described. Finally, the most common tests used to determine the comfort related properties like the flexibility and wrinkle resistance of the fabrics as well as with the air and water permeability and the capacity of the textiles to absorb water is described.

1. Strength-related textile properties

Among the properties related to the "strength" or mechanical performance of the textiles, the most important are the ones related to the response of the material under tensile and tearing forces and to the response to friction forces.

1.1. Tensile & Tearing forces

Tensile test

The mechanical behaviour of the textiles when are subjected to axial tensile forces is measured through tensile tests. This test allows determining the maximum or breaking force, tenacity and deformation of the textiles when they are stretched to allow predicting their wearing mechanical performance.

In the *tensile test*, a specimen with specific dimensions is stretched at constant speed until breaking. The necessary force to perform the stretching and the deformation of the material is registered. Figure 1 shows a typical curve obtained from tensile tests. The fabric's maximum force and, if required, the force at rupture—generally given in N—as well as the maximum elongation—in % after dividing the deformation value in mm by the clamping distance—are determined.

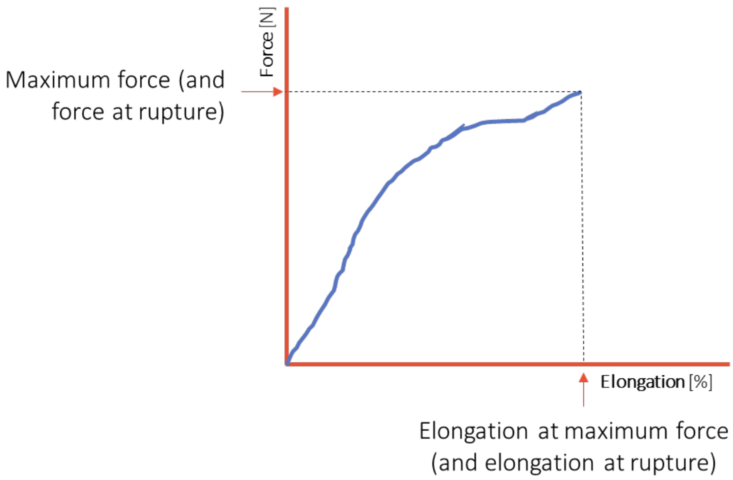

Figure 1. Image representing the typical curve obtained from the tensile test

In the **strip test** method, the width of the specimen fits with the clamps width. In this test, typically a specimen of 5 x 30 cm is used with a distance between clamps of 20 cm (see Figure 2, left). There is an ISO standard that defines the specific conditions of the test for woven fabrics (ISO 13934-1:2013), and another one for nonwoven fabrics (ISO 29073-3:1989).

For the **grab test** method, a wide specimen is mounted centred in the clamps (see Figure 2, right). The specimen has dimensions of 10 cm width and around 15 cm length, and the distance between clamps depends on the fabric type (woven or nonwoven). There is an ISO standard that stablishes the testing conditions for woven fabrics (ISO 13934-2:2014), and another one for nonwoven fabrics (ISO 9073-18:2008). This method is more appropriate to know the wearing behaviour. In this method only the maximum force is determined.

In both methods, five specimens have to be tested by in each direction—warp and weft for woven fabrics or machine and cross direction for nonwoven fabrics—, and the constant speed will depend on the type of test.

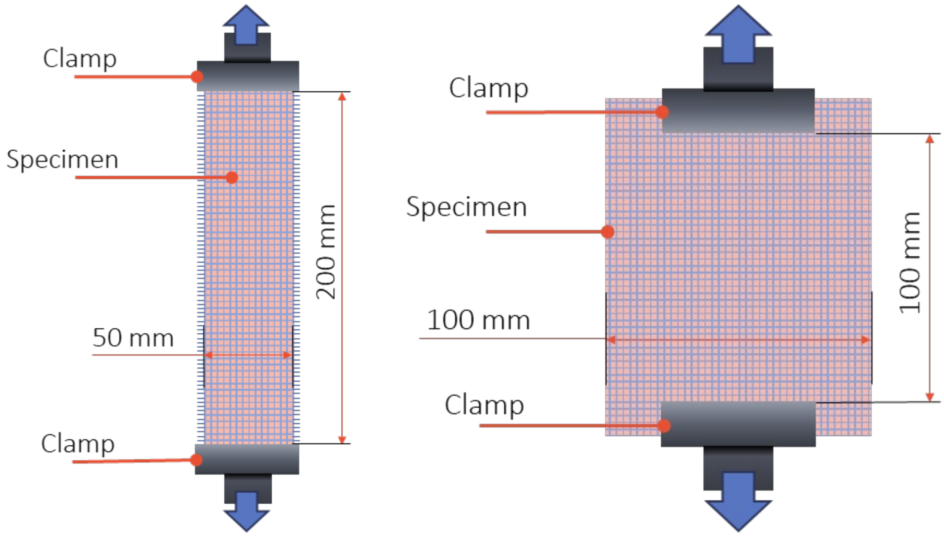

Figure 2. Specimen used for the strip tensile test (left) and for the grab tensile test (right)

Tearing test

In the *tearing test*, the resistance that offers a fabric to continue tearing at a constant speed, once started, is determined. The tearing tests are performed in the same dynamometer used for tensile tests. The average force for tearing is determined from the curves (see Figure 3).

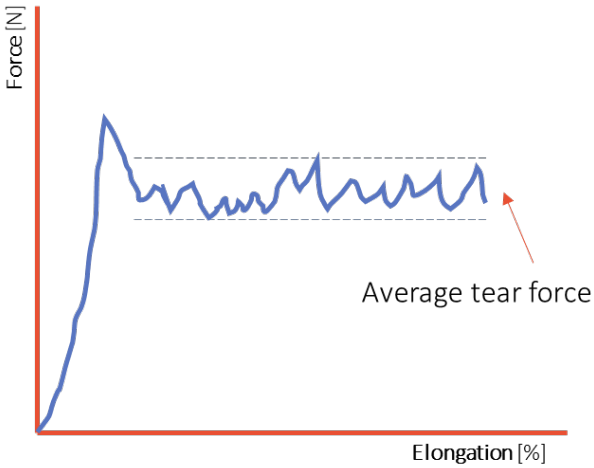

Figure 3. Image representing the typical curve obtained from the tearing test

Single or *double tear* configurations are used. In the **single tear** method (ISO 13937-2:2000), a trouser-shaped specimen is used (see Figure 4). In the **double tear** test (ISO 13937-4:2000), a tongue-shaped test specimen is used (see Figure 5). In both methods, five specimens have to be tested by in each direction—warp and weft for woven fabrics or machine and cross direction for nonwoven fabrics—. The rate for clamps displacement is 100 mm/min.

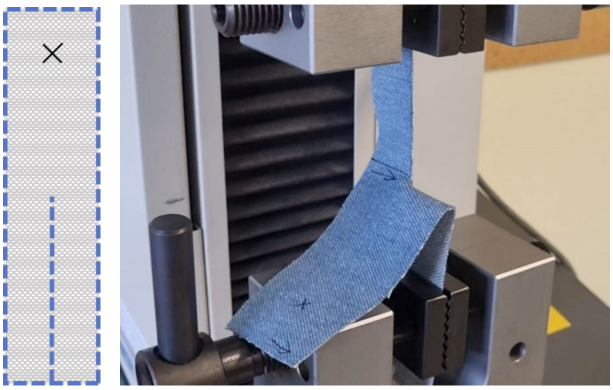

Figure 4. Specimen used for the single tear test

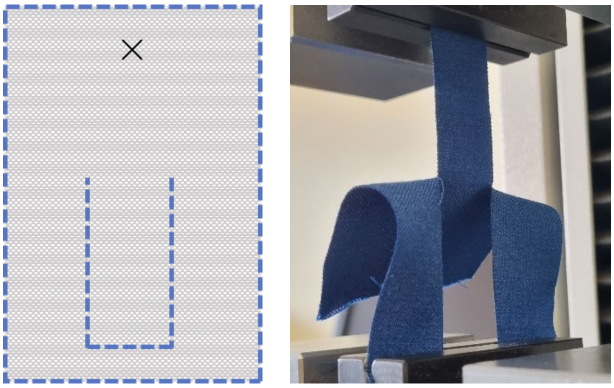

Figure 5. Specimen used for the double tear test

1.2. Abrasion & Pilling

During its use and maintenance, fabrics rub either with themselves or with external elements. That friction can cause the appearance of fluff, fibre balls and, in the event extreme wear or tear of the fabric due to strong abrasion. In the garments, the greatest wear occurs in areas of frequent and intense friction, as is the case of the crotch of trousers, armpits, elbows, etc. To evaluate the resistance to friction there are different methods, which determine the resistance to *abrasion* and *pilling*.

Abrasion tests

The most common method to determine the **resistance to abrasion** of textiles is the Martindale test. In this method, two circular surfaces are in contact. The upper surface (specimen holder) is covered with the fabric to be tested, while the bottom one can be covered with the same fabric or an abrasive surface such a standard fabric, for instance (see Figure 6, left). The specimen is subjected, under a specific load, to the scrubbing action with the abrasive element following a translational movement that forms a Lissajous curve (see Figure 6, right). At the same time, the specimen holder rotates freely around its own axis, perpendicular to the horizontal plane. The test consists of determining the number of cycles necessary to produce failure—reached when wear-off is observed in the fabric—, or the loss of weight suffered by the test piece after a certain number of abrasion cycles (ISO 12947-1,3, 4:1998 and ISO 12947-2:2016).

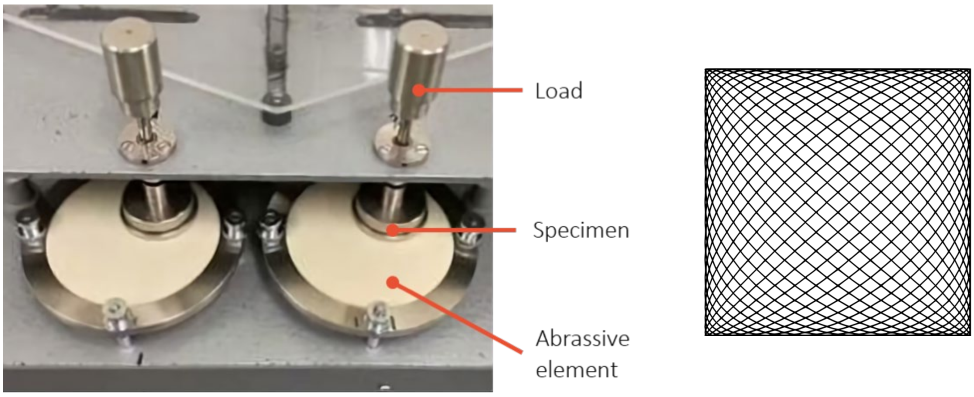

Figure 6. Image showing the configuration of the abrasion test (left) and the Lissajous curve (right).

Pilling tests

Pilling manifests itself on the surface of the fabric, in the form of little balls of variable dimensions. These are produced during use due to physical-mechanical processes to which garments are subjected to, especially as a consequence of the friction in certain areas of the garment, were the fabrics frictions with itself and/or with other external elements. There are two types of methods to determine the resistance to pilling of the textiles: the *container methods* and the *flat methods*.

The **container methods** are the best simulate the behaviour of a fabric during use. These methods use different containers coated, on their inner walls, with moderately abrasive surfaces—usually cork—(see Figure 7a). The specimens are introduced into the containers where remain for a long period of time—hours—, rubbing against each other and with the walls due to the rotation of the containers at low speed—60 rpm on the ICI Pilling tester (ISO 12945-1:2020—or at high speed—1,200 rpm on the Random Tumble Pilling Tester (ISO 12945-3:2020)—.

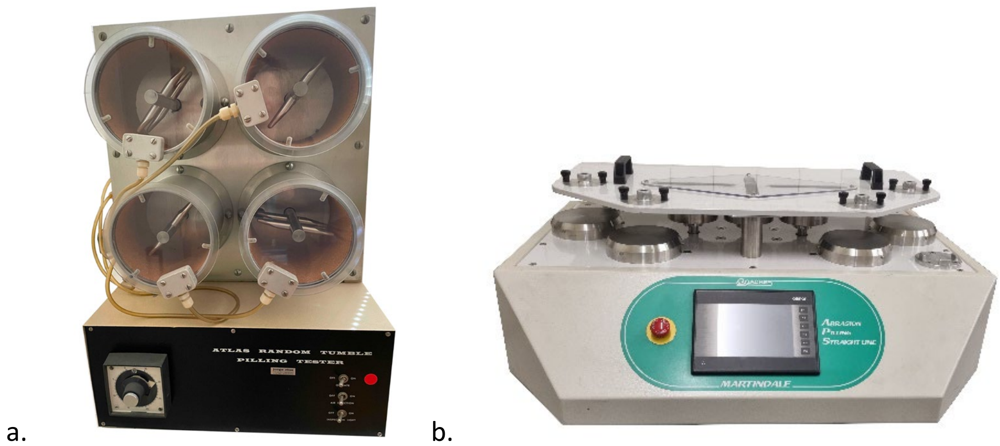

Figure 7. Random tumbler instrument to measure the pilling with container method, and Martindale equipment to measure the pilling by means of a flat method.

The pilling can be also measured with specimens placed in a **flat position** in contact with another fabric or surface located in a parallel plane using the Martindale principle (ISO 12945-2:2020) as well as on the abrasion test but, in this case, evaluating the formation of the little balls (see Figure 7b).

Want to learn more about this topic?

In the following videos, you can see the how to perform the tests:

- Determination of Breaking Strength of Fabric: https://www.youtube.com/watch?v=GuA_GRAHl9Y
- Determination of Tear Strength of Fabric (Single Rip Method): https://www.youtube.com/watch?v=abml7QrFWR
- Determination of Tear Strength of Fabric (Double Rip Method): https://www.youtube.com/watch?v=jVzEjwnln0Y
- ISO11612 Technical fabrics Tests Methods by *Marina Textil*: https://www.youtube.com/watch?v=VeI_7FgkicA
- Fabric Pilling Test. Random Tumble Pilling Tester: https://www.youtube.com/watch?v=tHVem8l4BLw
- Determination of Fabric Propensity to Surface Fuzzing and to Pilling (ICI Box Method): https://www.youtube.com/watch?v=TwiLOP8FDms
- Determination of Fabric Propensity to Surface Fuzzing and to Pilling (Martindale Method): https://www.youtube.com/watch?v=9jg_jTohPjw
- Determination of Abrasion Resistance of Fabric by Using the Martindale Method Specimen Break-off: https://www.youtube.com/watch?v=l9YJU8LaRNs

2. Haptic-related properties

2.1. Tailorability (FAST)

Tailorability can be defined as the ease or difficulty that a fabric offers to overcome industrial clothing operations—extending, cutting, sewing and ironing—. It is not therefore a property related to the quality of use of the final product as a garment but rather a *convertibility* property of the fabric.

Tailorability is commonly measured using the Fabric Assurance by Simple Testing (FAST) equipment. This system measures the mechanical properties of fabrics subjected to small loads, which are those suffered during the industrial clothing processes. It consists of three instruments and a test method. The instruments measure the deformations under small loads —*compressibility*, *stiffness* and *extensibility*—, and the test method measures the dimensional stability of the fabrics.

Compressibility

The **compressibility** is measured as the difference of thickness of the fabric when it is subjected to two types of compressive loads—2 g/cm^2 and 100 g/cm^2 respectively—(see Figure 8).

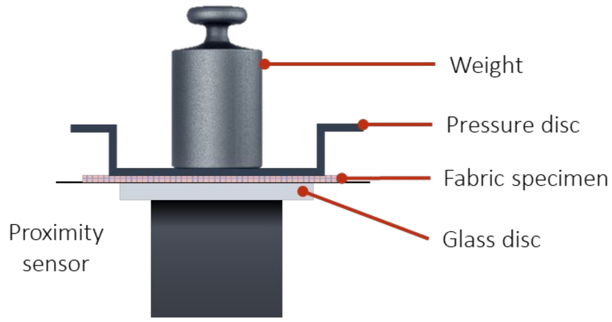

Figure 8. Configuration of the compressibility test (left) and instrument used (right)

Flexural Stiffness

The **flexural stiffness**—in both for warp and weft directions—is measured by means of the cantilever length method (see Figure 9).

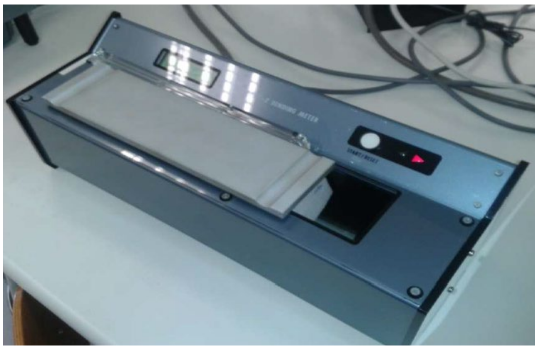

Figure 9. Image a picture of the instrument used to measure the stiffness with the FAST method

Extensibility

The **extensibility** is measured subjecting the fabric to different loads (see Figure 10).

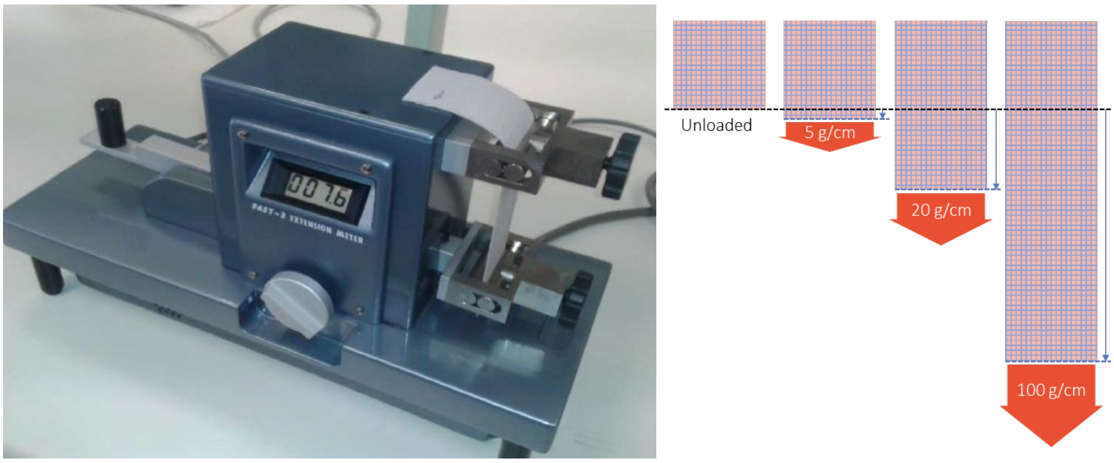

Figure 10. Picture of the instrument used to measure the extensibility (left) and loading scheme of the FAST method (right)

Dimensional stability

The **dimensional stability** of the fabrics is measured determining the relaxation shrinkage (ER) and the hygroscopic expansion (EH). In this test, the specimen is firstly subjected to a drying process at 105 ºC for 1 hour. Then, the distance between the marks of the specimen is determined (L1). Afterwards, the specimen is immersed in distilled water at room temperature for 30 minutes. Following, it is extracted and dried with some absorbing materials, and the distance between marks is determined (L2). Finally, the specimen is dried again at 105 ºC for 1 h and the distance between marks measured (L3). From this information, the ER and EH are determined as is shown in Figure 11.

$$ER = 100\frac{L1 - L3}{L1}$$

$$EH = 100\frac{L2 - L3}{L3}$$

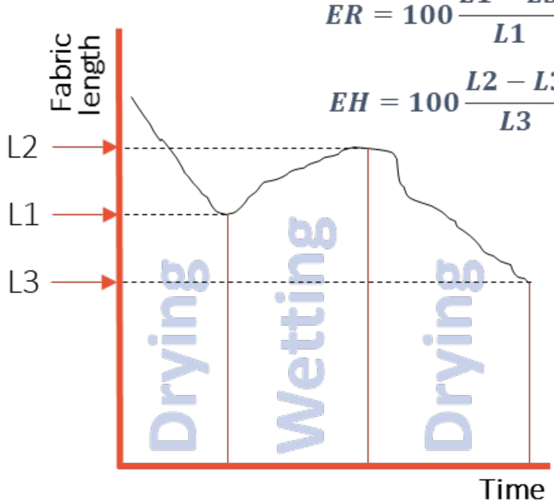

Figure 11. Graphic and equations to determine the relaxation shrinkage (ER) and the hygroscopic expansion (EH) *with the FAST method*

2.2. Drapability

The **drapability** is defined as the degree to which a fabric deforms when allowed to hang freely by action of its own weight. The drapability is determined with the fabric drape tester. In this test, a circular fabric specimen is placed, horizontally, on top of a metal disc that is smaller than the specimen itself. Due to this, part of the fabric that volley freely. Besides, just below the centre of the circular specimen, a light bulb projects a beam of light upwards, revealing the projected shadow of the specimen (see Figure 12). Then, the projected shadow is determined. More or less shadow is generated depending on the fabric's drapability, allowing the evaluation of this property.

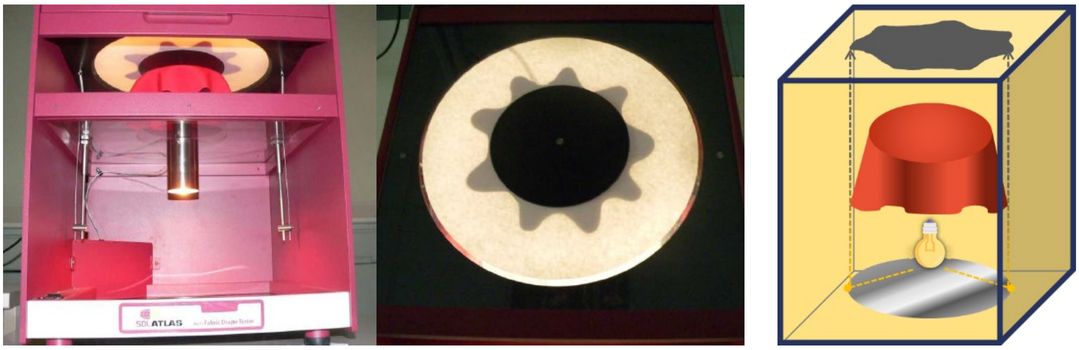

Figure 12. Equipment to determine the drapability and shadow projected to be measured.
Scheme created used icons by Freepik at flaticon.com

2.3. Fastness

Washing fastness

In smart textiles for applications in clothing and home textiles, it is very important to determine the resistance of the functions of the textile after subjecting it to washing cycles (**washing fastness**). This test consist on subjecting the fabrics to several washing cycles —usually 1, 5, 10, 20 or 50—, and then evaluating the functional property that is considered as key for the product's performance. The washing conditions, which are variable, are defined in an ISO standard (ISO 6330).

Colour Fastness

The **colour fastness** is the measure of the retention of the original colour of the textiles when they are exposed to different use actions or conditions such as light, washing, rubbing onto different surfaces, wear, ironing, high temperatures, perspiration, water, or sea water, among others. The sample in original and exposed conditions is compared by means of standardised grey scales typically going from 1—lower colour retention— to 5—higher colour retention— (see Figure 13). Depending on the application, different colour fastness must to be selected for each smart textile product, and further tested under the conditions collected on the corresponding standard. In Table 1, few examples of the ISO standards for colour fastness are collected.

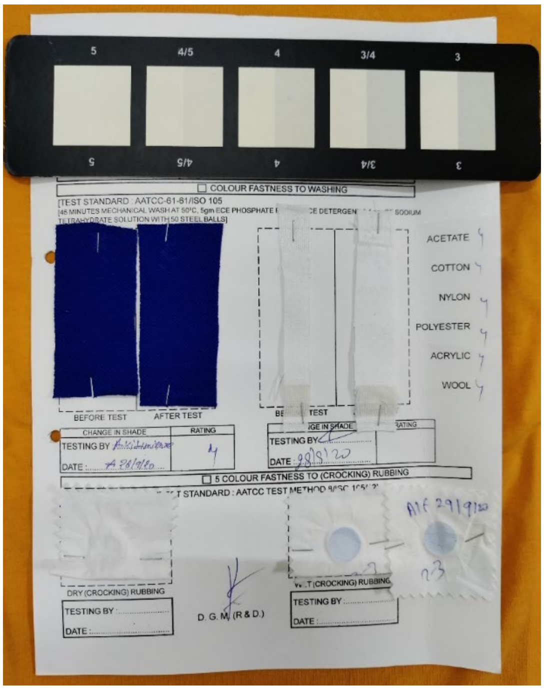

Figure 13. Report for demonstrating the colour fastness of dyed textiles.

Table 2. Selection of ISO standards about colour fastness

Reference	***Topic***
ISO 105-A01:2010	Textiles. Tests for colour fastness - Part A01: General principles of testing
ISO 105-B01:2014	Textiles. Tests for colour fastness - Part B01: Colour fastness to light: Daylight
ISO 105-B02:2014	Textiles. Tests for colour fastness - Part B02: Colour fastness to artificial light: Xenon arc fading lamp test
ISO 105-B03:2017	Textiles. Tests for colour fastness - Part B03: Colour fastness to weathering: Outdoor exposure
ISO 105-D01:2010	Textiles. Tests for colour fastness - Part D01: Colour fastness to drycleaning using perchloroethylene solvent
ISO 105-E01:2013	Textiles. Tests for colour fastness - Part E01: Colour fastness to water
ISO 105-E02:2013	Textiles. Tests for colour fastness - Part E02: Colour fastness to sea water
ISO 105-E03:2010	Textiles. Tests for colour fastness - Part E03: Colour fastness to chlorinated water (swimming-pool water)
ISO 105-N01:1993	Textiles. Tests for colour fastness - Part N01: Colour fastness to bleaching: Hypochlorite
ISO 105-P01:1993	Textiles. Tests for colour fastness - Part P01: Colour fastness to dry heat (excluding pressing)

Want to learn more about this topic?

In this video of the *Heriot Watt University*, you will learn more about the FAST (Fabric Assurance by Simple Testing) methodology: https://www.youtube.com/watch?v=f6LMOT6r9VA

3. Comfort-related properties

3.1. Stiffness

The flexibility of the fabrics is one of the most important textile properties. Shirley method is the most used to determine the **stiffness** or the flexure resistance of textiles. This test consists of retaining a strip fabric at one end, in horizontal position, and left free or cantilevered the other end. Due to the weight of the fabric itself, it flexes or bends, increasing said bending as the length increases of the cantilever. The procedure consists of determining the length of cantilever fabric necessary for the bending or bending of the free end to form a fixed angle, with about a horizontal plane (see Figure 14). The detailed conditions of the test are described in the ASTM (ASTM D1388-96R02) and UNE (UNE 40392:1979) standards.

Figure 14. Equipment used to measure the stiffness.

3.2. Wrinkle recovery angle

To study the wrinkling tendency of fabrics, there are various test methods but the most widespread is the one that measures the **ability to recover wrinkles** after subjecting the fabrics to wrinkling under a specific load. When the load is removed, the recovery of the specimen is allowed and the remaining wrinkle angle is measured for samples horizontally folded (ISO 2313-1:2021) or vertically folded (ISO 2313-2:2021).

3.3. Water vapour resistance

The **water vapour resistance** is the opposite of the water vapour permeability, which is the capacity to allow moisture to pass through. The water vapour resistance is related to the ability of fabrics to allow the passage of sweat, a fundamental property in the thermo-physiological comfort of the human body. The permeability or diffusivity of water vapour through a fabric is the amount of steam passing through the fabric with a pressure difference. The different methods can be divided in gravimetric or hot plate methods. The simplest and most used ones are the gravimetric. Among different tests, the most used ones are two ISO standards (ISO 15496:2018, ISO 11092:2014).

3.4. Thermal resistance

The thermal resistance of the fabric measures the capacity of the textile to create a thermal barrier between the heat source and the user or component that has to be protected by the fabric. It is very important to know the level of protection for clothing and technical applications. There are different test to determine the thermal resistance of textiles but the most common used is the hotplate test (ISO 11092:2014).

3.5. Air permeability

The air permeability of the textiles is very important property that in wearable and other technical applications in which it is necessary to control the amount of air that can pass through the fabric under certain conditions. The air permeability is understood to be the velocity of the airflow passing perpendicularly through the fabric, under the conditions specified by the standard on test surface, pressure drop and time. There is a standard for woven fabrics (ISO 9237:1995) and another one for nonwoven fabrics (ISO 9073-15:2007).

3.6. Water wicking

The water wicking capacity of the textile—it is to say, the capacity to force the water pass through the fabric to the outer—is an important property related to the comfort. This property is usually tested wicking the fabric in water and determining the wicking distance at different time intervals—vertical wicking test (AATCC 197)—or determine the water spreading in a fabric—horizontal wicking test (AATCC 198)—.

Want to learn more about this topic?

In the following videos, you can see the how to perform the tests:

- Determination of Bending Strength of Fabric: https://www.youtube.com/watch?v=0VJ5djFt9Oc
- Measuring Air Permeability of Textile Products: https://www.youtube.com/watch?v=KFsQb9ws_CU
- Determining Crease Recovery Angle: https://www.youtube.com/watch?v=uQJdBE2yANQ
- Determination of Water Vapour Permeability: https://www.youtube.com/watch?v=rxknxpQXmn0
- Different information to test Comfort Performance: https://aeshm.hs.iastate.edu/current-students/facilities/laboratories-for-functional-textiles-and-protective-clothing/lab-for-clothing-comfort-performance/
- Determination of the Vertical Wicking: https://www.youtube.com/watch?v=1JBojM1ofVg
- Determination of Horizontal Wicking: https://www.youtube.com/watch?v=nKfbSSiJzI0
- Determination of Vertical and Horizontal Wicking: https://www.youtube.com/watch?v=oL3TCdh2YTc

Summary

In this lecture you have learn how to determine the textile properties of smart textiles and the common standards used for testing: (1) the strength-related textile properties through tensile, tearing, abrasion and pilling tests; (2) the haptic-related properties testing the tailorability, drapability and fastness; and (3) the comfort-related properties, measuring the stiffness, recovering angle, water vapour resistance, air permeability, thermal resistance and water wicking.

References

Water wicking properties

AATCC Test Method 197-2011, *Vertical Wicking of Textiles*

AATCC Test Method 198-2011, *Horizontal Wicking of Textiles*

Stiffness properties

ASTM D1388-96R02 *Test Method for Stiffness*

Wrinkle recovery angle

ISO 2313-1:2021 Textiles. Determination of the recovery from creasing of a folded specimen of fabric by measuring the angle of recovery - *Part 1: Method of the horizontally folded specimen*

ISO 2313-2:2021 Textiles. Determination of the recovery from creasing of a folded specimen of fabric by measuring the angle of recovery - *Part 2: Method of the vertically folded specimen*

Washing fastness

ISO 6330:2021 Textiles. *Domestic washing and drying procedures for textile testing*

Nonwoven fabric properties

ISO 9073-3:1989 Textiles. Test methods for nonwovens - *Part 3: Determination of tensile strength and elongation*

ISO 9073-15:2007 Textiles. Test methods for nonwovens - *Part 15: Determination of air permeability*

ISO 9073-18:2007 Textiles. Test methods for nonwovens - *Part 18: Determination of breaking strength and elongation of nonwoven materials using the grab tensile test*

Air-related properties

ISO 9237:1995 Textiles. *Determination of permeability of fabrics to air*

Thermal and water vapour resistance properties

ISO 11092:2014 Textiles. Physiological effects - *Measurement of thermal and water-vapour resistance under steady-state conditions (sweating guarded-hotplate test)*

Pilling properties

ISO 12945-1:2020 Textiles. Determination of fabric propensity to surface pilling, fuzzing or matting - *Part 1: Pilling box method*

ISO 12945-2:2020 Textiles. Determination of fabric propensity to surface pilling, fuzzing or matting - *Part 2: Modified Martindale method*

ISO 12945-3:2020 Textiles. Determination of fabric propensity to surface pilling, fuzzing or matting - *Part 3: Random tumble pilling method*

Abrasion properties

ISO 12947-1:1998 Textiles. Determination of abrasion resistance of fabrics by the Martindale method - *Part 1: Martindale abrasion testing apparatus*

ISO 12947-2:2016 Textiles. Determination of abrasion resistance of fabrics by the Martindale method - *Part 2: Determination of specimen breakdown*

ISO 12947-3:1998 Textiles. Determination of abrasion resistance of fabrics by the Martindale method - *Part 3: Determination of mass loss*

ISO 12947-4:1998 Textiles. Determination of abrasion resistance of fabrics by the Martindale method - *Part 4: Assessment of appearance change*

Tensile properties

ISO 13934-1:2013 Textiles. Tensile properties of fabrics - *Part 1: Determination of maximum force and elongation at maximum force using the strip method*

ISO 13934-2:2014 Textiles. Tensile properties of fabrics - *Part 2: Determination of maximum force using the grab method*

Tear properties (woven fabrics)

ISO 13937-2:2000 Textiles. Tear properties of fabrics - *Part 2: Determination of tear force of trouser-shaped test specimens (Single tear method)*

ISO 13937-4:2000 Textiles. Tear properties of fabrics - *Part 4: Determination of tear force of tongue-shaped test specimens (Double tear test)*

Properties related to water vapour

ISO 15496:2018 Textiles. *Measurement of water vapour permeability of textiles for the purpose of quality control*

Stiffness properties

UNE 40392:1979 *Determination of the Flexural Rigidity of Fabrics*

Partnership

Project coordinator
TUIASI - Universitatea Tehnica Gheorghe Asachi din Iasi
www.tuiasi.ro

AEI Tèxtils - Agrupació d'Empreses Innovadores Tèxtils
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CIAPE – Centro pre l'Apprendimento Permanente
www.ciape.it

CRE.THI.DEV - Creative Thinking Development
www.crethidev.gr

TITERA - Technically Innovative Technologies
www.titera.tech

UB – Högskolan i Boras
www.hb.se

UNIWA - Panepistimio Dytikis Attikis
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