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Analysis of Abrasion Characteristics in Textiles

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1. Introduction

Wear in textile materials is one of a limited number of fault factors in which an object loses its usefulness and the economic implication can be of enormous value to the industry. The terms wear and abrasion are sometimes confused. Wear is a very general term covering the loss of material by virtually any means. As wear usually occurs by rubbing together of two surfaces, abrasion is often used as a general term to mean wear (Brown, 2006).

The resistance of textile materials to abrasion as measured on a testing machine in the laboratory is generally only one of several factors contributing to wear performance or durability as experienced in the actual use of the material. While "abrasion resistance" (often stated in terms of the number of cycles on a specified machine, using a specified technique to produce a specified degree or amount of abrasion) and "durability" (defined as the ability to withstand deterioration or wearing out in use, including the effects of abrasion) are frequently related, the relationship varies with different end uses, and different factors may be necessary in any calculation of predicted durability from specific abrasion data (ASTM D 4966).

Abrasion is the physical destruction of fibres, yarns, and fabrics, resulting from the rubbing of a textile surface over another surface (Abdullah et al., 2006). Textile materials can be unserviceable because of several different factors and one of the most important causes is abrasion. Abrasion occurs during wearing, using, cleaning or washing process and this may distort the fabric, cause fibres or yarns to be pulled out or remove fibre ends from the surface (Hu, 2008; Kadolph, 2007). Abrasion ultimately results in the loss of performance characteristics, such as strength, but it also affects the appearance of the fabric (Collier & Epps, 1999).

The main factors that reduce service life of the garment are heavily dependent on its end use. But especially certain parts of apparel, such as collar, cuffs and pockets, are subjected to serious wear in use (Figure 1). Abrasion is a serious problem for home textiles like as carpets and upholstery fabrics, socks and technical textiles as well. Yarn abrasion is another important subject that should be considered during processing.

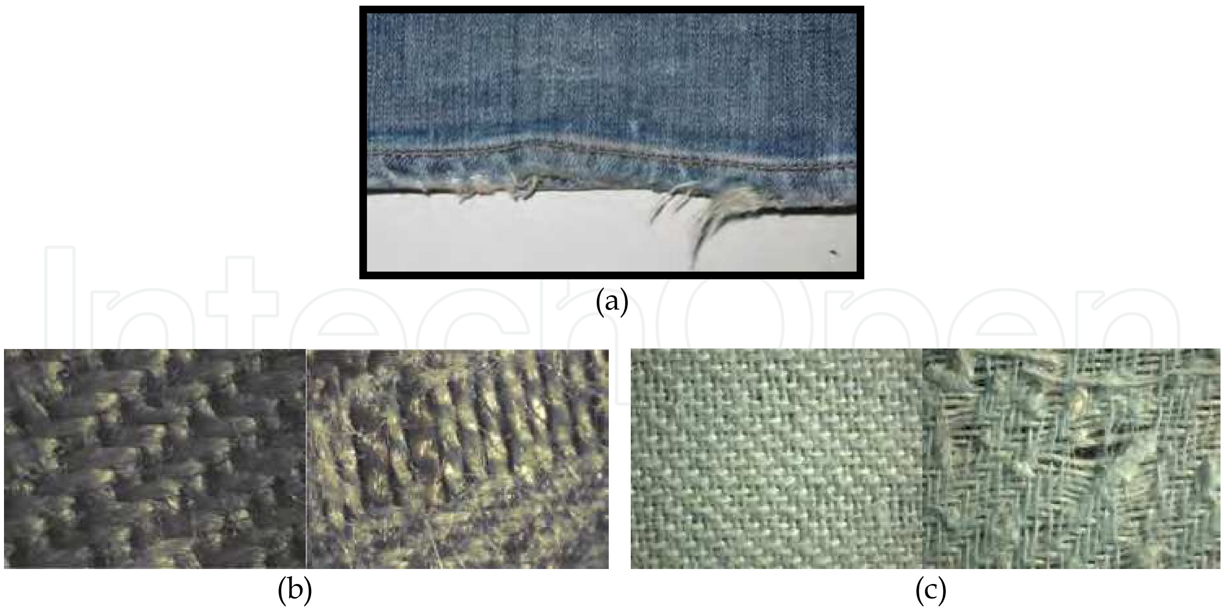


Fig. 1. Abraded textile products (a) edge of pants, (b) (c) surface appearances of fabrics - before (left) and after (right) the abrasion test.

In this chapter, detailed information about the abrasion and abrasion resistance of the textile materials are discussed. In the first part, the abrasion and wear mechanism are explained. In the second part, abrasion of the fabrics (factors affecting abrasion such as fibre, yarn and fabric properties, parameters affecting the test results, testing and evaluation methods), yarn abrasion (yarn on yarn and yarn external abrasion), abrasion characteristics of socks and technical textile fabrics are analyzed. Studies on the mentioned subjects are given as well.

2. Abrasion mechanism of textiles

Abrasive wear in textiles is caused by different conditions mainly given below:

- Friction between textile materials, such as rubbing of a jacket or coat lining on a shirt, pants pockets against pants fabric etc.
- Friction between the textile materials to the external object, such as rubbing of trousers to the seat, friction of the yarn to the needle etc.
- Friction between the fibres and dust, or grit, in a fabric that results in cutting of the fibres. This is an extremely slow process, it may be observed on flags hanging out or swimwear because of the unremoved sand.
- Friction between the fabric components. Flexing, stretching, and bending of the fibres during the usage causes fibre slippage, friction to each other and breakage (Mehta, 1992).

The study of the processes of wear is part of the discipline of tribology and the mechanism of wear is very complex. Under normal mechanical and practical procedures, the wear-rate normally changes through three different stages: primary stage or early run-in period, where surfaces adapt to each other and the wear-rate might vary between high and low; secondary stage or mid-age process, where a steady rate of wearing is in motion. Most of the components operational life is comprised in this stage. Tertiary stage or old-age period is where the components are subjected to rapid failure due to a high rate of wearing (http://en.wikipedia.org/wiki/Wear). Some commonly referred to wear mechanisms include: Adhesive wear, abrasive wear, surface fatigue, fretting wear, erosive wear. Adhesive, abrasive wear and surface fatigue mechanism play an important role in the abrasion mechanism of the yarns and fabrics.

Adhesive wear, occurs between surfaces during frictional contact and generally refers to unwanted displacement and attachment of wear debris and material compounds from one surface to another. The adhesive wear and material transfer due to direct contact and plastic deformation are the main issues in adhesive wear. The asperities or microscopic high points or surface roughness found on each surface, define the severity on how fragments of oxides are pulled off and adds to the other surface. This is partly due to strong adhesive forces between atoms, but also due to accumulation of energy in the plastic zone between the asperities during relative motion.

Abrasive wear, occurs when a hard rough surface slides across a softer surface. ASTM (American Society for Testing and Materials) defines it as the loss of material due to hard particles or hard protuberances that are forced against and move along a solid surface. Abrasive wear is commonly classified according to the type of contact and the contact environment. The type of contact determines the mode of abrasive wear. The two modes of abrasive wear are known as two-body and three-body abrasive wear. Two-body wear occurs when the grits or hard particles remove material from the opposite surface. The common analogy is that of material being removed or displaced by a cutting or plowing operation. Three-body wear occurs when the particles are not constrained, and are free to roll and slide down a surface.

Fatigue wear of a material is caused by a cycling loading during friction. Fatigue occurs if the applied load is higher than the fatigue strength of the material. Fatigue cracks start at the material surface and spread to the subsurface regions. The cracks may connect to each other resulting in separation and delamination of the material pieces. One of the types of fatigue wear is fretting wear caused by cycling sliding of two surfaces across each other with small amplitude (oscillating). The friction force produces alternating compression-tension stresses, which result in surface fatigue (http://en.wikipedia.org/wiki/Wear, June2011).

In terms of wear mechanism in textiles, abrasion first modifies the fabric surface and then affects the internal structure of the fabric, damaging it (Manich et.al, 2001; Kaloğlu et al., 2003). Good abrasion resistance depends more on a high energy of rupture than on high tenacity at break. Abrasion is not influenced so much by the energy absorbed in the first deforming process (total energy of rupture), as by the work absorbed during repeated deformation. This work is manifested in the elastic energy or the recoverable portion of the total energy. Thus, to prevent abrasion damage, the material must be capable of absorbing energy and releasing that energy upon the removal of load. Energies in tension, shear, compression, and bending are all important for the evaluation of surface abrasion; however, these energies are unknown, and therefore elastic energies in tension permit at least a quantitative interpretation of abrasive damage in fibres and fabrics (Abdullah et al., 2006; as cited in Hamburger, 1945).

Fibres in use are subject to a variety of different forces, which are repeated many times (Hearle & Morton, 2008). The gradual breakdown of the internal cohesion of the individual fibres or by a gradual breakdown of the forces of structural cohesion between the fibres results fabric failure. The relative occurrence of these two phenomena depends to a great extent upon the fabric geometry, but there are limitless factors involved (e.g., construction of yarns and weaves) depending on the individual behavior of different fibres (Figure 2) (Abdullah et al., 2006).

(a) (b)

Fig. 2. Abrasion of fibres over rotating pin: (a) nylon, (b) wool (Hearle & Morton, 2008)

Fig. 3. Fibre rupture occurred as abraded against standard worsted fabric (Abdullah et al., 2006)

During the course of abrasion in textiles, fibre to fibre cohesion plays an important role, usually influenced by yarn twist or close fibre packing. Abrasion behavior indicates that fibre cohesion is strong in the fabric system, and it causes the shear of the fibres themselves. Frictional forces developed in the yarn due to the motion of the abrasion test are dissipated largely in the fibres by the development of tensile and shear stresses; repetition of such stresses results in fibre fatigue, which causes the loss of fibre mechanical properties, leading to rupture. Fibres in the crowns are broken down in succession, and this causes a reduction in fibre cohesion and yarn strength. In lateral abrasion cycles, frictional forces are able to displace fibre from their normal position, and these fibres ruptures through bending and flexing (Figure 3). In addition, it is also possible that some cracking is initiated by abrasion and then propagated by bending action (Abdullah et al., 2006).

Although the mechanism of abrasion is similar, because of the differences in the measurement methods, abrasion resistance of textile materials can be studied in two parts such as fabric abrasion and yarn abrasion

3. Abrasion of fabrics

3.1 Factors affecting abrasion resistance of fabrics

Abrasion resistance of the textile materials is very complex phenomenon and affected by many factors, mainly classified as follows: Fibre, yarn, fabric properties and finishing processes. Some of these parameters affect fabric surface whereas some of them has an influence on internal structure of the fabrics. For example fibre characteristics like wool ratio and fineness play a significant role in surface abrasion, while yarn and fabric characteristics like yarn linear density and interlacing coefficient are significantly related with structural abrasion (Manich et al., 2001).

3.1.1 Fibre properties

The mechanical properties and dimensions of the fibres are important for abrasion. Fibre type, fibre fineness and fibre length are the main parameters that affect abrasion.

Fibres with high elongation, elastic recovery and work of rupture have a good ability to withstand repeated distortion; hence a good degree of abrasion resistance is achieved. Nylon is generally considered to have the best abrasion resistance, followed by polyester, polypropylene (Hu, 2008). Blending either nylon or polyester with wool and cotton is found to increase abrasion resistance at the expense of other properties (Saville, 1999). Higher wool rate increase the mass loss (Manich et al., 2001). Acrylic and modacrylic have a lower resistance than these fibres while wool, cotton and high modulus viscose have a moderate abrasion resistance. Viscose and acetates are found to have the lowest degree of resistance to abrasion. However, synthetic fibres are produced in many different versions so that the abrasion resistance of particular variant may not conform to the general ranking of fibres (Saville, 1999).

The removal of the fibres from yarn structure is one of the reasons of the abrasion. Therefore factors that affect the cohesion of yarns will influence the abrasion resistance of fabrics as well. Longer fibres incorporated into a fabric confer better abrasion resistance than short fibres because it is harder to liberate them from the fabric structure. For the same reason filament yarns are more abrasion resistant than staple yarns made from the same fibre (Saville 1999; Hu, 2008).

The using of finer fibres in the production of yarns causes increment in the number of the fibre in cross section with higher cohesion which results better abrasion resistance. So abrasion retention is better for fabrics with finer fibres (Kaloğlu et al., 2003).

3.1.2 Yarn properties

Yarn structure, count, twist and hairiness are the main properties which affect abrasion of the textile fabrics. Increasing linear density at constant fabric mass per unit area increases the abrasion resistance of the fabrics (Saville, 1999). As yarn got thinner, abrasion resistance values of knitted fabrics decrease and breaking occurs in lower cycles (Özgüney et al., 2008).

Twist is another parameter affecting abrasion. There is an optimum amount of twist in a yarn to give the best abrasion resistance. At low-twist, fibres can easily be removed from the yarn so that it is gradually reduced in diameter. At high twist levels the fibres are held more tightly but the yarn is stiffer so it is unable to distort under pressure when being abraded (Saville, 1999).

Yarn hairiness has a negative effect in terms of mass loss during abrasion. An increase in yarn hairiness, due to the higher level of protruding fibres from yarn surface, reduces fabric abrasion resistance.

The production method of yarn has also an influence on the abrasion resistance, such that carded fabric gives lower resistance than that of combed fabric (Manich et al., 2001). Even yarn structure, using long fibre and lower yarn hairiness are the reasons of that result. Knitted fabrics from ring spun yarns have better abrasion resistance than knitted fabrics from OE spun yarns (Candan et al.,2000; Candan & Önal, 2002). Ring spun yarns are hairier but more compactly structured than OE yarns, this well aligned compact structure doesn't promote easy fibre wear off (Paek, 1989).

Compact yarn fabrics have higher abrasion resistance values compared to the ring yarn fabrics with the same fabric construction. Since the fibres of compact yarns are held more tightly within the yarn structure and higher participation of the fibres into the yarn structure exists, compact yarns have a denser and closer structure compared to the ring yarns. The compact yarn has lower hairiness, high tensile resistance as a result of that fibre movements causing limited abrasion (Akaydın, 2009, 2010). Fabrics woven from compact yarns have also lower weight loss compared to those woven from ring yarns (Ömeroglu & Ülkü, 2007). Sirospun is a modified ring spinning process that two rovings per spindle are fed to the drafting system within specially developed condensers separately and drafted simultaneously. Fabrics knitted from sirospun yarns show better abrasion resistance than ring, air-jet and OE yarns because of the better evenness, hairiness, regular and tightly structure (Örtlek et al., 2010). However as considering the results of fabrics produced with two ply yarns, fabrics from sirospun yarns wear faster than two fold ring spun yarn (Kaloğlu et al., 2003).

Another factor that affects the abrasion is the number of yarn plies. As the number of ply threads per yarn increases, the thickness and the mass per unit area increases and it causes an improvement in abrasion characteristics of the fabric.

3.1.3 Fabric properties

Fabric construction, thickness, weight, the number of yarn (thread density) and interlacing per unit area are the fabric properties affecting abrasion.

Weave type has a significant effect on abrasion resistance of the fabrics. Woven fabric properties will differ by changing the weave pattern which is evaluated not only as an appearance property, but also as a very important structure parameter. If one set of yarns is predominantly on the surface then this set will wear most; this effect can be used to protect the load bearing yarns preferentially. Long yarn floats and a low number of interlacings cause the continuous contact area of one yarn strand to expand and this facilitates the yarn to lose its form more easily by providing easier movement as a result of the rubbing motion. So long floats in a weave such as sateen structures are more exposed and abrade faster, usually cause breaking of the yarns and increasing the mass loss. In this way, holding the fibres in the yarn structure becomes harder and the removal of fibre becomes easier (Kaynak & Topalbekiroğlu, 2008). But the fabrics that have lower floats such as flat plain weave fabrics have better abrasion resistance than other weaves because the yarns are more tightly locked in structure and the wear is spread more evenly over all of the yarns in the fabric (Hu, 2008).

Like as woven structure, knitting structure has also an important effect on abrasion characteristics of knitted fabrics. Average abrasion resistance values of interlock knitted fabrics are higher than rib and single jersey fabrics (Özgüney et al., 2008). The reason of that is more stabile, thicker and voluminous structure of the interlock fabrics (Akaydın, 2009). Course length for the knitted fabrics is so important that the weight loss percent after abrasion increases with increasing course length. Open, slack knitted fabric structure is abraded more than denser fabrics (Kaloğlu et al., 2003).

The fabric mass per square meter and fabric thickness that are the main structural properties of fabrics have an effect on abrasion resistance. Higher values of these factors ensure higher abrasion resistance.

The other parameter that affects the abrasion is thread density of the fabric. The more threads per unit area in a fabric are the less force to each individual thread is, therefore the fabrics with a tight structure have higher abrasion resistance than those with a loose structure. However as the threads become jammed together they are the unable to deflect under load and thus absorb the distortion (Saville, 1999).

The literature contains papers dealing with the abrasion resistance of the specific type of the fabrics. One of them characterizes certain properties of flocked fabrics produced from different fibre type by measuring the abrasion resistance. Abrasion resistance of the flocked fabrics is related to the flock fibre length and density of flock fibre ends. The flocked fabrics with low flock fibre density and high flock fibre length show more resistance to abrasion in comparison with the flocked fabrics which have high flock fibre density and short flock fibre length. The wet rubbing resistance of the flocked fabrics is less than the dry rubbing resistance (Bilişik, 2009).

Another study is about the performance of upholstery fabrics woven with chenille yarns. Chenille yarn material, yarn twist, and pile length have a significant effect on the abrasion resistance of the chenille yarns and fabrics. Twist levels and pile lengths affect yarn cohesion. There is an improvement in abrasion resistance of the fabrics with increasing twist, pile length, and the use of natural fibres as pile materials, which may be due to increasing frictional behavior between the pile and lock yarns (Özdemir & Çeven, 2004).

3.1.4 Finishing process

Finishing treatments, the types and concentration of the chemicals used in the treatment processes are also the parameters affecting the abrasion characteristics of the fabrics.

Grey fabrics have lower abrasion resistance compared to dyed fabrics with the same construction. During the dyeing operation, fibres on the fabric surface will cling to it, hence the fabric will achieve a closer state, and the movement of fibres within the yarn will be limited (Akaydın 2009, 2010).

Laundering process affects the abrasion resistance. The abrasion resistance of both undyed and dyed fabrics is negatively influenced by the laundering treatment (Candan et al., 2000). The degree of damage in fibres within the fuzz entanglements tends to increase with an increased number of launderings, and that the damage varies from small cracks and fractures to slight flaking depending on the fabric and yarn (Candan & Önal, 2002).

Another process that is important for fabric abrasion is bleaching and enzymatic process. The fabrics applied bleaching and enzymatic processes have higher abrasion resistance with regard to grey knitted fabrics. However as enzymatic treatment is applied to the dyed fabrics the abrasion tendency become worse compared to non-enzymatic dyed fabric (Kretzschmar et al., 2007)

Nano-silicone softener treatment causes decrease in abrasion resistance of the fabrics. The mass loss ratios of the samples with nano-silicone softeners are higher than mass loss ratios of the samples without nano-silicone softener. It is the probable result of fibre mobility inside the fabric which is increased by nano-silicone softener. Silicone softeners provide better wrinkle recovery, tear strength, and abrasion resistance than the cationic softener for 100% cotton woven fabric (Çelik et al., 2010).

The laser fading process is acknowledged as a very strong alternative compared to the conventional physical and chemical processes used for aged-worn look on denim fabrics. Even with the lower pulse time of laser beams, abrasion resistance significantly decreases after fading process and with the higher pulse times, the decrease in abrasion resistance values is much more apparent (Özgüney et al., 2009).

3.2 Methods for testing abrasion resistance of fabrics

Most abrasion tests depend on applying energy to the fabrics and measuring their response to it. The manner of transferring the energy from machine to the fabric is different for different machines, but the basic principles are the same (Abdullah et al., 2006).

There are three types of abrasion in terms of occurrence; flat, edge and flex abrasion. Therefore different abrasion test methods have been described by the abrasion type, the test head movement or testing device setup. The differences among the procedures include the type of equipment, abradant (the material that rubs against the specimen), material used (including woven, nonwoven, and knit apparel fabrics, household fabrics, industrial fabrics, and floor coverings) and assessment method. In all of the test methods, the tested specimen is rubbed in a particular manner against an abradant which may be a fabric, or a emery sheet for either a certain amount of time for a certain number of strokes or cycles (Kadolph, 2007).

ASTM and ISO define several methods to quantify abrasion resistance of textile materials and introduce methods for the evaluation of abraded fabrics. However, there is not a linear relationship between successive measurements using any of these methods and progressive amounts of abrasion (Savilla, 1999). In Table 1, these test methods and relevant test equipments are given.

Test Standard		Testing Device / Method
ASTM D 4966	Standard Test Method for Abrasion Resistance of Textile Fabrics	Martindale Abrasion Tester
ASTM D 3884	Test Method for Abrasion Resistance of Textile Fabrics	Rotary Platform Double-Head (RPDH)
ASTM D 3885	Test Method for Abrasion Resistance of Textile Fabrics	Flexing and Abrasion Method
ASTM D 3886	Test Method for Abrasion Resistance of Textile Fabrics	Inflated Diaphragm
ASTM D 4157	Test Method for Abrasion Resistance of Textile Fabrics	Oscillatory Cylinder Method
ASTM D 4158	Test Method for Abrasion Resistance of Textile Fabrics	Uniform Abrasion Method
AATCC-93 Test Method	Abrasion Resistance of Fabrics: Accelerator Method	Accelerator Method
ISO 12947-1	Determination of the abrasion resistance of fabrics by the Martindale method Part 1: Martindale abrasion testing apparatus	Martindale Abrasion Tester
ISO 12947-2	Determination of the abrasion resistance of fabrics by the Martindale method Part 2: Determination of specimen breakdown	Martindale Abrasion Tester
ISO 12947-3	Determination of the abrasion resistance of fabrics by the Martindale method Part 3: Determination of mass loss	Martindale Abrasion Tester
ISO 12947-4	Determination of the abrasion resistance of fabrics by the Martindale method Part 4: Assessment of appearance change	Martindale Abrasion Tester

Table 1. Test methods of abrasion resistance of fabrics

3.2.1 Flat abrasion

Flat abrasion occurs when flat objects is rubbed to a flat material. Flat resistance tends to be good for most materials because the force of rubbing is distributed over a wide area. However for many products flat abrasion resistance is assumed to occur when the curve is gradual or the bend is shallow such as what occurs in a shirt or jacket as it bends across the back of the wearer or on the seat of an upholstered chair (Kadolph, 2007). Martindale Tester, Taber Abraser, Uniform Abrasion Tester are the instruments working on the flat abrasion mechanism.

In Martindale abrasion resistance tester (Figure 4), circular specimens are abraded under known pressure against a standard fabric. Abrasion resistance is measured by subjecting the specimen to rubbing motion in the form of a geometric figure, denoted Lissojous motion (Figure 5), that is, a straight line, which becomes a gradually widening elipse, until it forms another straight line in the opposite direction and traces the same figure again under known conditions of pressure and abrasive action (ASTM D 4966). The advantage of the Martindale abrasion test is that the fabric sample gets abrasion in all directions. Stress develops along the fiber from the force acting transverse to the fiber axis as a result of surface friction; the magnitude of surface friction developed is directly related to the harshness of standard worsted fabric abradant.

Fig. 4. Martindale Abrasion Tester

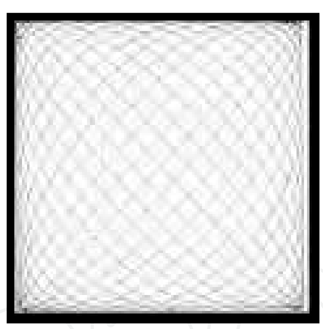


Fig. 5. Lissojous motion

Specimens are circular of either 38 mm or 140 mm in diameter. Normally the abradant is silicon carbide paper or woven worsted wool of which the specifications are given in Table 2, mounted over felt. Polyurethane foam disk is placed under the specimen for fabric having a mass/unit area less than 500 g/m^2. The small test specimen is sitting on the large abradant and then cycled backwards and forwards. If assessment of appearance change needs to be carried out, then larger test pieces (140 mm in diameter) are required. The roles are reversed and the abradant is placed in the holder with the specimen as the base platform. A force of either 9 (for apparel fabrics) or 12 kPa (for upholstery and technical fabrics) is applied to the top of the specimen to hold it against the abradant. The standard abradant should be replaced at the start of each test and after 50 000 cycles if the test is to be continued beyond this number (Hu, 2008; Saville, 1999; Özdil, 2003).

	Warp	Weft
Yarn lineer density	R63, tex/2	R74, tex/2
Threads per unit length	17/cm	12/cm
Single twist	540 ±20 tpm 'Z'	500 ±20 tpm 'Z'
Twofold twist	450 ±20 tpm 'S'	350 ±20 tpm 'S'
Fibre diameter	27.5 ±20 μm	29 ±20 μm
Mass per unit area of fabric, min	5.8 oz/yd² (195 g/m²)	

Table 2. Specification for standard wool abrasion fabric (ASTM D 4966)

The rotary platform double head method (Taber abrader) can be used for most fabrics. The specimen is abraded using rotary rubbing action under controlled conditions of pressure and abrasive action, and subjected to multidirectional abrasion using a rotary rubbing action. Abrasive heads of rubber based compound simulate mild and harsh abrasion. The test specimen, mounted on a turntable platform, turns on a vertical axis, against the sliding rotation of two abrading wheels. The fabric is subjected to the wear action by two abrasive wheels pressing onto a rotating sample. The wheels are arranged at diametrically opposite sides of the sample so that they are rotated in the opposite direction by the rotation of the sample. One abrading wheel rubs the specimen outward toward the periphery and the other, inward toward the center. The resulting abrasion marks form a pattern of crossed arcs over an area of approximately 30 cm^2 (Figure 6a). Load adjustment for varying the load of the abrader wheels on the specimen is possible (ASTM D 3884).

In ASTM D 4158, the uniform abrasion testing machine is used. In the apparatus, a specimen is mounted in a holder and abraded uniformly in all directions in the plane and about every point of the surface of the specimen. The Uniform Abrasion Tester (Figure 6b), consists of the abradant mounted at the lower end of a shaft, weights placed on the upper end of the shaft to produce constant pressure between abradant and specimen throughout the test, lever and cam for raising and lowering the abradant, shaft, and weights. Essentially, the surface of the abradant lies in a plane parallel to the surface supporting the specimen and presses upon the specimen. The abradant and specimen rotate in the same direction at very nearly but not quite the same angular velocity (250 rpm) on noncoaxial axes which are parallel to within 0.0025 mm (0.0001 in.). The small difference in speed is to permit each part of the specimen to come in contact with a different part of the abradant at each rotation. Each rotation is equivalent to one cycle (ASTM D 4158).

(a) (b)

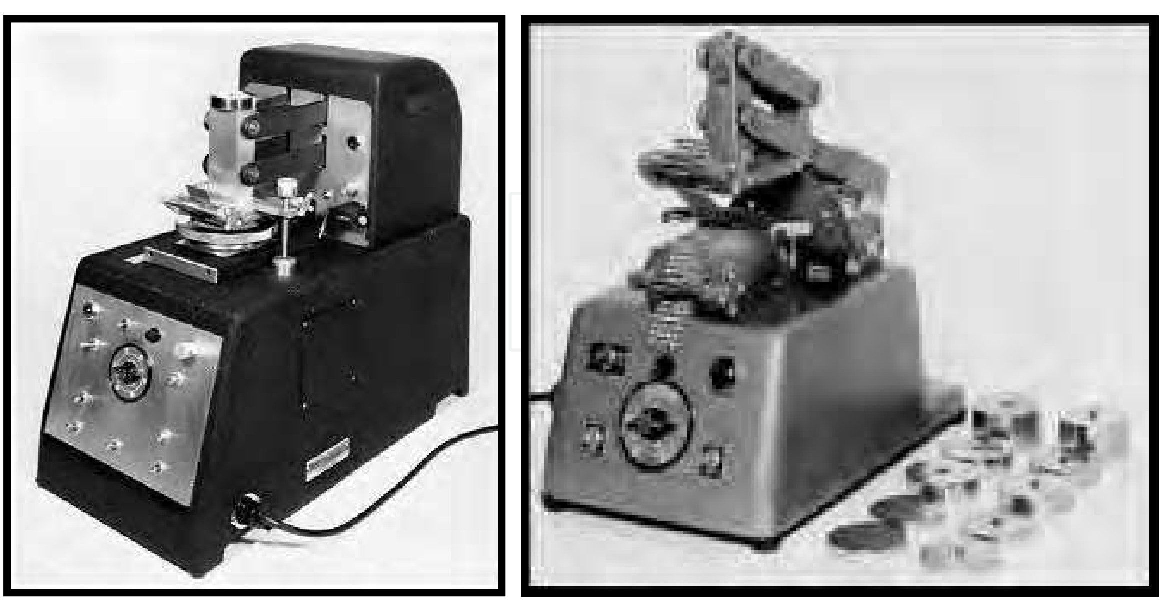
Fig. 6. (a) Rotary Platform Double Head Abrader, (b) Uniform Abrasion Testing Machine

3.2.2 Flex abrasion

Flex abrasion is the most common abrasion type to which a textile product is subjected. In flex abrasion the material is bent or flexed during rubbing. Flex abrasion occurs in apparel, furnishings and industrial products. Very little of the surface of most products is completely flat during usage, therefore flex abrasion tests may reflect the usage conditions more (Kadolph, 2007). Oscillatory cylinder, inflated diaphgram abrasion tester, flex abrasion testing machine are the instruments working on flex abrasion mechanism.

In ASTM D 4157 oscillatory cylinder method, abrasion resistance is measured by subjecting the specimen to unidirectional rubbing action under known condition of pressure, tension, and abrasive action. During the test fabric is pulled tight in a frame and held stationary. Oscillating Cylinder Section, equipped with edge clamps to permit mounting of a sheet of abrasive material over its surface, capable of oscillating through an arc. Individual test specimens cut from the warp and weft directions are then rubbed back and forth using an ACT approved #10 cotton duck fabric as the abradant. The procedure often is used for upholstery, leather and other materials (ASTM D 4157).

In inflated diaphgram method (Figure 7a), a specimen is abraded by rubbing either unidirectionally or multidirectionally against an abradant having specified surface characteristics. A specimen is held in a fixed position and supported by an inflated rubber diaphragm which is held under constant pressure. The abradant is mounted upon a plate, which is rigidly supported by a double-lever assembly to provide for free movement in a direction perpendicular to the plane of the reciprocating specimen clamp. The abradant plate assembly should be well balanced to maintain a vertical pressure equivalent to a mass of 0 to 2.2 kg (0 to 5 lb) by means of dead weights (ASTM D 3886).



(a) (b)

Fig. 7. (a) Schematic Diagram of Inflated Diaphragm Abrasion Tester, (b) Commercial Flexing and Abrasion Tester

In ASTM D 3885, abrasion resistance is measured by subjecting the specimen to unidirectional reciprocal folding and rubbing over a specific bar under specified conditions of pressure, tension, and abrasive action by Flex Abrasion Testing Machine (Figure 7b). This test method is useful for pretreating material for subsequent testing for strength or barrier performance. The pressure and tension used is varied, depending on the mass and nature of the material and the end-use application. Testing machine consist of Balanced Head and Flex Block Assembly that has two parallel, smooth plates. The balanced head is rigidly supported by a double lever assembly to provide free movement in a direction perpendicular to the plate of the flex block. A positioning device is provided to position the flexing bar and yoke assembly while loading the specimen such that the edge of the flexing bar is parallel to the fold of the specimen during the test (ASTM D 3885).

3.2.3 Edge and Flex abrasion

In edge abrasion the material is folded back on itself while it is being abraded. In products, pleats, folds, cording, cuffs, collars, hems, pocket flaps are most subject to edge abrasion. Most products show damage along edges before damage elsewhere in the product becomes apparent because the force is concentrated on a small portion of the material (Kadolph, 2007). So the edge abrasion is a harsh measure of fabric’s resistance to wear.

The accelerator abrasion tester (Figure 8) has an action that is quite different from most other abrasion testers. In the test a free fabric specimen is driven by a rotor inside a circular chamber lined with an abrasive cloth. The specimen suffers abrasion by rubbing against itself as well as the liner. In AATCC 93 method, each specimen is subjected to flexing, rubbing, shock, compression and other mechanical forces while the specimen is tumbling. Abrasion is produced thorough the specimen by rubbing of yarn against yarn, fibre against fibre, surface again surface and surface against abradant (AATCC 93; Kadolph, 2007)

Fig. 8. Accelerator abrasion tester

3.3 Factors affecting abrasion test results

During testing, the resistance to abrasion is also greatly affected by the conditions of the tests, such as the nature of the abradant, variable motion of the abradant over the area of specimen, the tension of the specimen, the pressure between the specimen and the abradant, and the condition of the specimen (wet or dry).

The type of abrasion like flat, flex or edge abrasion or a combination of more than one affect the test results as expected.

In many fabrics the abrasion resistance in the warp direction differs from that of the weft direction. Ideally the rubbing motion used by an abrasion machine should be such as to eliminate directional effects. In jacquard and textured fabrics, the test sample should include both the textured and different parts, sensitive to abrasion.

Abradants can consist of anything that will cause wear. A number of different abradants have been used in abrasion tests including standard fabrics, abrasive paper (glass paper, sand paper etc.) or stones (aluminum oxide or silicon carbide), steel plates and metal ‘knives’. The nature of abradants and the type of action control the severity of the test. For the test to correspond with actual wear in use it is desirable that the abrasive should be similar to that encountered in service. The abradant itself wear during the test so they should be replaced after a certain usage time (Hu, 2008 ; Saville, 1999).

Abrasion tests are all subject to variation due to changes in the abradant during specific tests. The abradant must accordingly be discarded at frequent intervals or checked periodically against a standard. With disposable abradants, the abradant is used only once or discarded after limited use. With permanent abradants that use hardened metal or equivalent surfaces, it is assumed that the abradant will not change appreciably in a specific series of tests. Similar abradants used in different laboratories will not change at the same rate, due to differences in usage. Permanent abradants may also change due to pick up of finishing or other material from test fabrics and must accordingly be cleaned at frequent intervals.

The measurement of the relative amount of abrasion may also be affected by the method of evaluation and may be influenced by the judgment of the operator (ASTM D 3884).

The pressure between the abradant and the sample and the test speed affects the severity and rate at which abrasion occurs. It has been shown that using different pressures can seriously alter the ranking of a set of fabrics when using a particular abradant. Excessive pressure and testing speed can result in shorter testing time but however, the results can not simulate the normal usage conditions. The tension of the mounted specimen is also important, and it should be same for all samples. Tension during the test is provided by backing foam or inflated diaphragm.

3.4 Evaluation methods of abrasion tests

There are different options for assessment of the tested fabrics as given below.

- First one is finding endpoint which counts the number of cycles until the fabric ruptures, two or more yarns have broken or a hole appears. The end point is different according to fabric type; for woven structure abrading is continued until two threads are broken while one broken yarn causing a hole for knitted fabric. Removing of the fabric fusses completely, and occurring a hole in 0.5 mm diameter is the end points for fused and for nonwoven fabrics respectively.

- Second option is assessment of the abraded fabric for a set time or number of cycles in terms of some aspect such as loss of mass, loss of strength, change in thickness or other relevant property. The loss of any property before and after abrasion is reported as loss in the relevant property or as a percentage calculated by the formula:

Loss percentage in relevant property (%) = ((A-B)/A)*100, where: A = relevant property before abrasion, and B = after abrasion

According to ISO 12947-3 standard, the weight loss in certain cycles is determined based on the end breaking cycle, then at the every intervals the abraded sample is taken from the device, weighted in the sensitivity of 1 mg, percentage of the weight loss is calculated and the graph is plotted.

Series of experimental	Abrasion cycles at the breakage of the sample	Abrasion cycles for determination of weight loss
a	≤1000	100, 250, 500, 1000, (1250)
b	> 1000 ≤ 5000	500, 750, 1000, 2500, 5000, (7500)
c	> 5000 ≤ 10000	1000, 2500, 5000, 7500, 10000, (15000)
d	> 1000 ≤ 25000	5000, 7500, 10000, 15000, 25000, (40000)
e	> 25000 ≤ 50000	10000, 15000, 25000, 40000, 50000, (75000)
f	> 50000 ≤ 100000	10000, 25000, 50000, 75000, 100000, (125000)
g	> 100000	25000, 50000, 75000, 100000, (125000)

Table 3. Intervals for the measurement of weight loss

- The third method is the evaluation of any visual changes that occurred as a result of abrasion test. The end point is reached when there is a change in shade or appearance that is sufficient to cause a customer to complain or the visual appearance after the predetermined abrasion cycles (ISO 12947-4). Visual change considers the effect that a specified number of cycles have on the lustre, colour, surface nap or pile, pilling, matting or any chance resulting from abrasion. Average number of rubs required to reach a gray scale rating of three or lower is recorded while assessing colour related changes.

None of the above assessment methods produces results that show a linear or direct comparison with one another (Bird, 1984).

4. Yarn abrasion

The issue of yarn abrasion has been defined both as the attrition of yarn upon itself (yarn to yarn) or another surface (yarn to wire, etc.) and the resistance of yarn to suffer damage when abraded upon a surface (Johns, 2001). A yarn which is being knitted or woven into a fabric or wound onto a package runs around many guides during the process. As a yarn passes over a metallic surface, either it gets abraded or it abrades the metallic surface, which is an undesirable effect causing wear of machine parts (Saville, 1999). Yarn abrasion resistance is an important factor affecting weavability (Lawrence, 2003). The yarn-to-yarn friction between warp and weft yarns at every crossover is important in determining the shear property and consequently the formability of woven fabrics (Liu et al., 2006).

The factors, which affect the yarn abrasion, can be detailed as; yarn friction, yarn type, twist multiple, hairiness, contaminants and applied lubricants (Johns, 2001, as cited in Alterman, 1985; Barella, 1989; Beckert, 1999; Chattopadhya& Banerjee, 1996; Steve, 1986, Süpüren et al., 2008). Average surface length which is highly correlated with the abrasion resistance of yarns is also introduced as a new yarn structural parameter. The length of fibres exposed on the yarn surface depends on their interactions with surrounding fibres on the yarn. The yam abrasion resistance was found inversely proportional to the average surface length (Choi & Kim, 2004). For synthetic yarns, it is indicated that, abrasion behavior of the yarns is associated with the fundamental properties such as the polymer and fibre molecular weight, undrawn fibre orientation and crystalline structure, drawn fibre properties, and elevated temperature post-treatment (Ross & Wolf, 1966).

The coefficient of friction is a significant characteristic of textile yarns, because it defines the amount of resistive shear force a yarn will exert and have exerted upon it during fabric forming or preparation processes (Thomas & Zeiba, 2000). As the friction between the yarn and the abradant increases, the abrasion resistance decreases (Johns, 2001, as cited in Jeddi & Sheikhzadeh, 1994).

Yarn type is another important parameter for the abrasion resistance. Generally, ring-spun yarns have higher snagging tendency and lower abrasion than rotor yarns (Lawrence, 2003). Air-jet spun yarns are less resistant to abrasion than ring-spun yarns, because the former are bound by outer wrapper fibres only and have no internal twist (Thomas & Zeiba, 2000). The abrasion resistance of the sirospun yarn is better than that of the two-plied and the single yarns (Sun & Cheng, 2000).

Resistance to abrasion increases as the twist multiplier increases (Johns, 2001). At low twist levels, yarns can be easily splitted therefore yarns with high twist levels are abraded less than yarns with low twist levels.

The abrasion resistance of the two-plied yarn depends on both single-yarn twist and ply twist. Single-yarn twist and ply twist have a more influential effect on the yarn-to-yarn and yarn-to-pin abrasion resistances respectively of cotton two-ply yarns (Palaniswamy & Mohamed, 2006).

It is known that during weaving, the yarns experience the abrasive action of the moving loom parts such as heddle eyes, reeds, whip rolls, and picking elements (Goswami et al., 2004). Sizing is applied to the warp yarns to improve their abrasion resistance and strength and to reduce friction (Lawrence, 2003). The yarn abrasion resistance was found higher in sized yarn with a higher twist level (Kovačević & Gordoš, 2009). The size formulations used for spun yarns (including blends) also contain other ingredients such as lubricants and binders. The lubricants help to reduce the friction and abrasion between the adjacent yarns and between yarns and heddles, dropwires, shuttles, rapiers, or projectiles (Goswami et al., 2004).

4.1 Measurement methods of testing yarn abrasion

There are various measurement methods to measure abrasion properties of yarns, including yarn on yarn abrasion and yarn external abrasion, which comprises different test procedures.

4.1.1 Yarn on yarn abrasion

The yarn-on-yarn abrasion test is described in ASTM D 6611, "Standard Test Method for Wet and Dry Yarn-on-Yarn Abrasion Resistance". A length of yarn is inter-wrapped in contact with itself between three pulleys that are positioned in a defined geometry to produce a specific intersection angle. A weight is attached to one end of the yarn to apply a prescribed tension. The other end is drawn back and forth through a defined stroke at a defined speed until the yarn fails due to abrasion upon itself within the inter-wrapped region (Figure 9). The yarn abrasion test can be conducted in either the dry state or the wet state (ASTM D 6611).

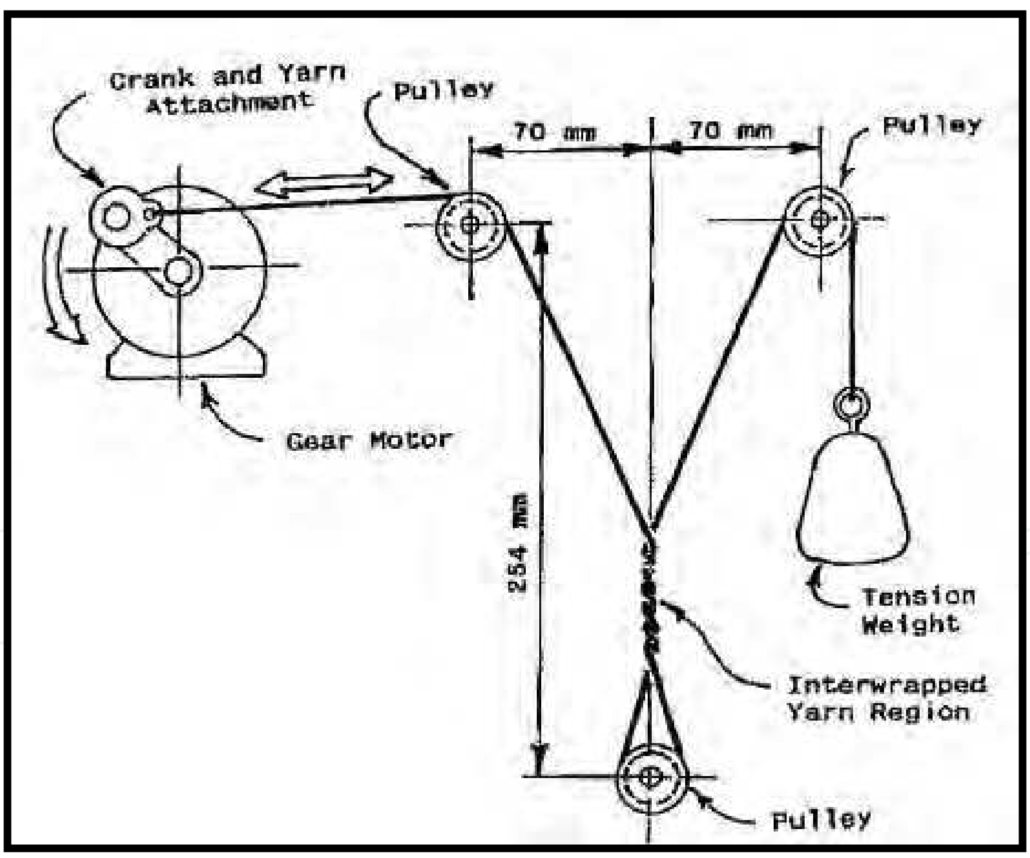


Fig. 9. Yarn-on-yarn abrasion setup (ASTM D 6611)

Zweigle Staff-Tester G 556 (Figure 10), measures accurately abrasion and breakage tendency before further processing. The yarn runs with constant tension via the hysteresis brake into the tester. The thread is guided over two easy-going rollers in such a way, that the running-in section coils around the running-out section over an angle of approximately 180 degrees. At this coiling point there is intense thread-to-thread friction. Various metal or ceramic elements can be placed into the running path of the thread. A funnel below the coiling point collects the parts rubbed-off from the yarn or avivage. The built-in blast exhausts the dust into a small, easily removable filter. By using an accurate balance the weight of the yarn and/or avivage rubbings can be determined (http://citeseerx.ist.psu.edu).

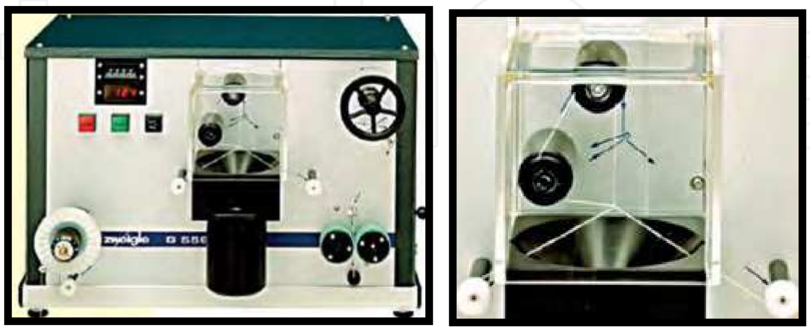


Fig. 10. Staff tester (http://citeseerx.ist.psu.edu)

Lint generation (lint shedding) test can be conducted by Lawson-Hemphill's CTT (Constant Tension Transport) instrument to measure yarn to yarn abrasion (Figure 11). The instrument is a dynamic yarn transport system with the ability to maintain a specific yarn tension and let the yarn run at any selected speed up to 360 m/min. It simulates the production conditions in the testing laboratory and therefore it gives idea about the production performance (Thavamani, 2003).

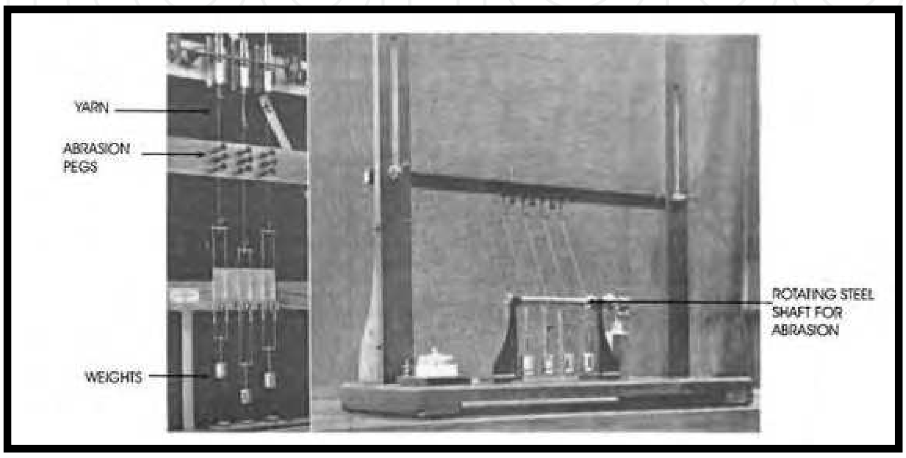
The CTT Lint Generation Test determines how much lint a yarn will generate under certain manufacturing conditions, including: yarn-to-yarn thread paths, yarn-to-metal thread path, yarn-to-ceramic and yarn-to-needles, sinkers and reeds (at any angle). During the lint test, the yarn is wrapped around itself. As the yarn is moving, the generated lint will be collected on a piece of paper under the vacuum sealed enclosure. The amount of lint that is generated is expressed as mg/1 km. Therefore, abrasion properties of different yarns can be compared based on their weight loss (www.lawsonhemphill.com).

Fig. 11. CTT Instrument with Lint Generation Test Module (www.lawsonhemphill.com)

4.1.2 Yarn external abrasion

External abrasion resistance is important in many applications and there are different measurement methods to evaluate yarn abrasion resistance.

Oscillating stress tester (Figure 12a) incorporates the abrasion element consisting of three rows of case-hardened steel pegs. Yarns hanging from the jaws just touch the pegs in the top and bottom rows, and the middle pegs can be traversed sideways to deflect the yarns around by a desired amount. In a test, the yarn hanging from the jaws passes to one side of the corresponding top and bottom pegs and around the opposite sides of the displaced middle peg, and thus abrade the yarn when reciprocated. Owen and Locke also modified the instrument to apply abrasion by the rotating steel shaft, as shown in Figure 12b. The shaft was rotated by a belt driven from a small electromotor to provide abrasion to yarns at the point of contact (Goswami et al., 2004).



(a) (b)

Fig. 12. Oscillating stresses abrasion tester (Goswami et al., 2004)

Using these modified equipment, Owen and Locke subjected yarns to a fixed number of abrasion cycles and measured the breaking strength of such abraded yarns. The results were expressed in terms of percent deterioration in the breaking load, calculated as follows:

$$\text{deterioration (\%)} = \frac{MSYBA - MSYAA}{MSYBA} \times 100$$

where, $MSYBA$= mean strength of yarn before abrasion and $MSYAA$= mean strength of yarn after abrasion (Goswami et al., 2004).

As a yarn passes over a metallic surface (Figure 13), either it gets abraded or it abrades the metallic surface, which is an undesirable effect causing wear of machine parts (Johns, 2001). Therefore, the abrasiveness of the yarns is another abrasion characteristic of the yarns and can be tested by Lawson-Hemphill CTT (Constant Tension Transport) tester. In this test, the wires used in testing are secured at one end, stretched over a pulley and secured at the other end to a lever. When the wire is cut, the weight hanging on the lever enables the activation of auto stop mechanism. Suitable weight has to be used on the lever to give support to the wire to keep it straight when the wire is passing over it without stretching it unnecessarily (Thavamani, 2003). The yarn is run over a tensioned standardized copper wire and the abrasion factor is measured as the length of yarn it takes to cut the wire or, the surface destruction is measured with a microscope, after running of the yarn in a fixed length (Das & Hati, http://www.lawsonhemphill.com/pdf/lawson-hemphill-news-006.pdf)

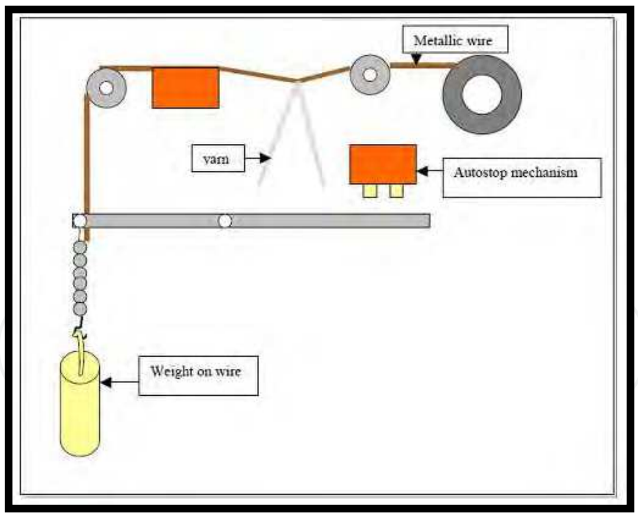
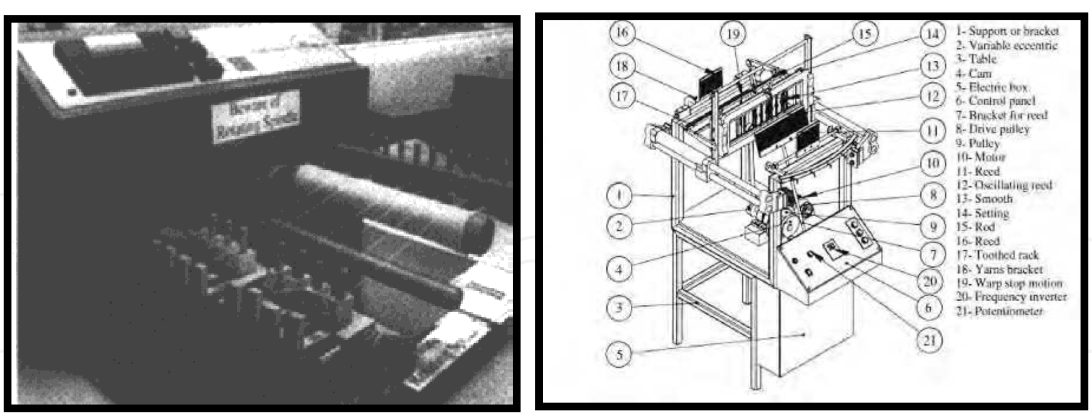


Fig. 13. Diagram to show the CTT set up of yarn and metallic wire (Thavamani, 2003)

Another instrument is Shirley yarn abrasion tester (Figure 14a), which consists of two reciprocating bars: one is made of hardened steel and the other is covered with the standard abradant used in the Martindale fabric abrasion tester. Eight yarn specimens are tested simultaneously. Yarns are threaded from the fixed holders and clipped onto the flexible holders where sensors are attached. The initial tension exerted on each yam is 0.5N. When a yam breaks, the flexible holder falls, a signal is sent to the control unit, and the number of rubs for that particular yarn is recorded (Choi & Kim, 2004).

The effect of yarn count and material type on the abrasiveness property is also significant for fancy yarns. Wool fancy yarns are more abrasive than the acrylic yarns and thicker yarns are more abrasive than the thinner yarns as well (Süpüren et al., 2008).



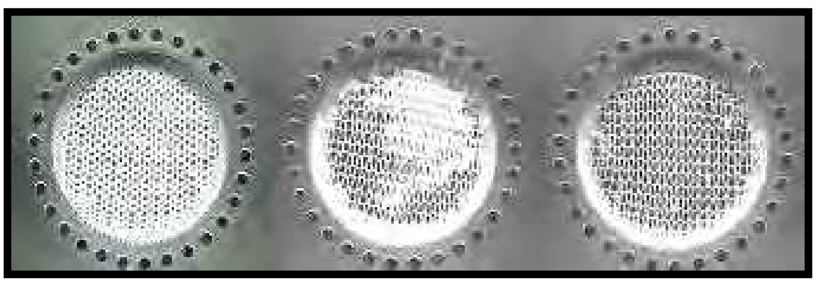
(a) (b)

Fig. 14. (a) Shirley yarn abrasion tester (Choi & Kim, 2004), (b) Simulator abrader tester (Boubaker et al., 2011)

A new abrader tester (Figure 14b) which simulates the weaving process, combines forces of traction, bending, yarn-to-yarn and yarn-to-metal friction. The repetitive deformations of spliced and parent yarns simulate the abrasion action on the weaving machine (Boubaker et al., 2011).

5. Abrasion resistance of socks

Socks, which are a necessary item of clothing, need to be comfortable, affordable and retain their quality throughout their life. The most significant problem is abrasion which can greatly reduce the materials life. Abrasion usually occurs on the heel, sole and toes of the socks. The span life of the socks is shorter than other textile materials because of higher abrasion within the shoes, slippers or even the ground during usage. The first stage of abrasion unrevals of the loose fibres from the fabric surface, eventually breakdown of fibres and a hole occur. If the sock consists of synthetic fibres with natural fibres, during rubbing action natural fibres, which give the desirable properties of the sock, move away, only synthetic fibres remain. This situation stated as thinning and gives the sock undesirable appearance and decreases the overall fabric thickness (Figure 15).



(a)

(b)

Fig. 15. (a) The thinning appearance of a Co/PA sock at the heel during abrasion resistance tests, (b) abraded socks (Özdil et al., 2005, 2009)

The Sock Testing Consortium accepted three methods for abrasion resistance of socks. These are CSI Stoll method, ILE SCR method and in present widely used Martindale method (Özdil et al., 2005). A modified specimen holder for the Martindale abrasion tester, which stretches the knitted material, is used for socks' abrasion (Figure 16). The holder takes a standard size 38mm diameter sample which is held to size by a pinned ring. A flattened rubber ball is pushed through the sample as the holder is tightened thus stretching it, test is carried out as fabric tests. The sample is inspected at suitable intervals until a hole appears or the material develops an unacceptable level of thinning (Özdil et al., 2009).

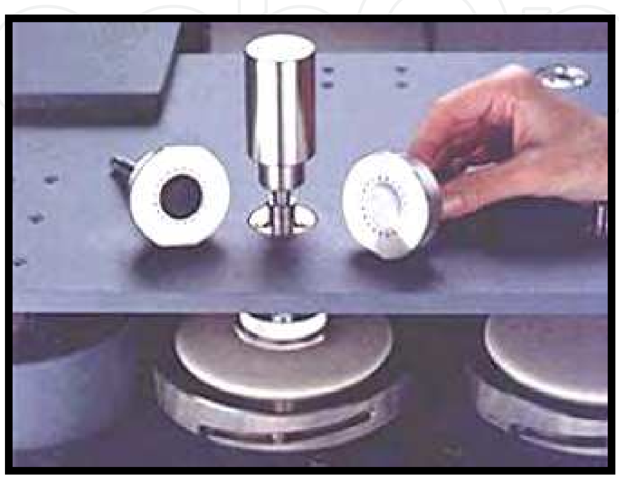


Fig. 16. Setting of sock kit on Martindale apparatus

There is not too much research related with sock abrasion. In one of the research abrasion resistance of 7 different types of socks consisting of different rates of Co-PA were searched with both laboratory tests and usage tests (Özdil et al., 2009, as cited in Wisniak & Krzeminska, 1987). Pilling test device was used for abrasion resistance and abrasion time of the sample assessed. It was found that the results from the laboratory and the usage tests were different. In another study the abrasion resistance of terry socks was investigated (Özdil et al., 2009, as cited in Miajewska & Kazmierczak, 1983). PA yarns for ground, wool and wool blends (wool+ PA, PAC+PA, wool+PAC) also cotton and cotton blends (Co+PA, Co+viscone+PA) for pile were used. It was found that the result of the wool and wool blends are evenly matched to each other and abrasion resistance of the cotton socks was better than wool socks. They used different yarns for piles to increase the abrasion resistance of the socks and found that the yarns spun with wool -PES blends gave the best results. The results of the PAC–wool yarns and PAC-linen yarns followed it respectively. Increased yarn twist, adding PA and folded PAC yarns increases abrasion resistance of the socks are the other results of them.

The effects of the yarn parameters and some finishing process on the abrasion resistance of socks were researched in detail (Özdil et al., 2009). It was found that the abrasion resistance value of socks can be increased by a number of measures; usage of thicker yarns, adding PA and elastic yarns to the structure, increasing the PES ratio in Co-PES yarns. The resistance of wool socks is higher than acrylic ones and the wool ratio in wool-acrylic samples has a positive influence on abrasion resistance. The abrasion resistance increases with mercerization process and decreases with the use of silicone softeners (Özdil et al., 2009).

6. Abrasion resistance in technical textiles

Abrasion resistance is one of the most important properties in special technical textile products. In order to measure the abrasion resistance of these products such as protective clothes, military fabrics, gloves, laminated fabrics, multi layered structures, special measurement procedures were developed.

Car seat is one of the most important parts of the interior of a car and abrasion resistance of the seat fabric is an important parameter for the usage. It is composed of metal structure, filling (molded polyurethane foam) and seat cover including exterior fabric, foam and support material (reinforcement material).The foam has influence on the abrasion resistance of car seats upholstery; increased height and weight of the foam, causes less weight and thickness loss. Non-usage of foam reduced the abrasion resistance significantly (Jerkovic et al., 2010). Fabric type has an important effect on abrasion resistance of car seat covers. The warp knit double bar raschel was found more resistant to abrasion than flat woven, circular knitted flat and warp knit flat fabrics (Pamuk & Çeken, 2008).

An abrasion test for geo-textiles uses a reciprocal back-and-forth rubbing motion of a sandpaper abradant against the geo-textile. The instrument used in this test is a Stoll Flex abrader modified to allow the fabric to be mounted on a stationary platform and the abrading medium on a reciprocating platform. The abrader can be loaded to provide a constant pressure and has an adjustable speed drive to allow the abrasive action to be controlled as required (Hodge, 1987).

In day-to-day applications, abrasion resistance is one of the most important properties that determine the duration of the useful life of the nonwoven articles. In particular, in many industrial filtration applications, filter media can undergo severe abrasive loading. Abrasive damage can manifest itself in two ways. Firstly, the filtration area can be damaged due to repeat contact with hard and sharp particulate materials in the fluid, and can result in pinhole damage over time. This in turn weakens the body of filter media and reduces its retention efficiency, resulting in rapid solids loss. In such cases, the process would have to be stopped and the cloths either changed or occasionally repaired with patches. A second source of abrasive damage is due to attrition between the cloth and the filter machinery. The abrasion resistance of the thermally bonded nonwoven articles is significantly dependent on not only the choice of fibre, but also the construction of the fabric (Wang et.al, 2007; as cited in Ramkumar et al, 2001), which is further influenced by both the web forming and thermal bonding processes (Wang et.al, 2007).

Abrasion has a potential mode of failure for either latex or non-latex medical glove materials. Resistance to abrasion is necessary to maintain barrier integrity during routine tasks such as twisting a capped needle onto a syringe or turning a knurled knob on a piece of equipment. An alternative method (Figure 17) for measuring durability of both latex and non-latex medical glove materials, utilizing abrasion resistance testing, has been developed.

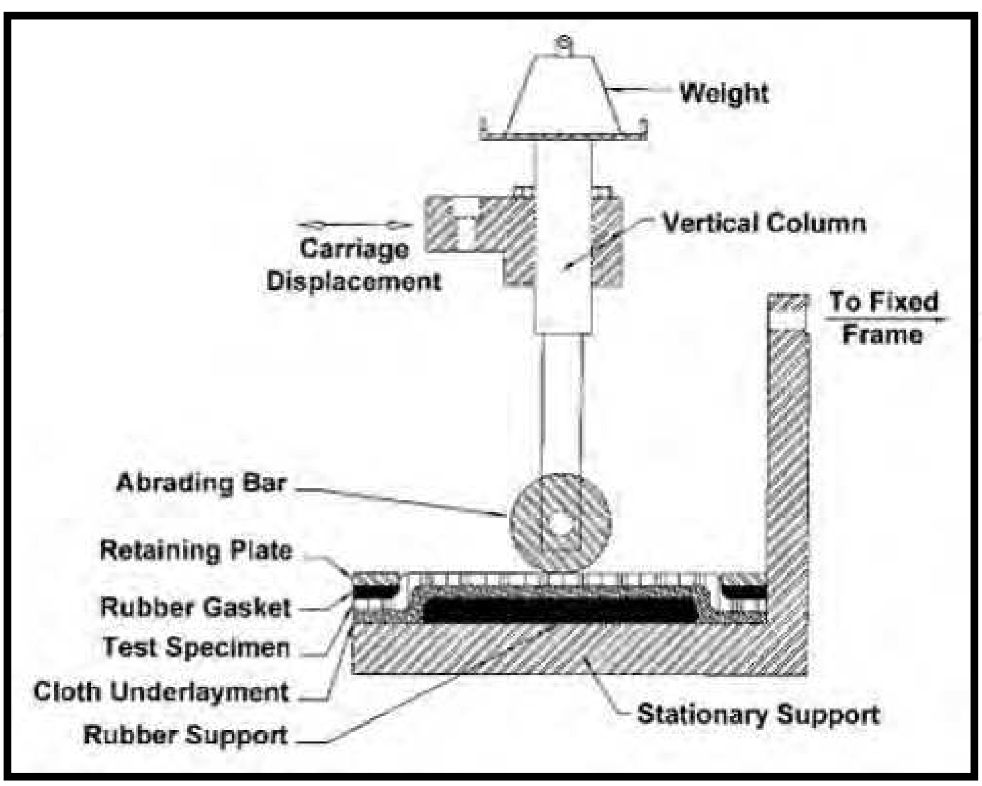


Fig. 17. Glove abrasion resistance apparatus (Walsh et al., 2004)

This device converts the rotary motion of an adjustable-speed, DC gear motor into oscillating linear displacement of a carriage that serves as a translating support for a vertical loading column. The abrader is linearly stroked against a test specimen at a rate that is preset by adjustment of a motor speed control. Along with displaying the preset number of cycles for a particular test sequence, the system control unit also indicates real-time values of test cycles and cycle rate (Walsh et al., 2004).

Established test machines such as the Martindale, revolving drum and Taber abrader were considered for the evaluation of "Protective clothing for motorcycle riders", but they are not capable of testing the multitudinous single and combination materials and constructions present in motorcyclists' protective clothing. The Darmstadt tester and the Cambridge tester are used for this measurement. The Darmstadt machine consists of a `doughnut' of concrete, in the centre of which is situated an electric motor. In testing, the motor is run up to a specified speed at which point the specimen holders are released and freefall the short distance down the axis of the shaft into contact with the surface of the concrete. The specimens continue to spin freely around the drive shaft and in contact with the concrete until coming to a halt. The mass of test specimens both before and after testing is recorded, and the difference established. In Cambridge tester, the test specimen is mounted on a holder which is attached to the free end of a horizontal, rigid pendulum which pivots at the opposite end to the specimen holder. In testing, the pendulum is released and falls onto the moving belt. A fine copper wire of 0.14mm diameter, located across the outer face of the specimen, is cut upon contact with the moving belt and this starts an electronic timer. A second wire is exposed and cut when the specimen is abraded through, which stops the timer and records the time taken to perforate the specimen. The more prolonged the period between contact and perforation, the better-performing the material. Para-aramid laminated constructions for motorcyclists' clothing was found better than polyester laminated construction, layered construction textile, air textured nylon and leather in terms of the results of impact abrasion resistance (Scott, 2005).

7. Conclusion

In this chapter, abrasion which affects serviceability of textile materials was explained in detail. The abrasion mechanism of textiles is a complex phenomenon and associated with the properties of fibers, yarns, fabric structure and applied treatments. Abrasion in textiles such as fabrics, yarns, socks and technical textiles can be measured by different methods. Due to the technological improvements and growing demands on the properties of textile materials, it seems the development of new test techniques and equipments will continue on this issue.

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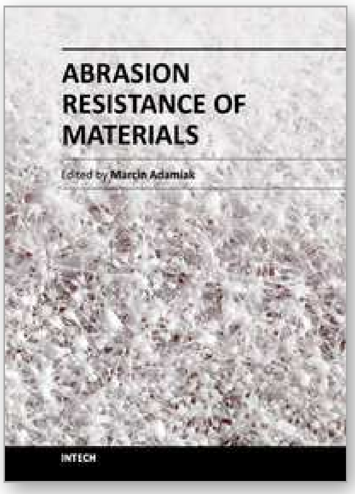

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