

ABSTRACT

SAHBAEE BAGHERZADEH, ARASH. Abrasion and Pilling Resistance of Nonwoven Fabrics Made from Bicomponent Fibers. (Under the direction of Dr. William Oxenham.)

The purpose of this research is to investigate key factors that affect structure and abrasion resistance of nonwoven fabrics produced from bicomponent fibers. The main objective of producing bicomponent fibers is to develop capabilities not existing in either polymer alone. By this technique, fibers with different cross sectional shape or geometry can be produced. Bicomponent fibers are commonly classified by their fiber cross section structures as side-by-side, sheath-core, islands-in-the-sea and citrus fibers or segmented-pie cross section types.

The properties of nonwoven fabrics are primarily determined by the properties of the fibers used to make them. Fundamentally, a fiber property is the response of a fiber to an imposed chemical environment or physical force.

In this research three types of nonwoven fabric classified with their fibers (Segmented, Islands in the Sea, and Trilobal) were used. Visual ranking, optical ranking, and weight loss were investigated to evaluate pill resistance of these fabrics.

Abrasion and Pilling Resistance of Nonwoven Fabrics
Made from Bicomponent Fibers

by

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With lots of love to the best sister in the world, Azadeh and the best friend

Mr. Javad.

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1 Introduction

With the rising popularity of nonwovens, greater demands for quality have been required as end-users have become more aware of its negative properties, however still a few studies have been reported on the geometry and dimensional properties of nonwovens fabrics produced from different kinds of bicomponent fibers.

The main objective of this research is to investigate the effects of fibers variables such as on fabric structure, pilling, and abrasion properties of nonwovens fabrics made from bicomponent fibers.

1.1 Specific Objective

The specific objectives of this proposal are:

- ▶ To summarize literature in the field
- ▶ To better understand the key factors which affect fabric structure, and pilling resistance of hydroentangled nonwoven fabrics produced from different types of bicomponent fibers.
- ▶ To compare the results of two different abrasion testers (Martindale and Random Tumble) and determine whether the relative results are dependent on the fabric specifications.

This research is undertaken to investigate the pilling performance of nonwovens fabrics made from bicomponent fibers in the standard situation and to determine the sensitivity of different testers for various fibers and fabrics parameters. The pilling behavior of different polyester/nylon66 blends were investigated for this purpose.

At the same time, it is illustrated that the interaction of various factors, including fiber properties (type, diameter, length, curvature and strength) and fabric construction (structure, compactness) determines the rate and extent of pill formation.

For this work, three different fabric types were investigated. The samples were classified in accordance with the type of fiber used to make the sample. Furthermore, the weight loss percent of fully relaxed dyed samples was also calculated after the relevant test cycles had been completed. This measurement of weigh loss allows the comparison of the severity of wear in the fabrics. Nonwoven fabrics produced from segmented fibers were investigated more in details. These samples were also examined under a scanning electron microscope (SEM).

2 Literature Review

2.1 Definition of Nonwoven

“Today’s nonwovens are highly engineered solutions made up of a variety of materials including fibers, powders, particles, adhesive, films and other materials that provide specific solution providing a multitude of functionalities”. [11]

As a main characteristic, the general definition indicates that nonwoven fabrics are made out of fibers, without any restriction. These can be very short fibers of a few millimeters in length as in the wetlaid process, or very long filaments. Properties and characteristics of a nonwovens fabric depend in large part on the type of fiber used in its construction. These fibers can be natural or synthetic, organic or inorganic. Such fibers can also be produced continuously in connection with the nonwovens process itself and then cut to length, or then extruded directly from polymer granules into a filament and then fibrous structure.

Nonwovens can be made absorbent, breathable, drapeable, flame resistant, heat sealable, light weigh, lint-free, mouldable, soft, stable, stiff, tear resistant, and water repellent, if needed. Obviously although, all the properties mentioned can not be combined in a single nonwoven, particularly those that are contradictory. [11, 12]

Their applications are multifold. Examples of their uses can be listed as follows:

- ▶ Personal care and hygiene: baby diapers, feminine hygiene products, adult incontinence items, dry and wet pads, but also nursing pads or nasal strips.
- ▶ Healthcare: surgical drapes, gowns and packs, face masks, dressings and swabs, osteomy bag liners, etc.
- ▶ Clothing: interlining, insulation and protection clothing, industrial workwear, chemical defence suits, shoe components, etc.
- ▶ Home: wipes and dusters, tea and coffee bags, fabric softeners, food wraps, filters, bed and table linens, etc.
- ▶ Automotive: boot liners, shelf trim, oil and cabin air filters, moulded bonnet liners, heat shields, airbags, tapes, decorative fabrics, etc.
- ▶ Construction: roofing and tile underlay, thermal and noise insulation, house wrap, underslating, drainage, etc.
- ▶ Geotextiles: asphalt overlay, soil stabilization, drainage, sedimentation and erosion control, etc.
- ▶ Filtration: air and gas, Hevac, Hepa, Ulpa filters
- ▶ Industrial: cable insulation, abrasives, reinforced plastics, battery separators, satellite dishes, artificial leather, air conditioning, coating.
- ▶ Agriculture, home furnishing, leisure and travel, school and office, etc.

Not only nonwovens are substitute just for their end cost, they have more and more additional or improved benefits for the users.

2.2 General Remarks

Nonwoven fabric technology is the most exciting segment of the textile industry and will be one of the most important in the years ahead as nonwovens fabrics penetrate many more areas now occupied mostly by “conventional textiles”.

Despite the maturity of some of the nonwoven technologies, their growth is expected to continue at a steady rate. Technologies which are expected to gain in importance are spunbonding, meltblowing, and spunlacing. [2]

Spunbonding - is direct fabric manufacturing from polymer in one step (Spin and bond). Polymer is prepared, melted, extruded, draw/quenched into continuous oriented filaments, deposited on a moving screen, and then bonded in a variety of ways. This technique is the most cost effective method of making a fabric. [11]

Meltblowing – is a one-step process that converts resin to fine fiber nonwovens webs or structures. This technique produces fine fibers (2-8 micron) for applications where small fibers, large fibers surface area and pore size are required. [11]

Spunlacing (Hydronentagling) – water jet entangled fabrics consisting of mechanically interlocked fibers and fiber bundles where the energy is supplied by high pressure streams of water in the form of columnar jets. [11]

Nonwoven fabrics are quite distinct and versatile in their characteristics and properties as compared to the conventional woven and knitted fabrics.

Key characteristics of nonwovens fabrics are as follows: [2]

- ▶ **Physical properties:** adjustable to a certain extent
- ▶ **Handle:** adjustable between extremely soft and extremely hard, but this adjustment causes marked changes in other properties
- ▶ **Drape:** falls between conventional textiles and paper
- ▶ **Surface area:** always greater than conventional textile fabric
- ▶ **Bulk:** adjustable, usually greater than conventional textile fabric
- ▶ **Appearance:** with some exceptions, less attractive than that of conventional textile fabric
- ▶ **Price:** usually more cost-effective than conventional textile fabric

Woven and knitted fabrics manifest their properties from the arrangement of fibers in the yarn and the arrangement of yarns in the fabrics. Likewise, the properties of nonwovens fabrics are largely dependent on fiber properties, fabric structural geometry, and particularly the type of fiber-to-fiber bonding. Moreover, nonwoven fabric properties can be “tailor-made” through the use of the various web manufacturing and bonding processes, the selective use of fibers/raw materials, and various bonding finishing processes. [2]

The properties of nonwoven fabrics are primarily determined by the properties of the fibers used to make them. Fundamentally, a fiber property is the response of a fiber to an imposed chemical environment or physical force. A major factor governing any fiber property is the composition and arrangement of the polymer molecules which make up the fiber. Fiber properties are generally categorized as either chemical or physical in nature.

Essentially, chemical properties are a direct function of the chemical composition of a fiber and determine its resistance to acids, bases, and solvents. Physical properties are scientifically affected by molecular arrangement and determine the reaction of a fiber to mechanical forces, moisture, heat, light, and electrical phenomena. Fiber density, geometry, and dimensions are also considered as physical properties. This research will provide a descriptive overview of fiber properties and their significance in determining the properties of hydroentangled fabrics. [3]

The nonwoven textile industry has made dramatic technical and commercial progress in recent years.

Worldwide consumption of nonwovens by 2007 is likely to reach more than 4.0 million tons. Production of Nonwovens is still concentrated in the USA (41% of world total), West Europe (30%), Japan (8%) and China produces 3.5%. By 2007, China will produce 7% of the world's total. World consumption of fibers in nonwoven production is 63% polypropylene, 23% polyester, 8% viscose rayon, 2% acrylic, 1.5% polyamide and 3% other high performance fibers. Future advancements will be in bicomponent fibers, micro fibers (split table bicomponent fibers or meltblown nonwovens), nano fibers, biodegradable fibers, super-absorbent fibers and high performance fibers. Also there will be more technological innovations such as 1) new, more efficient and economical processing technologies, 2) direct polymer to roll goods, 3) use of new types of composite nonwovens and laminates, and 4) new finishing techniques and novel additives. (Table 2.1) [10]

Table 2. 1: Fibers used in Nonwoven industry

TRADITIONAL TEXTILE FIBERS	HI-TECH FIBERS
PET	Aramid (Nomex/Kevlar)
Polyolefin (PP/PE)	Conductive Nylon
Nylon	Bicomponent
Cotton	Melamine (heat & flame resistant)
Rayon	Super absorbent
Wool	Hollow fibers
Lyocell	Spandex fibers (polyether)
Modacrylic	Fusible co-PET fiber
	PA-6 support/matrix fiber
	Glass micro-fiber
	Chlorofiber
	Antibacterial fiber
	Stainless steel
	Rubber thread
	PTFE
	Nanofibers

The major reason for using synthetic polymer to make fibers is that polymers have certain properties and performance characteristics which can be modified to gain fiber with specific properties. Some polymers are very elastic and stretch, while others are rigid and brittle and shatter when hit with a hammer. Some polymers are water-repellant while others are water-soluble and thicken or gel in water. Still other polymers dissolve in oils and hydrocarbon solvents. Some are smooth and transparent, while others are opaque and sticky, acting as glues or bonding agents. Some polymers have exceptional heat stability while others melt at a low temperature. All of these polymer properties can be controlled as desired, simply by understanding their chemical and physical features. [2]

The specific molecular structure along with the polymer-chain length and chain alignment accounts for essentially all of the physical properties of polymers.

Rigidity, elasticity, flexibility, toughness, crystallinity, and amorphous structure are all dependent upon these parameters and can have a great influence as to what polymer and what type of structure should best be employed for achieving specific performance characteristics.

The longer chains with the least amount of branching will increase polymer strength on stretching. Corresponding to the increased chain alignment, there will be a significant drop in elongation of the stretched polymer system. [2]

2.3 Nylon Fibers

The fiber has outstanding durability and excellent physical properties. Like PET fiber, it has a high melting point, which conveys good high- temperature performance. The fiber is more water sensitive than PET; despite this fact, nylon is not considered a comfortable fiber in contact with the skin. Its toughness makes it a major fiber of choice in carpets, including needle punched floor-covering products. Because of its relatively high cost, nylon has somewhat limited use in nonwoven products (Figure 2.1). It is used as a blending fiber in some cases, because it conveys excellent tear strength. [9]

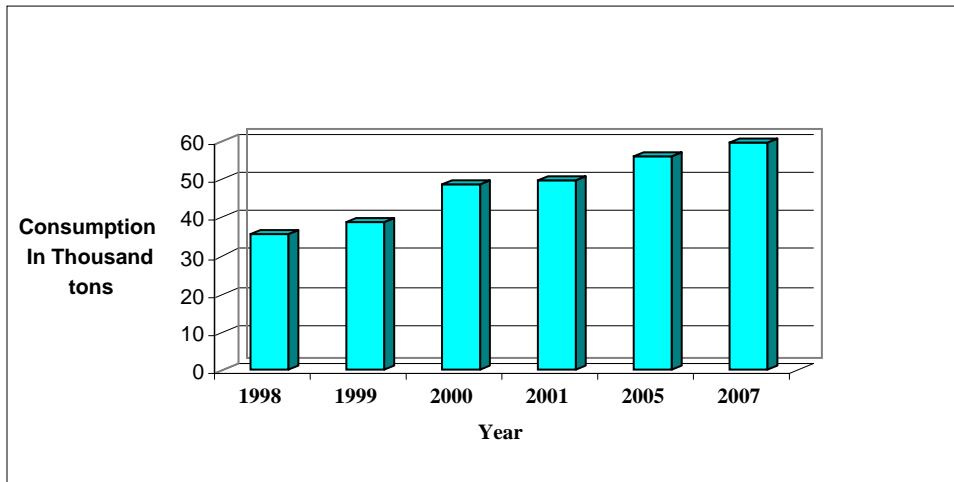


Figure 2. 1: World Consumption of Nylon fiber for Nonwovens

2.4 Polyester Fibers

2.4.1 General Polyester Fiber Characteristics:

- ▶ Strong
- ▶ Resistant to stretching and shrinking
- ▶ Resistant to most chemicals
- ▶ Quick drying
- ▶ Crisp and resilient
- ▶ Wrinkle resistant
- ▶ Mildew resistant
- ▶ Abrasion resistant
- ▶ Retains heat-set pleats and crease
- ▶ Easily washed

2.4.2 Relationship between Structure, Properties and Processing Parameters of PET Fibers

Properties of polyester fibers are strongly affected by fiber structure. The fiber structure, which has a strong influence on the applicability of the fiber, depends heavily on the process parameters of fiber formation such as spinning speed (threadlike stress), hot drawing (stretching), stress relaxation and heat setting (stabilization) speed.

As the stress in the spinning threadlike is increased by higher wind-up speed, the PET molecules are extended, resulting in better as-spun uniformity, lower elongation and higher strength, greater orientation and high crystallinity. Hot drawing accomplishes the same effect and allows even higher degrees of orientation and crystallinity. Relaxation is the releasing of strains and stresses of the extended molecules, which results in reduced shrinkage in drawn fibers. Heat stabilization is the treatment to "set" the molecular structure, enabling the fibers to resist further dimensional changes. Final fiber structure depends considerably on the temperature, rate of stretching; draw ratio (degree of stretch), relaxation ratio and heat setting condition. The crystalline and non-crystalline orientation and the percentage of crystallinity can be adjusted significantly in response to these process parameters. [8]

2.4.3 Mechanical Properties of Polyester Fibers

As the degree of fiber stretch is increased (yielding higher crystallinity and molecular orientation), so are properties such as tensile strength and initial modulus. At the same time, ultimate extensibility, elongation is usually reduced. An increase of molecular weight further increases the tensile properties, modulus, and elongation.

Typical stress strain curve for various polyester fibers are shown in Figure 2.2. It can be seen that the filament represented by curve C has a much higher initial modulus than the regular tenacity staple shown in curve D. High tenacity filament and staple (curve A and B) have very high breaking strengths and module, but relatively low elongations. Partially oriented yarn (POY) and spun filament yarns, exhibit low strength but very high elongation (curve E). [8]

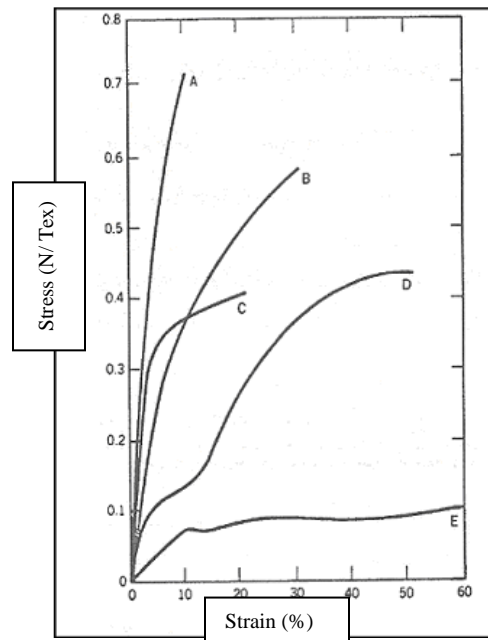


Figure 2. 2: Typical stress strain curve for PET fibers. (A-High tenacity filament, B-High tenacity staple, C-regular tenacity filament, D-regular tenacity staple, E-POY filament)

2.5 Bicomponent Fibers

The main objective in producing bicomponent fibers is to exploit capabilities not existing in either polymer alone. By this technique, it is possible to produce fibers of any cross sectional shape or geometry that can be imagined. Bicomponent fibers are commonly

classified by their fiber cross section structures as side-by-side, sheath-core, islands-in-the-sea and citrus fibers or segmented-pie cross section types.

In the current project the goal was to investigate abrasion and pilling resistance of nonwoven fabrics with three types of bicomponent fibers: Islands-in-the-Sea, Trilobal, and Segmented Pie structures. [10]

Islands-in-the-Sea- these are also called Matrix-Fibril. Technically these are complicated structures to make and use. In cross section, they are areas of one polymer in a matrix of a second polymer. These types of bicomponent structures facilitate the generation of micro denier fibers. The ‘islands’ are usually a melt spinnable polymer such as nylon, polyester or polypropylene. The finest denier that can be obtained normally is below 0.1denier (Figure 2.3). Basically, these fibers are spun from the mixture of two polymers in the required proportion; where one polymer is suspended in droplet form in the second melt. An important feature in production of matrix-fibril fibers is the necessity for forced cooling of the fiber immediately below the spinneret orifices. Different spinnability of the two components would almost disable the spinnability of the mixture, except for low concentration mixtures (less than 20%). [10]

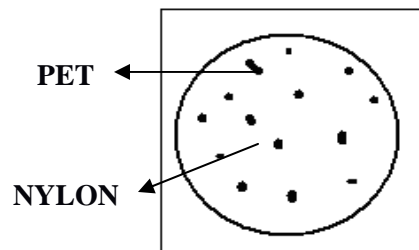


Figure 2. 3: Cross and Longitudinal Section of Island in the Sea Bicomponent Fibers

Segmented Pie- this structure as shown in Figure 2.4 is commonly referred to as "segmented pie structure". Alternate pie or wedges are made of nylon and polyester. The fiber contains around 16 segments in this picture. The fibers are made into a web and the fiber web is passed through a high-pressure jet of air or water to split the fibers. This splitting and entanglement makes the resultant fabric more strong. [10]

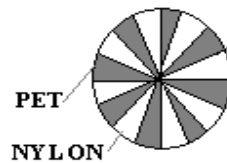


Figure 2. 4: Segmented pie structure

Sometimes, it becomes very difficult to card this type of fiber because of its different modulus properties. In order to overcome this problem their structure is altered as in Figure 2.5 and Figure 2.6.

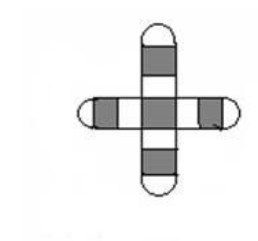


Figure 2. 5: Segmented Cross structure

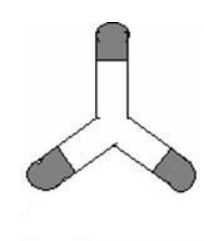


Figure 2. 6: Tipped Trilobal Structure

The purpose of blending is either to improve process ability or to obtain materials suitable for specific needs by tailoring one or more properties with minimum sacrifice in other properties.

The behavior of bicomponents may be expected to depend on the individual properties of the components in the blend, their relative proportions, degree of heterogeneity and the properties of the interface between the components. [10]

2.6 Abrasion of Nonwoven

The measurement of the resistance to abrasion of textile fabrics is very complex. The resistance to abrasion of nonwovens is affected by many factors that include the inherent mechanical properties of the fibers; the dimensions of the fibers; the blends of fibers, the construction of the fabrics; the type, kind, and amount of treatment added to the fibers, or fabric; the nature of the abradant; the variable action of the abradant over the specimen area abraded; the tension on the specimen; the pressure between the specimen and the abradant; and the dimensional changes in the specimen. [1]

Abrasion can result in four effects on appearance:

- ▶ **Crocking:** is the transfer of color from one fabric to another during abrasion.
- ▶ **Frosting:** is the change of the fabric color by localized abrasion.
- ▶ **Hole**
- ▶ **Pilling**

These effects are considered defects.

2.6.1 Pilling

Gintis and Mead pointed out that a loose fiber held at one end would quickly align itself with the abrading force, which thereby would minimize the effect on it. Also, it seems reasonable to assume that a free foreign fiber or a fractured fuzz fiber rolling around in the fuzz array would be likely to snarl up with fixed fuzz fibers and initiate the entanglement process. As soon as two fuzz fibers become entangled, their ability to align themselves with the abrading force is restricted, and considerably greater forces can be exerted on them.

It seems probable that such a discontinuity in bending modulus along the fiber length would encourage a flailing or lashing action during rubbing and that the resulting inter-fiber contact would more easily convert into permanent entanglement due to the hinge action of the fatigue zones.

Once two well-separated fuzz fibers have joined up by entanglement, the interaction between the abradant and these fibers becomes more effective. They can no longer align themselves with the force, and rolling and twist-snarling lead to greater entanglement, or sometimes to disentanglement.

As the pill body tightens and the anchor tips become firmly locked into the structure, increasing loads are placed on the anchors because the fibers can no longer align themselves with the frictional forces. As the abradant moves across the fabric, the pill slides or rolls with it until it is restrained by tensile forces in the tightest anchors.

The pull-out mechanism provides a source of fiber for pill growth that is independent of the adjacent-fiber structure, and, in addition, it makes the pill more mobile and increases the probability of adjacent-fiber pick-up. Clearly, tight fabrics structure leads to low pull-out and restricted pill growth and, for fibers with high tensile strengths, the pills that form are likely to become immobile and remain on the fabric surface without wearing off.

The reduced bending modulus of the fatigue zones enables the fiber to develop much smaller bending radii within the pill body, and, as the anchor fatigue rolls-up into the pill core, the morphology of the pill changes. [4]

Pills vary appreciably in size and appearance and depend on the presence of lint and degree of color contrast. These factors are not evaluated when pilling is rated solely on the number of pills. The development of pills may be accompanied by other surface phenomena such as loss of cover, color change, or the development of fuzz. Since the overall acceptability of a specific fabric is dependent on both the characteristics of the pills and the other factors affecting surface appearance, it is suggested that fabrics tested in the laboratory be evaluated subjectively with regard to their acceptability and not rated solely on the number of pills developed. A series of standards, based on graduated degrees of surface change of the fabric type being tested, may be set up to provide a basis for subjective ratings. The visual standards are most advantageous when the laboratory test specimens correlate closely in appearance with worn fabrics and show a similar ratio of pills to fuzz. [1]

Formation of fuzz and pill in nonwoven fabrics are extensively depends on:

- ▶ Raw Material (Elongation, Tensile strength, Shape of cross section, Diameter)
- ▶ Fabrics Parameters
- ▶ Bonding Techniques
- ▶ Bonding Parameters
- ▶ Testing Technique

2.6.2 Pilling is promoted by a number of factors: [2]

- 1- Pill formation rate—pill formation is a dynamic process in which pills are constantly formed and wear off. If the formation rate is greater than the break-off rate, then pills build-up on the surface.
- 2- The longer the staple length, the lower the pilling tendency, because there are fewer fiber ends protruding per unit area.
- 3- Coarser fibers are more rigid and hence they have a lower tendency to pill.
- 4- A circular cross section with smooth fiber surface allows the fiber to migrate to the surface of a fabric and form pills. Irregular cross sections reduce pilling.
- 5- Low tenacity fiber will increase pill wear-off rate.
- 6- In polyester blends, the higher the polyester content, the more pilling occurs.

Fuzz formation may be affected by friction, stiffness, breaking strength and abrasion resistance. Shape, fineness, stiffness, recovery, friction and elongation influence entanglement of fibers. After the pills have been formed, their rate of wear-off can affect the fabric appearance. Wear-off is a function of fiber breaking strength and flex life. However, spinning low molecular weight linear PET fiber is difficult. As the molecular weight is reduced, the melt viscosity decreases and a uniform fiber with satisfactory continuity of spinning cannot be produced. Melt viscosity can be raised by the addition of a cross-linking compound, which is prone to hydroxyl groups. Another property, important especially to the apparel industry, is crimp stability or crimp compression. Generally, the tighter the packing of molecular chains, the stiffer and more mechanically resistant the fiber is. Crimp stability of the fiber can be improved with an increase in heating temperature. In addition, crimp compression of the fiber can be decreased by increasing draw ratio when the fiber is produced. [6]

3 Discussion of Experimental Methodology

3.1 General Information

A specific objective of this project was to investigate the abrasion and pilling resistance of different nonwoven fabrics in three groups which are classified according to the fibers used in each group.

Since the test results show that each tester has a different sensitivity for different factors, it is recommend that at least 2 different testers be used in order to obtain reliable results, one of these being the Martindale while the other one is Random Tumble Tester.

Ball (1938) indicated eight measurable changes in textile materials as a result of abrasion:

- ▶ Tensile strength
- ▶ Thickness
- ▶ Weight
- ▶ Surface luster
- ▶ Air permeability
- ▶ Color
- ▶ Character of abraded material
- ▶ Appearance of surface

INDA introduced three machines (Martindale, Random Tumble, and Rotary testers) for evaluating abrasion and pilling resistance of nonwoven fabrics.

Short descriptions of these three test methods and how abrasion and pilling resistance of nonwoven fabrics were measured in each method are discussed below:

ASTM – D 4966 (Martindale Abrasion Tester Method):

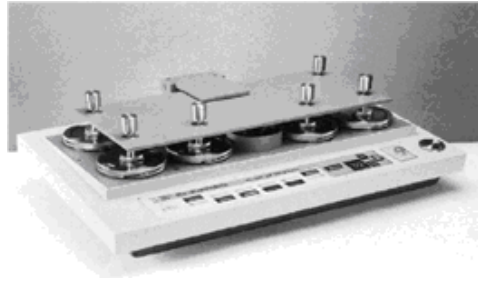


Figure 3. 1: Martindale Abrasion Tester

This test method covers the determination of the abrasion resistance of textile and nonwoven fabrics using the Martindale abrasion tester. Fabrics of all types may be tested by this method (Figure 3.1).

Fabrics are mounted on the Martindale Tester, and the face of the test specimen is rubbed against the face of the standard mounted fabric in the form of a geometric figure. The rubbing action is such that the fabric is rubbed over its whole surface in many different directions. (Lissajous pattern, specimen is abraded uniformly at every point). (Fig 3.2)

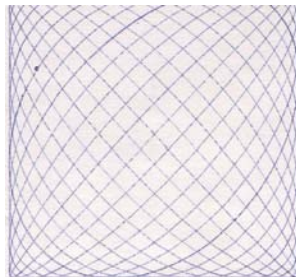


Figure 3. 2: Lissajous pattern

The resistance to abrasion in this test method also is affected greatly by the conditions of the tests, such as the nature of abradant; variable action of the abradant over the area of specimen abraded, the tension on the specimen, the pressure between the specimen and abradant, and the dimensional changes in the specimen. All samples were conditioned weighed before and after abrasion, and abrasion was assessed in terms of weight loss. Pilling was assessed both by using a visual rating and using an imaging system.

ASTM – D 3512 (Random Tumble Pilling Tester):



Figure 3.3: Random Tumble Pilling Tester

This test method covers the resistance to the formation of pills and other related surface changes on textile fabrics using the random tumble pilling tester. The procedure is generally applicable to all types of woven, knitted, and nonwoven fabrics (Figure 3.3).

Pilling and other changes in surface appearance, such as fuzzing, that occur in normal wear are simulated on a laboratory testing machine. Pills are caused to form on fabric by a random rubbing action produced by tumbling specimens in a cylindrical test chamber lined with a mildly abrasive material.

The degree of fabric pilling is evaluated by comparison of the tested specimens with visual standards that may be actual fabrics, or photographs of fabrics, showing a range of pilling resistance. The observed resistance to pilling is reported using an arbitrary rating scale. All samples were weighed before and after abrasion, and pilling resistance was determined using with both optical and visual methods.

ASTM – D 3884 – RPDM (Rotary Platform, Double Head Method):



Figure 3. 4: Rotary Platform, Double Head Method

This guide covers the determination of the abrasion resistance of textile fabrics using the rotary platform, double-head tester (RPDH). (Figure 3.4)

In this test, usually called the Tabor abrasion test, a specimen is abraded using rotary rubbing action under controlled conditions of pressure and abrasive action. The test specimen, mounted on a platform, turns on a vertical axis, against the sliding rotation of two abrading wheels. 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 .

Uncontrolled manufacturing or finishing variations occurring within a fabric or within lots of the same style of fabric can be detected satisfactorily with the RPDH tester.

Counting the pills and weighing their number with respect to their size and contrast, as a combined measure of pilling resistance, is not recommended in this method, because of the excessive time required for counting, sizing, and calculation. All samples were weighted before and after abrasion and abrasion resistance was determined base on the weight loss.

All the test methods and instruments that have been developed for abrasion resistance may show a high degree of variability in results obtained by different operators and in different laboratories; however, they represent the methods most widely used in the industry, because there is a definite need for measuring the relative resistance to abrasion.

[1]

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. [1]

These general observations apply to all types of fabrics, including woven, nonwoven, and knit apparel fabrics, household fabrics, industrial fabrics, and floor coverings. It is not surprising, therefore, to find that there are many different types of abrasion testing machines, abrasants, testing conditions, testing procedures, methods of evaluation of abrasion resistance, and interpretation of results. [1]

3.2 Experimental Design

The experiment consisted of 15 samples in three different categories depending on the fibers shape (Segmented, Island-in-the-Sea, and Trilobal). Table 1, 2, 3 lists the material characteristics recommended for measurement during this study.

Table 3. 1: Nonwoven Fabrics with Segmented Pie Structure Filament (N used for Nylon)

	Fiber	Cross Shape	gsm	Bonding
1	PET/N-25/75	Segmented 8 S/P	160	Spunbond/Hydro
2	PET/N-50/50	Segmented 8 S/P	170	Spunbond/Hydro
3	PET/N-75/25	Segmented 8 S/P	170	Spunbond/Hydro
4	PET/N-25/75	Segmented 16 S/P	190	Spunbond/Hydro
5	PET/N-50/50	Segmented 16 S/P	210	Spunbond/Hydro
6	PET/N-75/25	Segmented 16 S/P	190	Spunbond/Hydro
7	PET/N-50/50	Segmented 32 S/P	170	Spunbond/Hydro
8	PET/N-50/50	Segmented 64 S/P	170	Spunbond/Hydro
9	PET/N-75/25	Segmented 64 S/P	160	Spunbond/Hydro

Table 3. 2: Nonwoven Fabrics with Islands in the Sea Filament

	Fiber	Cross Shape	gsm	Bonding
1	PET/Nylon 60/40	Island-Sea/37	150	Spunbond/Hydro
2	PET/Nylon 60/40	Island-Sea/19	150	Spunbond/Hydro
3	PET/Nylon 60/40	Island-Sea/7	150	Spunbond/Hydro

Table 3. 3: Nonwoven Fabrics with Tipped Trilobal Filament

	Fiber	Cross Shape	gsm	Bonding
1	PET/Nylon 50/50	Trilobal Nylon (core)	135	Spunbond/Hydro
2	PET/Nylon 50/50	Trilobal PET (core)	135	Spunbond/Hydro

3.3 Measuring Methods

Many test methods have been developed to evaluate pilling, but none can detect pills conveniently and objectively or describe them comprehensively, especially for nonwovens. Objective and reliable methods are needed to estimate the effects of both fabric structure and abrasion related variables on fuzz and pill formation. Image analysis techniques and the historic method of comparing pill images with the corresponding images of a set of standard photographs have been used in an attempt to determine the pill grade. The software interface enables the operator to view a live image of the test sample and the respective pilling characterization data all on one screen.

The software can setup to output the data in comparison to any pictorial standard. This method uses a laser with an x – y stage to measure the distance from the laser to the fabric surface, thereby creating a height map (image) of the surface. A major advantage of this method is that it does not depend on illumination and measures the true surface character of the fabric. The method is however, slower and more expensive than most optical systems that are currently available. To objectively identify and estimate both fuzzing and pilling, a method has been developed that is capable of assessing changes easily and reliably.

This is accomplished by controlling the angle of incident light such that only objects raised from the surface are illuminated.

The laser method determines the geometric figures of the pill objects, including density (Referring to the total number of pill elements in the same area of the sample) and pill element size (pill area fraction), expressed as a percentage of the total area examined.

The system uses a ring light and a cylindrical reflector to illuminate the sample by transmitting a narrow band of light at the desired angle. The light angle and the distribution can be modified by changing the radius of the cylindrical reflector and/or the distance of the ring light to the sample. All sample were analyzed with Light Intensity 50, Brightness 0 and Contrast 100 (Fig 3.5). [12]

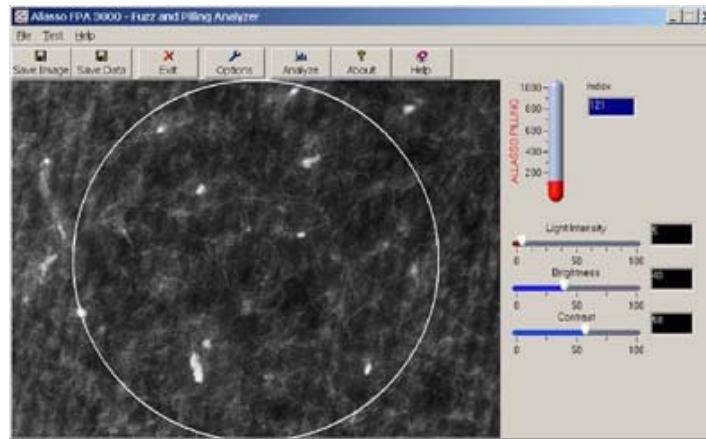


Figure 3. 5: Allaso Pilling Analyzer [12]

Additionally, pilling test specimens were evaluated by subjective comparison with standard picture of such specimens. This method is based on pill counts. Visual Standard method was used to recognize the difference between Allaso Pilling Analyzer and conventional method. Test specimens were evaluated by assigning to them a numerical rating of 1 to 5 which indicates their overall pilling in comparison with the standard. The average rating of each specimen reported by three evaluators.

- 5- No Pilling
- 4- Slight Pilling
- 3- Moderate Pilling
- 2- Severe Pilling
- 1- Very Severe Pilling

The difference between optical and visual techniques is that optical method (Allaso Pilling Analyzer) is sensitive to both fuzzes and pills, so it shows same result between two fabrics when one of them has more fuzzes and the other one has more pills. The best way to investigate pill resistance of a nonwoven fabric is to evaluate all abraded fabrics with both techniques (Optical and Visual ratings), as was done in this project.

4 Result and Discussion

Each of 15 fabrics in three groups was tested using the Martindale, and the Random testers and data was collected which could be used to assess abrasion and pilling resistance. The methods that were used for measuring abrasion and pilling resistance of fabrics are measuring weight loss, optical rating with Allaso Pilling Analyzer, and visual rating (comparing with standard pictures). The other physical parameters (peak load (lb), elongation (mm), initial modulus) were evaluated before abrading the samples. Each tester gave different information about abrasion and pilling for the same fabric. The aim of this project was to compare fabrics of each group with each other and hopefully determine the key factors influencing abrasion resistance.

4.1 Segmented Fiber

Nine fabric samples were compared in Martindale and Random testers. In this study all fabrics were made with segmented fibers with different percentage of polyester and nylon. The fabrics had been spunbonded and hydroentangled on both sides with a speed of 10 m/s [12]. The individual test results can be found in the Table 4.1.

Table 4. 1: Properties of fabrics made from segmented fibers

	FABRIC PARAMETERS			MARTINDALE 2000 CYCLES			MARTINDALE 6000 CYCLES			RANDOM TEST		
	PET/N (%)	No. Segment	g / m^2	WGT LOSS%	PILL RATING	PILL OPTICAL RATING	WGT LOSS%	PILL RATING	PILL OPTICAL RATING	WGT LOSS%	PILL RATING	PILL OPTICAL RATING
1	25/75	8 S/P	160	-1.18	2.5	211	0.917	1	221	0.312	4.75	123
2	50/50	8 S/P	170	-0.91	4.5	185	-0.58	3	161	0.28	4.5	164
3	75/25	8 S/P	170	-0.64	4.25	82	-0.45	4	219	0.511	5	135
4	25/75	16 S/P	190	0.20	4.5	200	0.121	3.5	278	0.877	5	125
5	50/50	16 S/P	210	0.08	4	254	0.503	4.5	235	0.024	5	120
6	75/25	16 S/P	190	-0.81	4	154	-0.97	2	197	0.122	5	166
7	50/50	32 S/P	170	-0.79	1	286	-1.27	1	245	0.218	3.5	203
8	50/50	64 S/P	170	-0.70	1	289	-1.2	1	230	0.67	3.5	240
9	75/25	64 S/P	160	-0.46	1.75	255	-5.69	1.5	200	0.58	4.5	141

4.2 Islands-in-the-Sea Fibers

Three fabric samples were compared in Martindale and Random testers. In this series the fabrics were made from Islands-in-the-Sea fibers with different percentage of polyester/nylon and different number of islands. All islands are polyester and seas are nylon66. They were spunbonded and hydroentangled on both sides with a speed of 10 m/s. The individual test results can be found in the Table 4.2.

Table 4. 2: Properties of fabrics made from Islands in the Sea fibers

	FABRIC PARAMETERS			MARTINDALE 2000 CYCLES			MARTINDALE 6000 CYCLES			RANDOM TEST		
	PET/N (%)	No. Islands in Sea	g/m^2	WGT LOSS%	PILL RATING	PILL OPTICAL RATING	WGT LOSS%	PILL RATING	PILL OPTICAL RATING	WGT LOSS%	PILL RATING	PILL OPTICAL RATING
1	60/40	37	150	-0.75	1	258	33.92	1.5	202	-1.14	4	69
2	60/40	19	150	-1.18	2	228	0.404	1	344	-0.49	3.5	171
3	60/40	7	150	-0.92	3.5	141	-0.38	3.5	14	-0.18	3.5	67
4	60/40	37	200	-0.78	2	278	-0.35	1	195	-0.12	1	250
5	60/40	19	200	-0.97	1	282	-0.79	2	250	0.041	3	245
6	80/20	19	200	-0.16	5	117	0.735	5	244	-0.16	5	137

4.3 Trilobal Fibers

Three fabric samples were compared in Martindale and Random testers. All fabrics were made from Trilobal fibers with different core (Polyester or Nylon). They were spunbonded and hydroentangled on both sides with a speed of 10 m/s. The individual test results can be found in the Table 4.3.

Table 4. 3: Properties of fabrics made from Trilobal fibers

	FABRIC PARAMETERS			MARTINDALE 2000 CYCLES			MARTINDALE 6000 CYCLES			RANDOM TEST		
	PET/N (%)	Trriped Trilobal	gsm	WGT LOSS%	PILL RATING	PILL OPTICAL RATING	WGT LOSS%	PILL RATING	PILL OPTICAL RATING	WGT LOSS%	PILL RATING	PILL OPTICAL RATING
1	50/50	N Core	135	-1.38	3.5	232	-0.12	3	235	0.445	4.5	192
2	50/50	P Core	135	-1.00	2	182	-0.44	1	213	0.064	4	196

4.4 Abrasion and Pilling Resistance

Abrasion and pilling resistance were assessed using Martindale and Random testers. In Martindale test all samples were evaluated at 2000 and 6000 cycles; in the Random tester all samples were evaluated after 30 minutes running. Comparison of weight loss and pill formation versus cycles has been investigated.

There exist two essentially different classes of factors which govern the abrasion resistance of nonwoven structures: the inherent abrasion resistance of the material substantively, and the geometry of the composite structure, which may be characterized as the “form factor”.

Fabric construction (form factor) and fiber type (inherent abrasion resistance) play a significant role in abrasion resistance of nonwoven fabrics. When performing the abrasion tests, fibers at the fabric surface are mechanically aggravated. The looser the fabric construction the easier it is for surface fibers to move. Tighter fabric constructions hold the fibers in place and restrict fiber movement. As all samples in each group were hydroentangled in the same process, the fibers’ characteristics play the most important roles in structure of fabrics. In segmented, islands in the sea, and trilobal fibers if fibrils split very well, they will contribute in hydroentangle bonding process better and fibers will entangle better, so the fabric’s construction would be tighter. Fiber splitting depends on percentage of polyester and nylon, number of segments or islands in the sea, and in trilobal fibers which one (polyester or nylon) is in the core.

If the hydroentangling process promotes splitting and bonding then the less fiber splitting, the more fuzzy fabric would be. In addition these factors also affect the bending rigidity of fibers.

If fibers are not split well, they will have higher bending rigidity because their count would be bigger than split fibers. So they will not be entangled as much as split fibers.

Fibers in fabrics constructed from weaker fibers tend to break away from the fabric surface before they form pills. Fabrics constructed from stronger fibers tend to form pills on the fabric surface. Fabric with better split fibers has stronger structure, less fuzz, and form less pills.

4.4.1 Segmented Fiber

4.4.1.1 8 Segments

Figure 4.1:

Before Abrasion

Figure 4.2:

Martindale
(2000 Cycles)

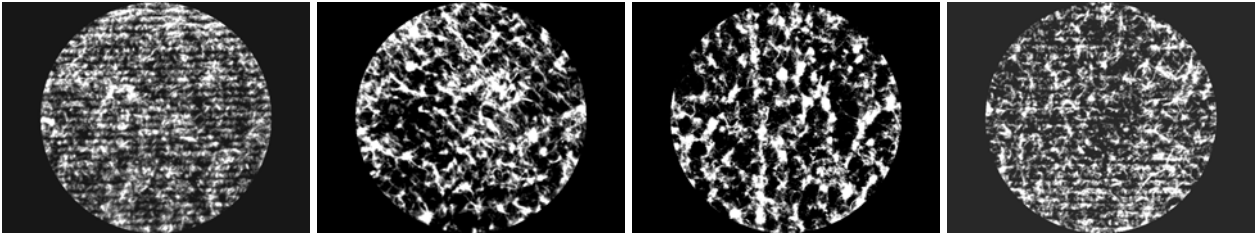
Figure 4.3:

Martindale
(6000 Cycles)

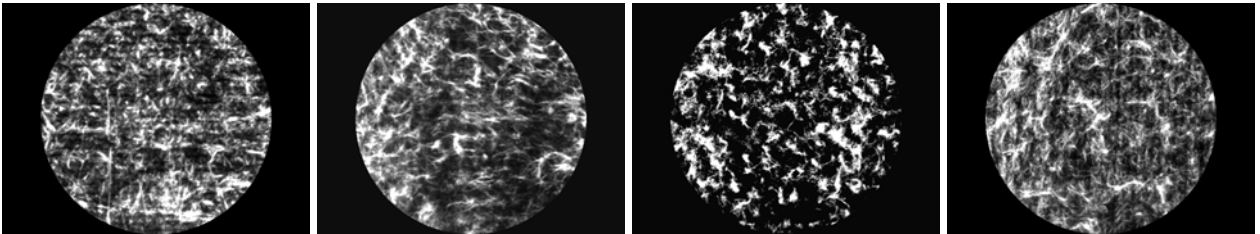
Figure 4.4:

Random Test
(30 min)

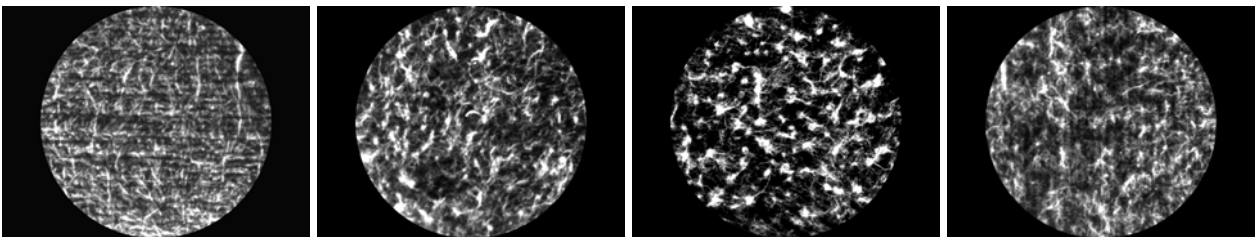
25PET/75N



50PET/50N



75PET/25N



Figures 4.1-4.4 show samples of 8 segments prior to and after specific abrasion. Figure 4.1 shows the samples before abrasion. Figure 4.2 and 4.3 show the samples after 2000 and 6000 cycles respectively on the Martindale abrasion tester. Figure 4.4 shows abraded fabrics after 30 minutes on the Random tester.

Properties of Initial Sample Material

From Figure 4.1 (before abrasion), it is apparent that the 25PET/75N blend has the clearest defined texture. Hydroentangled lines are also most obvious in this fabric, followed by 75PET/25N and 50PET/50N blends, in that order. The Fabric produced from 50PET/50N blend has the fuzziest appearance.

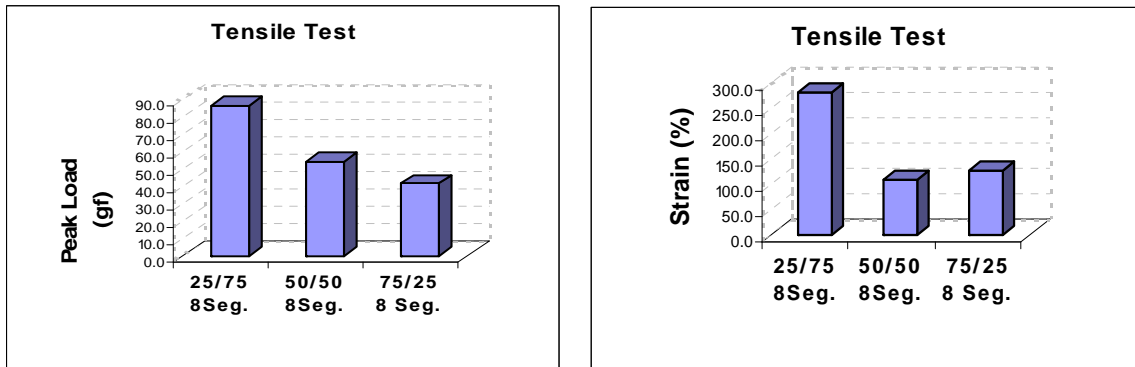
Tensile test of 8 segmented fibers (Fig. 4.5a) shows that 25PET/75N fiber is the strongest, followed by 50PET/50N and 75PET/25N fibers. Also 25PET/75N fiber clearly has the highest elongation.[11]

When the properties of fabrics containing these fibers are evaluated a different picture emerges. As Figure 4.6 shows, fabric with 50PET/50N blend is the strongest fabric structure in the machine direction, followed by fabrics with 75PET/25N and 25PET/75N blends, in that order. Additionally the 50PET/50N blend fabric also has the highest elongation in machine direction.

The only reason that weakest fibers make strongest nonwoven fabrics is that 50PET/50N-8Segments fibers were split better than 25PET/75N-8Segments, and separated fibrils entangled in hydroentangle bonding process better than non-split fibers.

These results indicate that in the same bonding process, the number of segments and percentage of each component has the most effect on fiber splitting and fabric structure.

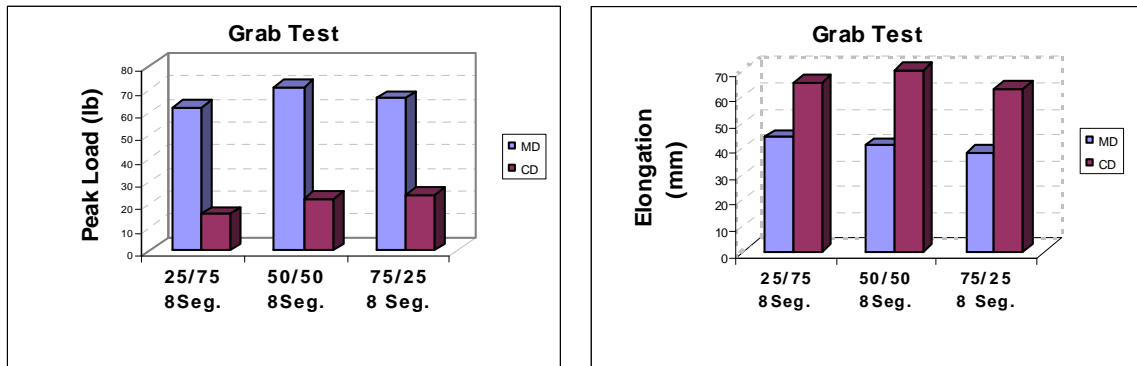
It is clear in 25PET/75N that the number of nylon fibrils is the same as polyester fibrils but the linear density of nylon fibrils is almost 3 times that of the polyester fibrils. The number and the linear density of nylon fibrils are the same as polyester fibrils in 50PET/50N, and the linear density of the polyester fibrils are 3 times that of the nylon fibrils in 75PET/25N blend.



(a) Peak Load

(b) Strain

Figure 4.5: Tensile Test for 8 Segmented Fibers



(a) Peak Load

(b) Elongation

Figure 4.6: Grab Test for Fabrics Produced from 8 Segmented Fibers

Figure 4.7 depicts the Load-Elongation curves for all three blends in 8-Segmented group. As shown in (a) the initial modulus of 25PET/75N combination is the highest, followed by 50PET/50N and 75PET/25N combinations, respectively. It is obvious from Figures 4.5 and 4.7, that fabrics made from stronger fibers have the highest initial modulus.

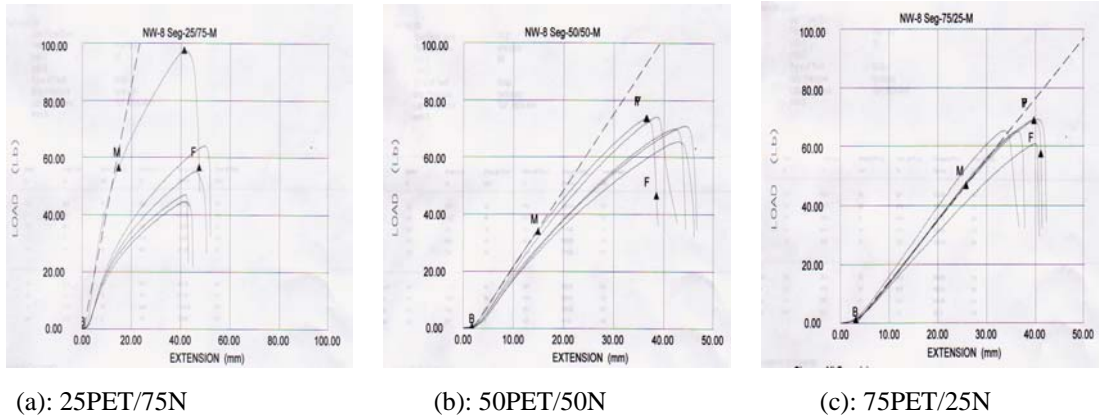


Figure 4.7: Load (lb)-Extension (mm) diagrams of 8 Segments Group

Results after Abrasion

In Figure 4.2 (abrasion after 2000 cycles) the differences between the samples appear to be obvious. The 25PET/75N blend has higher tendency to pill compared to the other two blends. It seems reasonable to assume that pills formed more on the 25PET/75N fabrics because of less fiber splitting leading to the most open fabric structure. Additionally this fabric was also made from the fibers which exhibited the highest initial tenacity.

Figure 4.8a (Optical Ranking) and Figure 4.8b (Visual Ranking) [Section 3.3] seem to confirm this, since the first sample has the most pills, followed by 50PET/50N and the 75PET/25N blends. The 75PET/25N blend has the fuzziest appearance. This result seems to indicate that fuzz formation alone is not the main factor in pill formation.

Figure 4.10 confirms this because this fabric gained more weight and that means the rate of pill formation in this fabric is greater than the rate of pill wear-off.

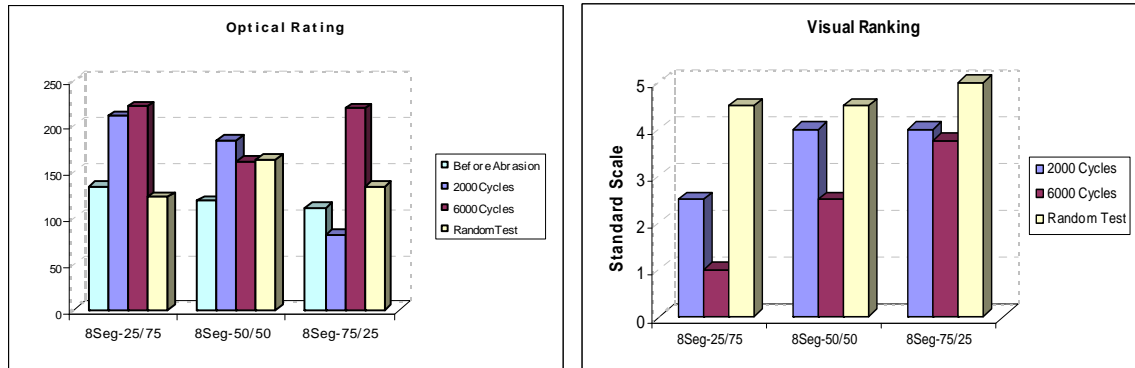
Figure 4.9 shows the comparison of the data observed from the optical assessment (using software) and visual assessment. It is clear that while there is a lot of deviation in the trend, in general a higher optical rating (bad pilling) is achieved for fabrics with a low visual rating (bad pilling). As indicated earlier the difference in these results could be due to the fact that the software always tends to be greatly influenced by surface fuzz-which is not true of the visual assessment.

Figure 4.10 shows that the 75PET/25N blend gained less weight than the others after 2000 cycles. It was observed during the abrasion test that the sample was actually shedding fibers and pills. This could be seen because they were blue fibers on opposed to the white abradant fabrics. It seemed probable that wool abradant debris was influencing the pill formation. And it is also clear however that several of the fabrics actually gained weight during abrasion. The only possible explanation for this phenomenon is that in addition to the fiber loss due to abrasion there was also a fiber gain due to transfer of fiber from the abradant on to the test sample. The transferred fibers become entangled with the fibers on the sample of the test specimen.

From Figure 4.3 (abrasion after 6000 cycles) it is evident that the 25PET/75N blend has the highest number of pills, and the sizes of the pills are bigger than after 2000 cycles, followed by 50PET/50N and the 75PET/25N blends.

* As can be seen from many of the results from the Martindale, the weight of the sample being tested, actually increased after abrasion. Thus in Figure 4.10 the positive values represent weight loss and the negative values indicate weight gain.

According to Cooke (1985), if the interfiber forces are reduced just enough to allow some pull-out but not enough to increase the total fuzz formation, then the total numbers of pills will be unchanged but the average pill mass will increase. In this case the pill will be larger. From Figure 4.10, it is obvious that 25PET/75N blend lost most weight (0.0016 g).



(a) Pill Optical Ranking

(b) Pill Visually Ranking

Figure 4.8: Pill Ranking (Optical & Visual)

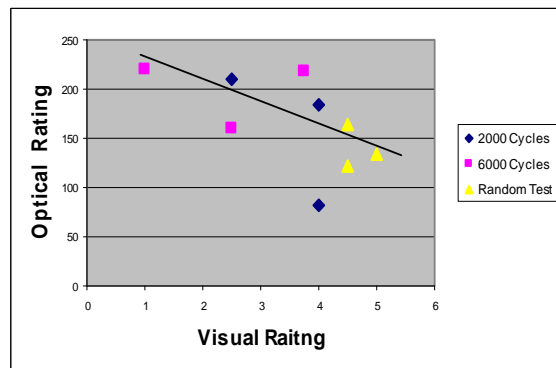


Figure 4.9: Comparing of Optical (software) & Visual assessment

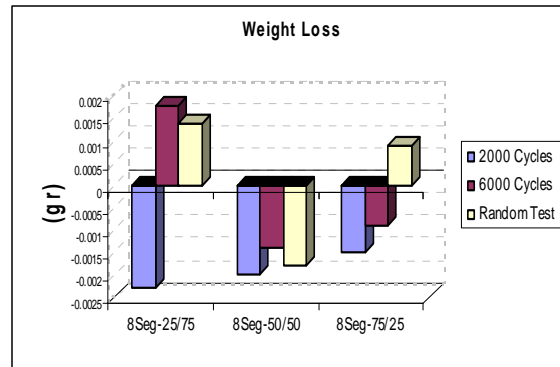


Figure 4.10: Weight loss for Fabrics with 8 Segmented Fibers

Figure 4.4 (after 30 min. in Random Tester) shows all samples are fuzzier after abrasion, and there is no obvious pill on the surface of fabrics. From Figure 4.10 it can be seen that after the Random Test, 25PET/75N lost more weight than the other two fabrics.

These results clearly indicate that different testers may give different pilling results for the same fabric.

In 8-segmented group, the 25PET/75N blend has the most pill formation, and the rate of pill formation was much greater than the rate of pill wear-off for this fabric. The 50PET/50N has the strongest structure and 75PET/25N has the best abrasion resistance.

4.4.1.2 16 Segments

Figure 4.11:

Before Abrasion

Figure 4.12:

Martindale:
2000 Cycles

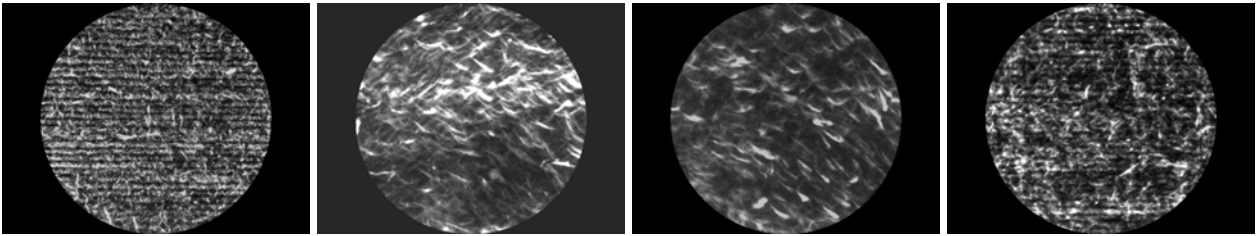
Figure 4.13:

Martindale:
6000 Cycles

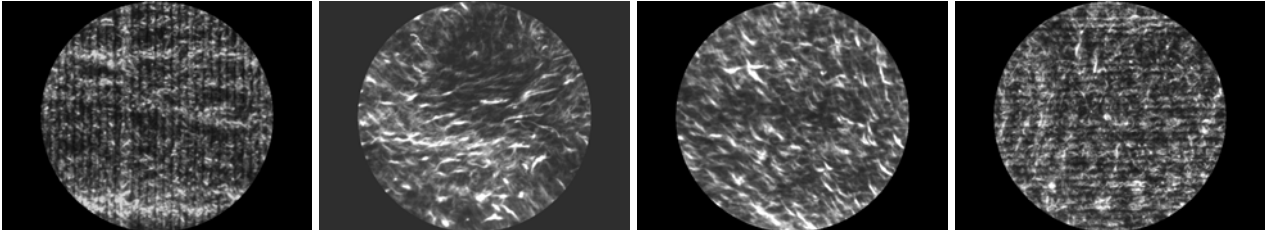
Figure 4.14:

Random Test:
30 min.

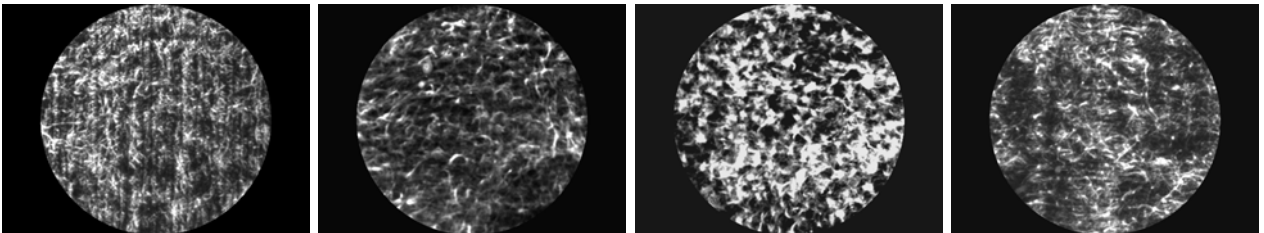
25PET/75N



50PET/50N



75PET/25N



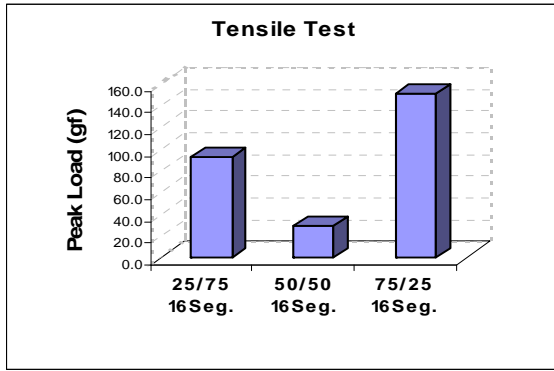
Figures 4.11-4.14 show samples of 16 segments prior to and after specific abrasion. Figure 4.11 shows the samples before abrasion. Figures 4.12 and 4.13 show the samples after 2000 and 6000 cycles respectively on the Martindale abrasion tester. Figure 4.14 shows abraded fabric after 30 minutes on the Random tester.

Properties of Initial Sample Material

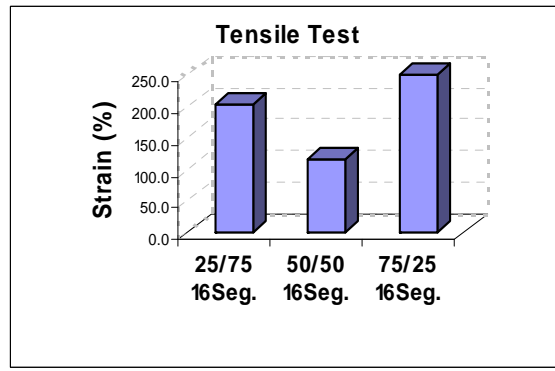
From Figure 4.11 (before abrasion), it is apparent that the textures of all three fabrics are different. Hydroentangled lines are most obvious in the 50PET/50N fabric, followed by 25PET/75N. Fabric produced from the 75PET/25N blend has the fuzziest appearance.

From Figure 4.15 (Tensile test of fibers), it is evident that 75PET/25N fiber is the strongest, followed by 25PET/75N and the 50PET/50N fibers [11]. Tensile test results of 16 segments fibers are in contrary to the 8 segments results where the 25PET/75N blend fiber was the strongest. So the number of segments plays a very important role in tensile test of segmented fibers. It is clear that in the 75PET/25N blend fibers the number of nylon fibrils is the same as polyester fibrils but the linear density of polyester fibrils is three times that nylon fibrils are. The number and the linear density of nylon fibrils is the same as polyester fibrils in 50PET/50N, and the linear density of the nylon fibrils is three times that of nylon fibrils in are 25PET/75N blend.

Figure 4.16 (Grab test of fabrics) shows, likes 8 segments fibers, that the weakest fibers (50PET/50N) made the strongest fabric. It is obvious that 50PET/50N-16 segment fibers were split better than the 75PET/25N-16 segment, which has the strongest fibers. As was mentioned in the previous section, the more fibers split, the stronger the structure of the fabric.

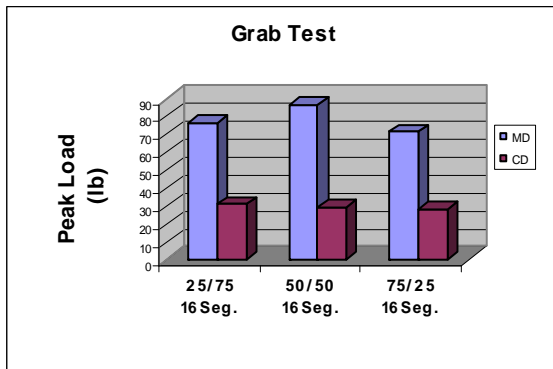


(a) Peak Load Chart for Fibers

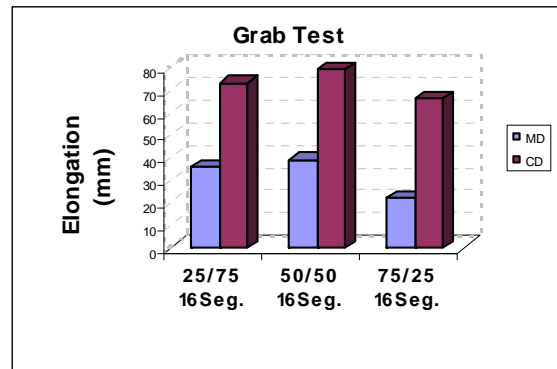


(b) Strain Chart for Fibers

Figure 4.15: Tensile Test for 16 Segmented Fibers



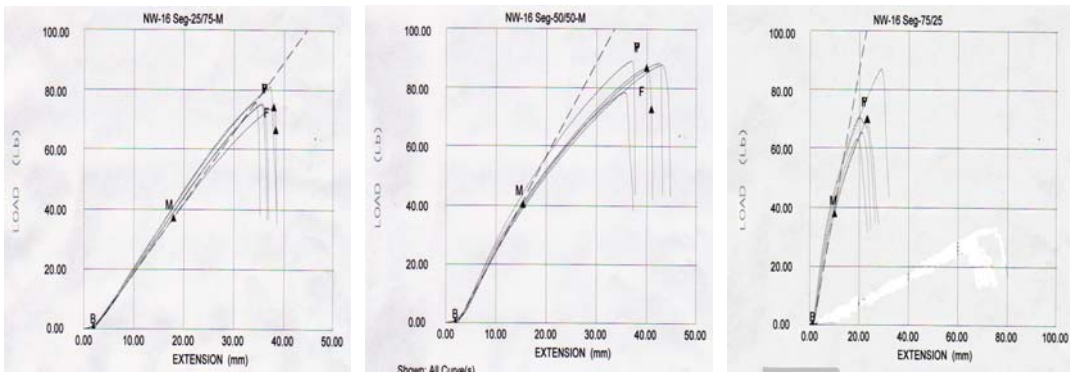
(a) Peak Load for Fabrics



(b) Elongation for Fabrics

Figure 4.16: Grab Test for Fabrics with 16 Segmented Fibers

Figure 4.17 depicts the Load-Elongation curves for all three blends in the 16-Segmented group. As shown in (c) the initial modulus of the 75PET/25N fabric is the greatest, followed by 50PET/50N and 25PET/75N fabrics, in that order. Like the 8 segments group the stronger the fiber, the higher the initial modulus of fabric.



(a): 25PET/75N

(b): 50PET/50N

(c): 75PET/25N

Figure 4.17: Load (lb)-Extension (mm) diagrams of 16 Segments Group

Abraded Results:

From Figure 4.12 (abrasion after 2000 cycles) there is no difference between 25PET/75N and 50PET/50N blend fabrics, because there are no obvious pills on either of them. Abrasion after 2000 cycles just made a lot of fuzz in the 25PET/75N and 50PET/50N fabrics. There are small pills on the 75PET/25N blend that are tied together like chains. As mentioned in chapter 3, the optical rating is more sensitive to fuzz than pills. In Figure 4.18 (Optical Ranking) after 2000 cycles, the 50PET/50N blend is the highest. But Figure 4.19 (Visual Rating) shows the 75PET/25N blend has the most pills. Figure 4.20 shows that unlike the other two fabrics the 75PET/25N fabric gained weight rather than losing it. Because of the loose fabric structure of 75PET/25N fabric, anchor pull-out occurred more than pill wear-off.

In Figure 4.13 (abrasion after 6000 cycles), it is evident that the 75PET/25N blend has the highest number of pills and the pills are bigger than after 2000 cycles and cover all of the abraded part. The 25PET/75N and 50PET/50N blends have no pills and are just fuzzy. From Figures 4.18 and 4.19, it is apparent that 75PET/25N has the most pills and the least fuzz.

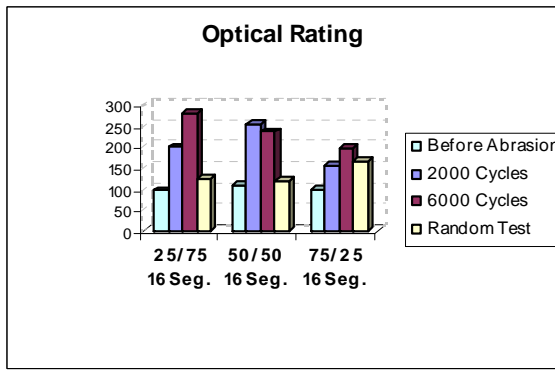


Figure 4.18: Pill Optical Ranking (with software)

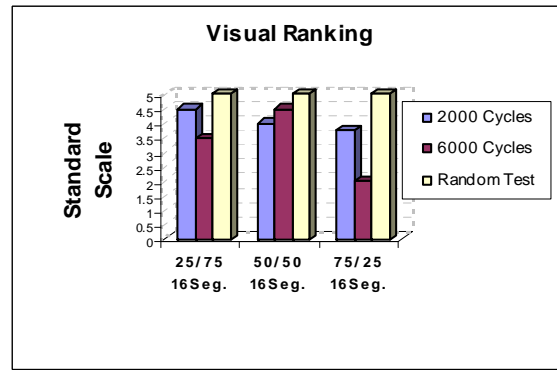


Figure 4.19: Pill Visually Ranking

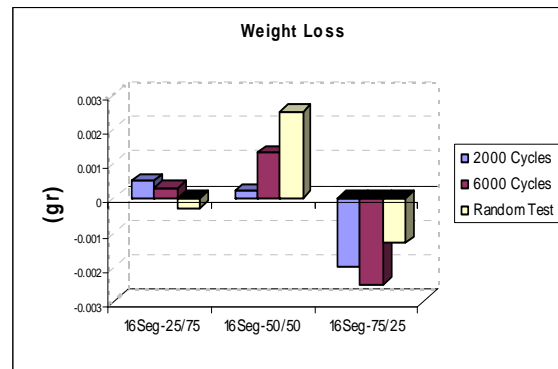


Figure 4.20: Weight loss for Fabrics with 16 Segmented Fibers

Figure 4.14 (after 30 min. in Random Tester) shows all samples are just fuzzier after abrasion, and there are no obvious pill on the surface of the fabrics. In 25PET/75N and 50PET/50N blends even hydroentangled lines are obvious after Random test. Figure 4.18 shows that the 75PET/25N blend is the fuzziest one. Figure 4.19 depicts that all samples have rank 5 which means no pill was formed. Figure 4.20 shows that after the Random Test, 50PET/50N fabric lost most weight in this group.

These results again indicate that different testers may give different pilling results for the same fabric.

In the 16-segmented group, the 75PET/25N blend fabric has the loosest fabric structure and most pill formation. The 50PET/50N fabric has the strongest structure as in the 8-Segmented group and 25PET/75N has the best abrasion resistance.

Comparing results of 8 segmented group with 16 segmented group, in the 8 segmented group the 25PET/75N fabric has the highest pilling grades and in 16 the segmented group the 75PET/25N fabric has the highest pill formation. Thus no trend can be drawn at this time to relate an increase in number of fiber segments to pill formation. But in both groups the 50PET/50N blend has the strongest structure.

4.4.1.3 32&64 Segments

Figure 4.21:

Before Abrasion

50PET/50N-32Seg

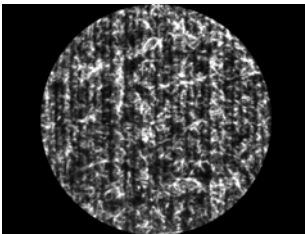


Figure 4.22:

Martindale:
2000 Cycles

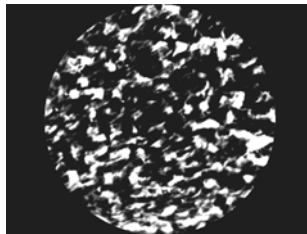


Figure 4.23:

Martindale:
6000 Cycles

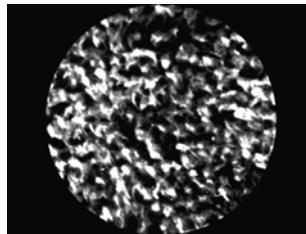
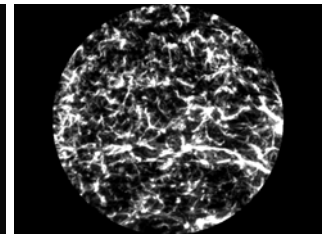
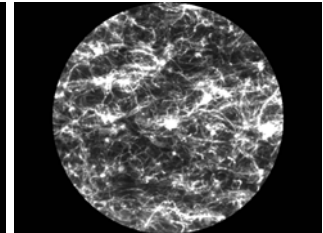
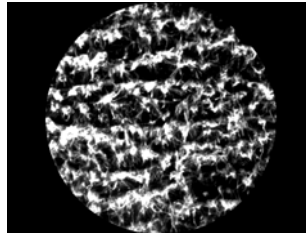
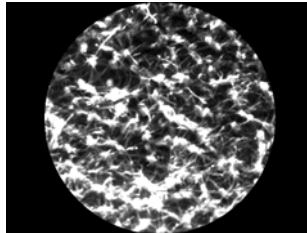
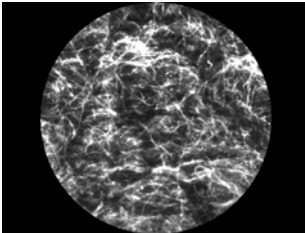


Figure 4.24:

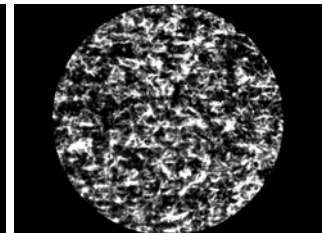
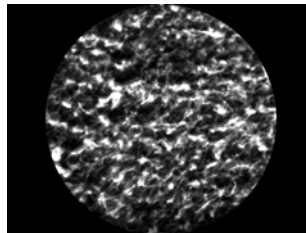
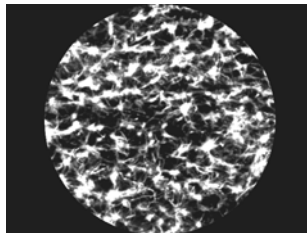
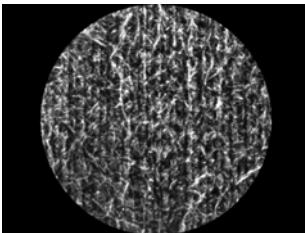
Random Test:
30 min.



50PET/50N-64Seg



75PET/25N-64Seg

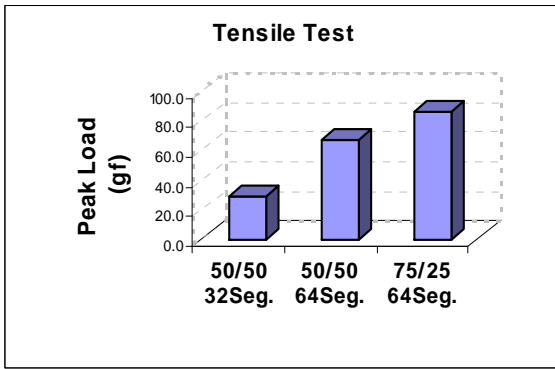


Figures 4.21-4.24 show samples of 32&64 segments, prior to and after specific abrasion. Figure 4.21 shows the samples before abrasion. Figure 4.22 and 4.23 show the samples after 2000 and 6000 cycles on the Martindale abrasion tester. Figure 4.24 shows abraded fabric after thirty (30) minutes on Random tester.

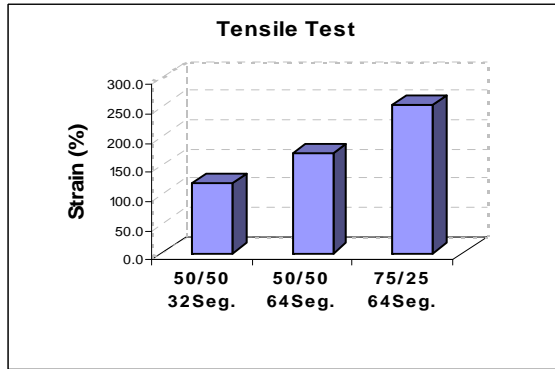
Properties of Initial Sample Material

From Figure 4.21 (before abrasion) the textures of all three fabrics are obvious. Hydroentangled lines are not as clear as for the 8 and 16 segments group. When compared to 8 and 16 segmented groups, this group has the fuzziest appearance. Fabric made from 50PET/50N-64 segment blend has the fuzziest appearance. The differences among these groups will be discussed in detail in the next section.

From Figure 4.25 (Tensile test of fibers), it is evident that the 75PET/25N-64 segment fiber is the strongest, followed by 50PET/50N-64 segmented and the 50PET/50N-32 segmented fibers [11]. Tensile tests of different segmented fibers revealed that the higher the number of segments, the stronger the fiber. So number of segments plays a significantly important role in tensile test. But as Figure 4.26 (Grab test of fabrics) shows fabric with the 50PET/50N-32 segmented blend has the strongest structure, followed by fabrics with 50PET/50N-64 segment and 75PET/25N-64 segment blends, in that order. Like 8 and 16 segmented fibers, the weakest fibers made the strongest fabric. The 50PET/50N-32 segmented fibers were split better than 64 segmented fibers, but comparing with other groups (8 and 16 segments) fabrics of this group has the weakest structure. So fibers in this group were split less than other groups, and will form more pills.

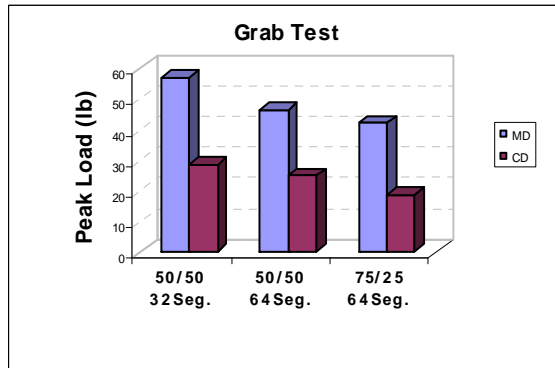


(a) Peak Load Chart for fibers

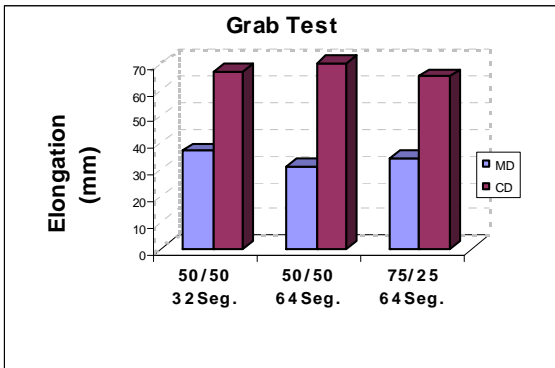


(b) Strain Chart for Fibers

Figure 4.25: Tensile Test for Fibers with 32&64 segments



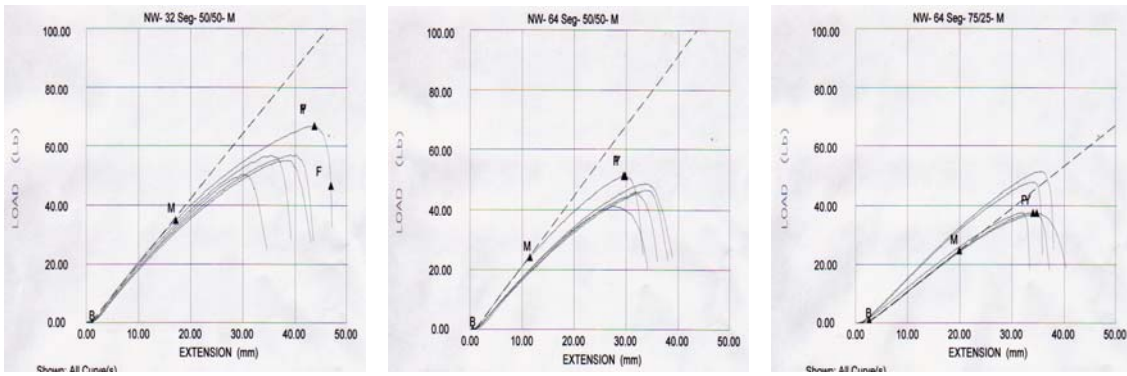
(a) Tensile Test for Fabrics



(b) Elongation for Fabrics

Figure 4.26: Grab Test for Fabrics with 32&64 segments

Figure 4.27 depicts the Load-Elongation curves for all three combinations in 32&64-Segmented group. As shown in Figure 30(a) the initial modulus of 50PET/50N-32Seg blends is the highest, followed by 50PET/50N-64Seg and the 75PET/25N-64Seg blends, in that order. Unlike the 8 and 16 segmented group where the stronger the fiber, the higher the initial modulus of the fabric, in this group fabric made from the weakest fibers has the highest initial modulus.



(a): 25PET/75N-32 Seg.

(b): 50PET/50N-64 Seg.

(c): 75PET/25N-64 Seg.

Figure 4.27: Load (lb)-Extension (mm) diagrams of 32&64 Segments Group

Abraded Results

Figure 4.22 (abrasion after 2000 cycles) shows the differences among abraded fabrics in this group. Almost all three fabrics were covered with pills and there seems to be no free standing fuzz. It looks as though all of the fabrics in this group have the propensity to pill. The differences are in the shape and size of the pills. This result confirms the assumption that fabrics in this group have the loosest structure when compared with the 8 and 16 segmented groups. In 50PET/50N-32 segmented there are a lot of tough pills that covered all of the abraded part. The difference between 50PET/50N-64Seg and 75PET/25N-64 segmented is that the pills in 50PET/50N-64Seg are bigger than those in 75PET/25N-64 segmented fabric. As the linear density of the nylon fibrils in 75PET/25N-64Seg fibers is smaller than nylon fibrils in 50PET/50N-64Seg fibers, this seems to indicate that nylon fibrils give more pills.

In Figure 4.23 (abrasion after 6000 cycles) it is evident that there is no big difference between samples with them after 2000 cycles, just pills got bigger.

From Figure 4.27 there is less fuzz than after 2000 cycles. This shows that with loose structures, anchor pull-out occurred more. As in the 8 and 16 segment groups the reduced interfiber forces are just enough to allow some pull-out but not enough to increase the total fuzz formation. Thus the total numbers of pills will be unchanged but the average pill mass will increase. In this case the pill will be larger.

From Figure 4.28 (Optical rating, after 2000 cycles), the 50PET/50N-32Seg and 50PET/50N-64Seg blends have the highest rating, followed by the 75PET/25N-64 segmented. But, after 6000 cycles Figure 4.28 shows a lower optical rating than with 2000 cycles. Figure 4.29 shows 50PET/50N-32Seg and 50PET/50N-64Seg blends have the most pills, followed by 75PET/25N-64Seg. Figure 4.30 shows that the 250PET/50N-32Seg and 50PET/50N-64Seg fabrics lost the same weight in the Martindale test, so the only factor that changes the size and shape of pills is the denier of nylon fibrils.

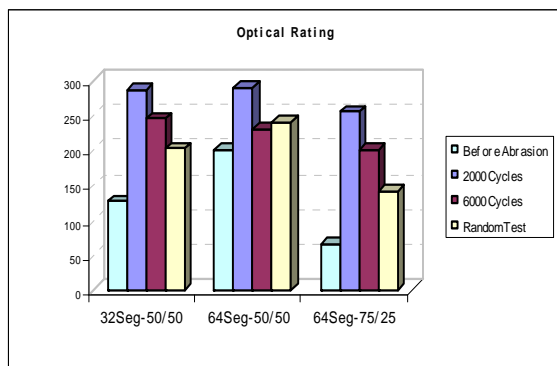


Figure 4.28: Optical Ranking

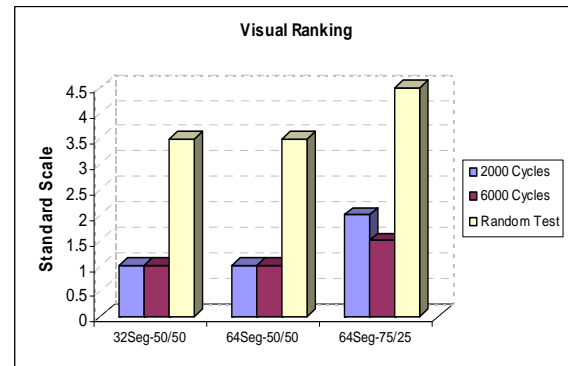


Figure 4.29: Visually Ranking

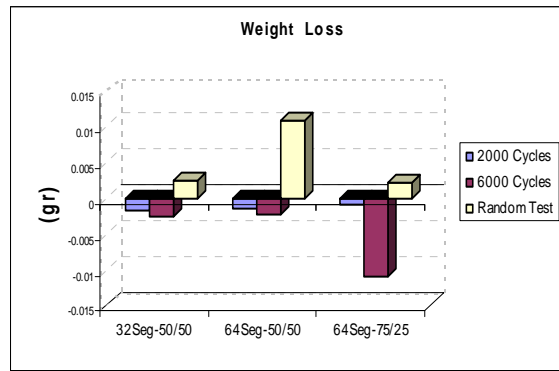


Figure 30: Weight loss for Fabrics with 32&64 Segmented Fibers

Figure 4.24 (after 30 min. in Random Tester) shows all samples are fuzzier and have pills after abrasion in the Random tester. From optical ratings (Figure 4.28), 50PET/50N-64 segmented deg blend has the highest rating, followed by 50PET/50N-32 segmented and finally by the 75PET/25N-64 segmented blends, in that order. But from Figure 4.29 (visual rating), 50PET/50N-32 segmented and 50PET/50N-64 segmented have the same scale (3.5), and 75PET/25N-64 segmented has almost the same value as original one (4.5). Figure 4.30 shows after the Random Test, 50PET/50N-64 segmented fabric lost the most weight in this group.

These results reiterate the earlier conclusion that different testers may give different pilling results for the same fabric.

In this group, all three fabrics exhibited higher pill formation when compared with other segmented groups. The higher rating of pill formation is due to the loose structure of these fabrics. As will be shown in the next section, fabrics of this group have the worst fiber splitting.

4.4.1.4 Pilling Resistance of Nonwoven Fabrics Made From Segmented Fibers

Properties of Initial Sample Material

This section focuses on more details of the properties of a series of nonwovens fabrics made from segmented fibers. Four fabrics with the same percentage of polyester/nylon66 (50PET/50N66) but different number of segments (8, 16, 32, and 64) were compared. In addition to the physical tests, samples were also examined under a scanning electron microscope (SEM) to see the cross section of fibers and how they were split after the hydroentangling bonding process.

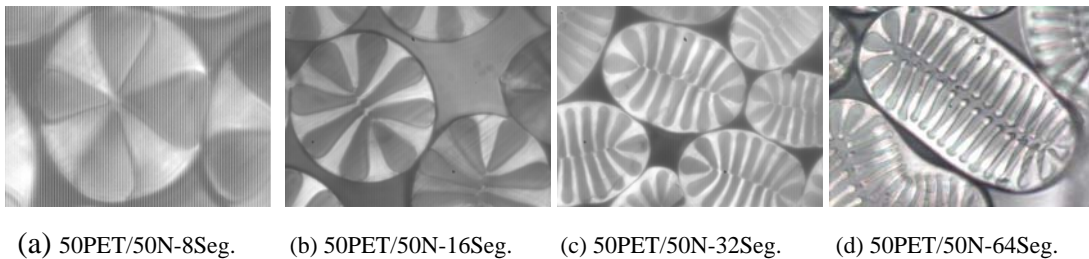
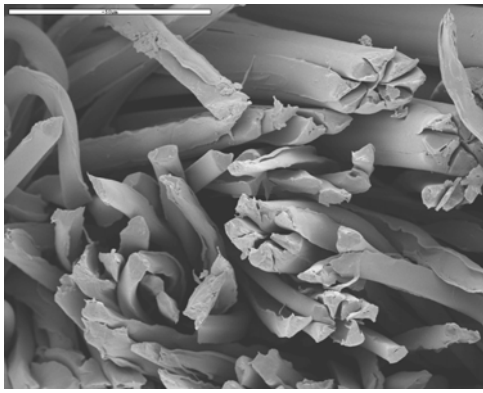


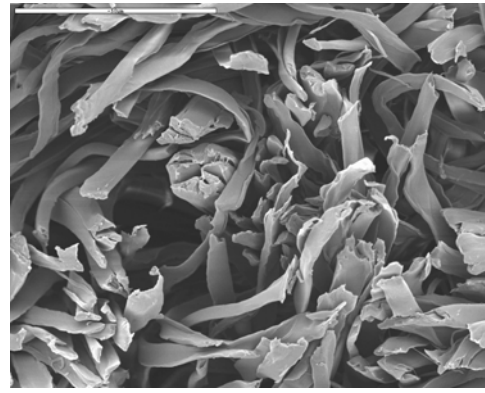
Figure 4.31: Cross Shapes of Segmented Fibers [11]

Figure 4.31 shows the cross section of different segmented fibers. It can be seen, in the 50PET/50N blend, that as the number of segments increase, the cross section of fiber is more elliptical.

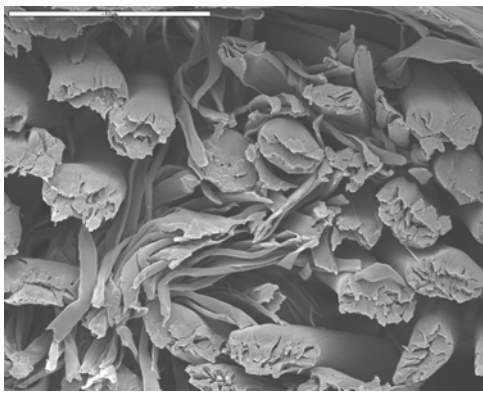
SEM pictures of fabrics structure can be seen in Figure 4.32. The SEM study was designed mainly to evaluate how fibers were split in different fabrics. As it is shown in Figure 32(b) the 50PET/50N-16 segments fibers split better than the others.



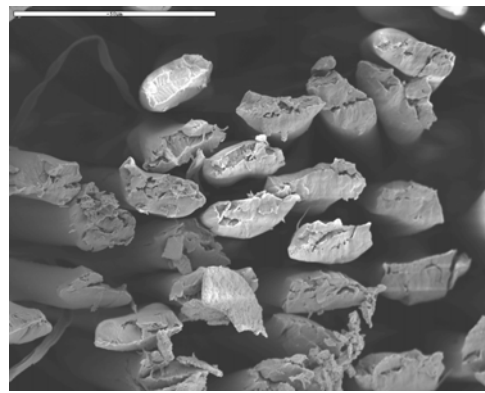
(a) 50PET/50N-8Seg.



(b) 50PET/50N-16Seg.



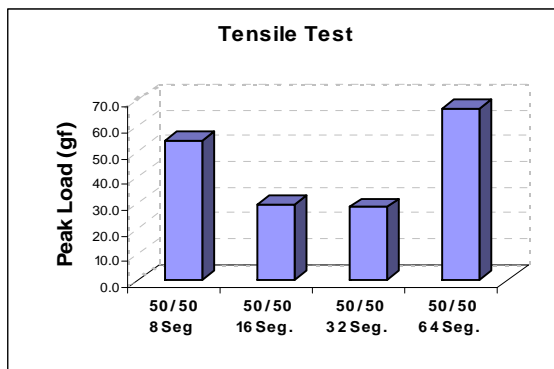
(c) 50PET/50N-32Seg.



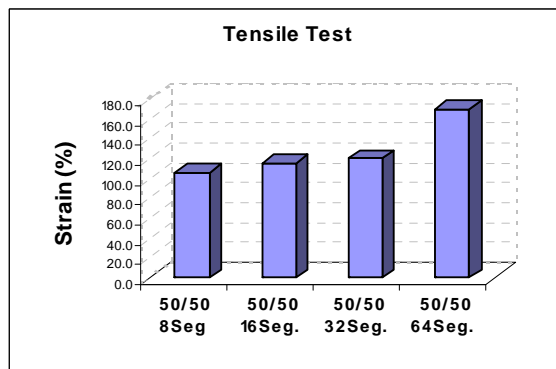
(d) 50PET/50N-64Seg.

Figure 4.32: SEM Pictures from Side of Fabrics [11]

Figure 4.33 shows results of tensile test of segmented fibers. Figure 34 (a) and (b) show peak load and strain of fibers. [11]



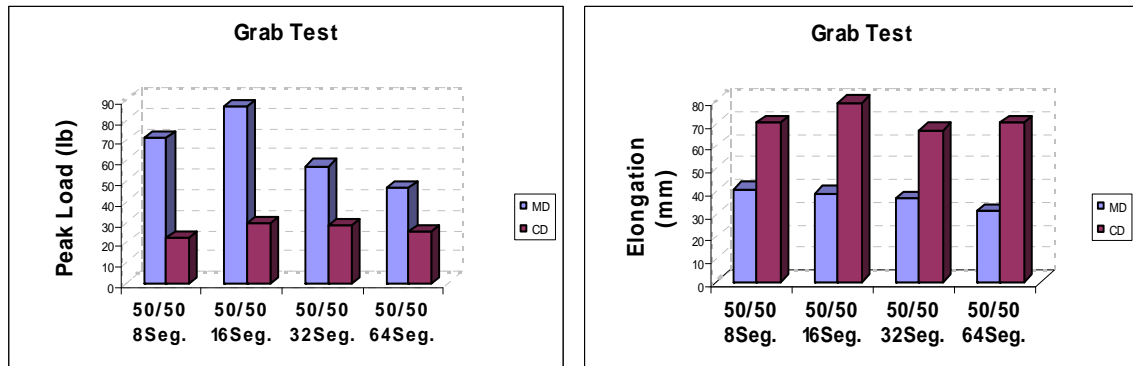
(a) Peak Load Chart



(b) Strain Chart

Figure 4.33: Tensile Test for Segmented Fibers

Figure 4.34 depicts results of grab test of different fabrics. Figure 4.34(a) shows peak load and 4.34(b) shows elongation for different nonwoven fabrics with different segments fibers.



(a) Peak Load Chart

(b) Strain Chart

Figure 4.34: Grab Test for Fabrics with Segmented Fibers

From figure 4.33(a) and (b) it is obvious that 50PET/50N-16 segmented fibers have the least peak load and elongation compared to other fibers in this group. But as it is shown in Figure 4.34(a) and (b) fabric with 50PET/50N-16 segmented fibers has the strongest structure. The main factor for making strong structure directly depends on the fiber splitting. Figure 4.32 confirms this since it is clearly seen that most 50PET/50N-16 segments fibers were split after the hydroentangling bonding process.

Splitting better means fibrils contribute in the hydroentangling bonding process better and thus make stronger fabric structures. Because fibrils have lower modulus (bending rigidity) than non-split fibers, they will deform easier under the water pressure and will assist in inter-fiber entanglement and hence make tighter structures.

Figure 4.35 (Load-Elongation curves) shows Load-Extension diagrams for each fabric with the same percentage of polyester/nylon but different number of segments. As it is obvious from these figures, the strongest structure (50PET/50N) has the highest initial modulus. However, the looser the structure of the fabric, the lower the initial modulus of the fabric. These results are contrary to the result of load-elongation results of each group that show the stronger the fiber, the higher will be the initial modulus of the fabric.

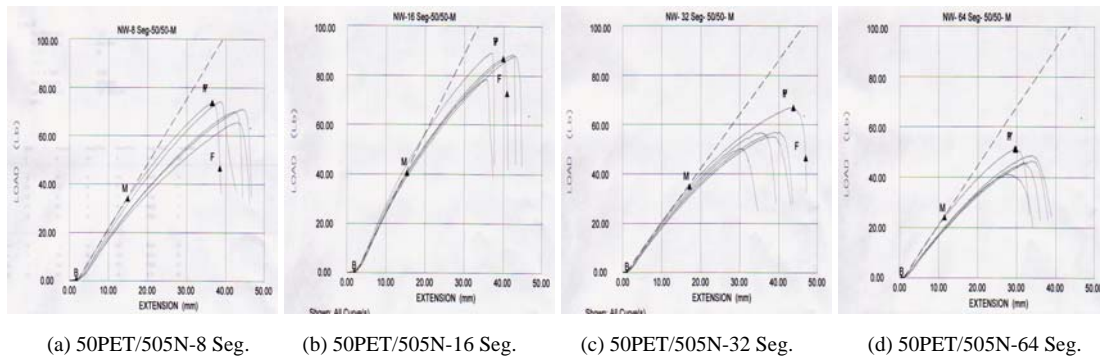


Figure 4.35: Load (lb)-Extension (mm) diagrams

We can assume that in each group that strength of fabrics is close to each other, the initial modulus of fabrics depends to the strength of fibers. But when the differences are significant, the initial modulus of fabric depends on the structure of the fabric.

From Figure 4.36, it seems reasonable to assume that the differences among the textures are due to their differences in fiber splitting. It is apparent from Figure 4.36(b) that 50PET/50N-16 segments combination has the clearest texture compared to the others fabrics. From Figure 4.36(d) it is obvious that the 50PET/50N-64 segments fibers were not split, so the fabric has the fuzziest appearance.

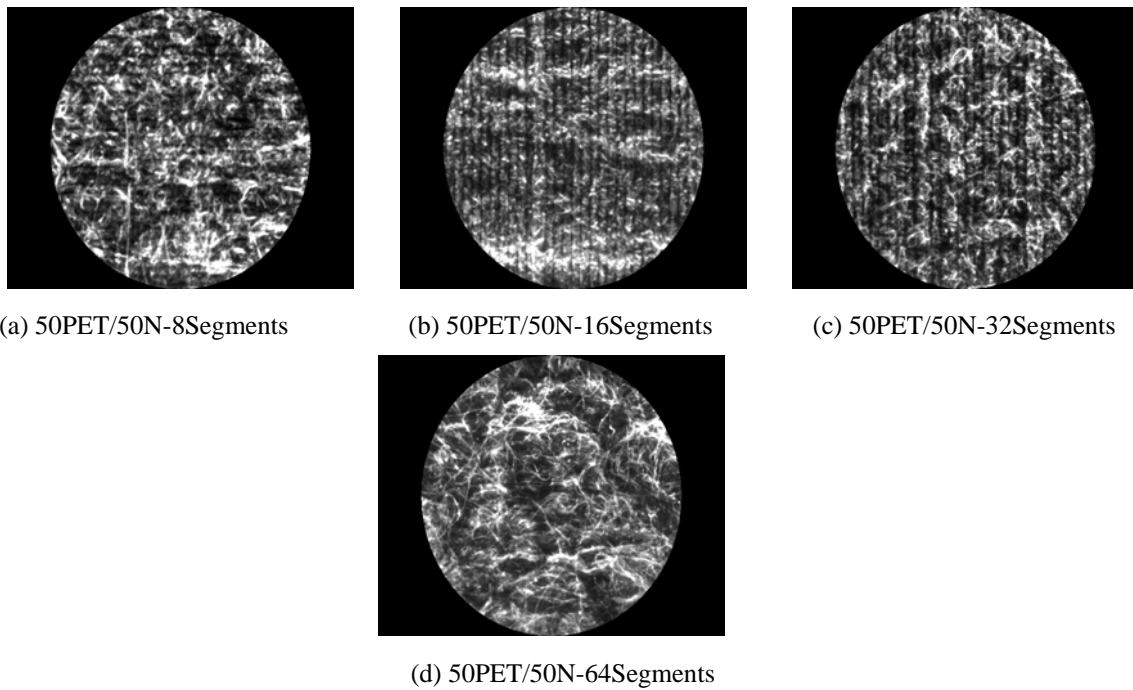
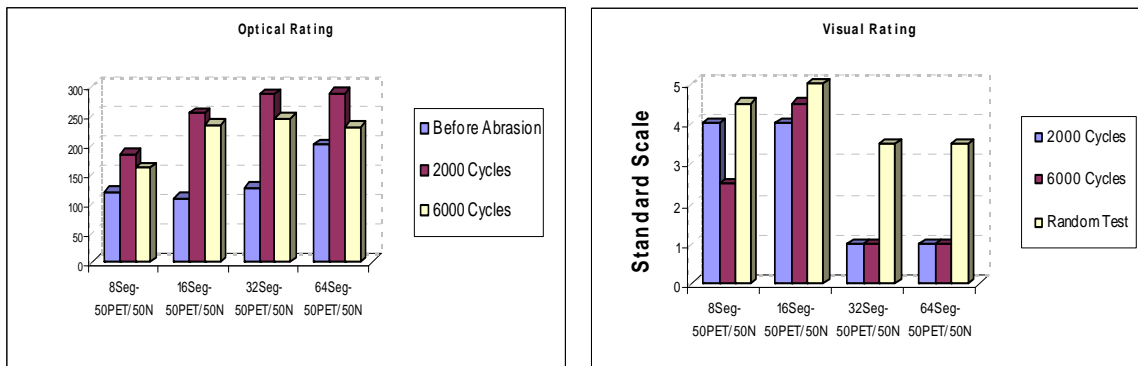


Figure 4.36: Pictures of Fabrics' texture before Abrasion



(a) Optical Rating

(b) Visual Rating

Figure 4.37: Optical and Visual Rating

Figure 4.37 shows pill rating of these fabrics after Martindale and Random tests in both optical and visual methods. From Figure 4.37(b), it is apparent that 50PET/50N-16 segments fabric has the best pill resistance among fabrics made from segmented fibers. 32 and 64 segmented blends have a higher tendency to pill compared to other blends.

We observed that the incidence of pills in 50PET/50N blended fabrics increases as the number of segments increases. The high rate of pill formation and retention in these fabrics is due to strong fibers and loose fabric structure. So pill formation takes place by fibers working out of the fabric to form free standing fuzz in which the fibers or other fibers become more entangled. For these fibers the rate of pill formation is much greater than the rate of pill wear-off.

4.4.2 Islands-in-the-Sea Fibers

4.4.2.1 60PET/40N-150gsm

Figure 4.38:

Before Abrasion

60PET/40N - 37 islands

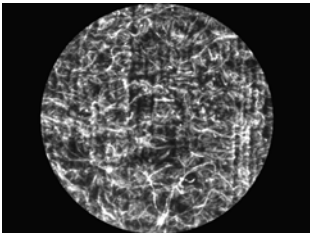


Figure 4.39:

Martindale:
2000 Cycles

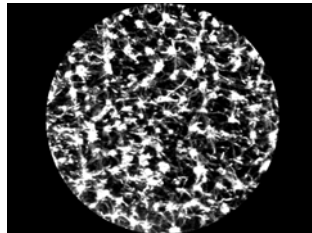


Figure 4.40:

Martindale:
6000 Cycles

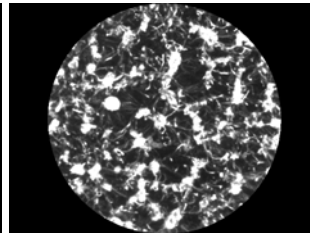
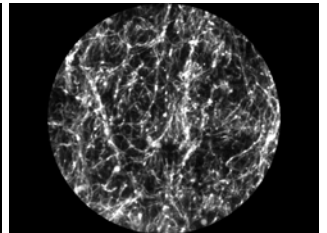
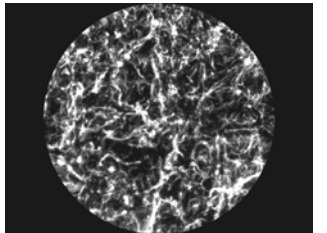
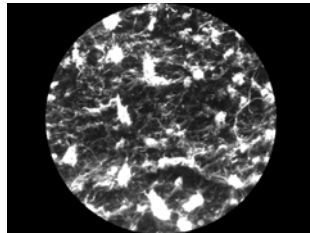
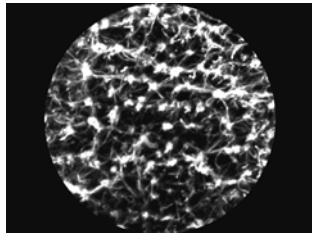
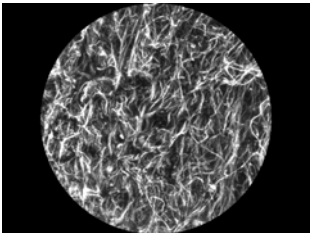


Figure 4.41:

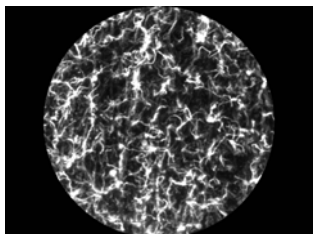
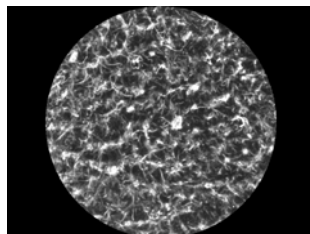
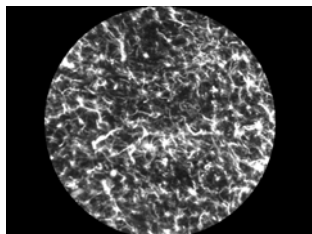
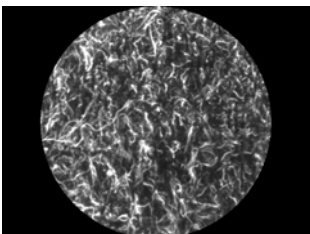
Random Test
30 min.



60PET/40N - 19 islands



60PET/40N-7 islands



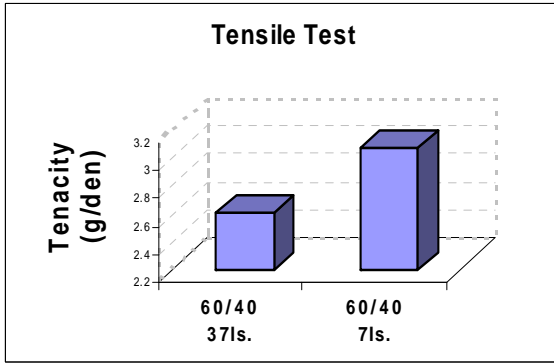
Figures 4.38-4.41 show samples of fabrics with Islands-in-the-sea fibers prior to and after specific abrasion. Figure 38 shows the samples before abrasion. Figure 4.39 and 4.40 show the samples after 2000 and 6000 cycles on the Martindale abrasion tester. Figure 4.41 shows abraded fabric after 30 minutes on Random tester.

Properties of Initial Sample Material

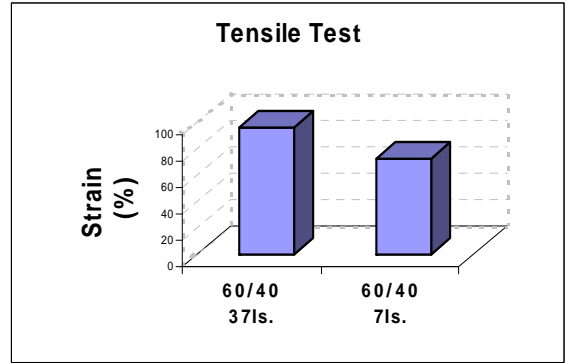
Figure 4.38 (before abrasion) shows the texture of all three fabrics. As it can be seen hydroentangled lines are not obvious in any of blends, but 7 islands fabric has the most uniform appearance. Also 19 islands fabric has the fuzziest appearance. As it is evident the percentage of polyester (60%) and nylon (40%) are the same in all blends. The only difference among the blends is the number of islands (polyester) in the sea (nylon66). So the number of islands plays a very important role in the structure of fabric when other factors are the same. The greater the number of islands is, the smaller the linear density of polyester fibrils.

Figure 4.42 shows the tenacity (g/den) and strain (%) of 7 islands and 37 islands fibers. As can be seen, the tenacity of 7 islands fiber is greater, but their elongation of that is less than that of 37 islands fibers. In contrary to the segmented fibers, where the higher the number of segments the stronger the fiber, for islands in the sea fiber is stronger when the number of islands is less.

* Only two fibers were available for evaluating.



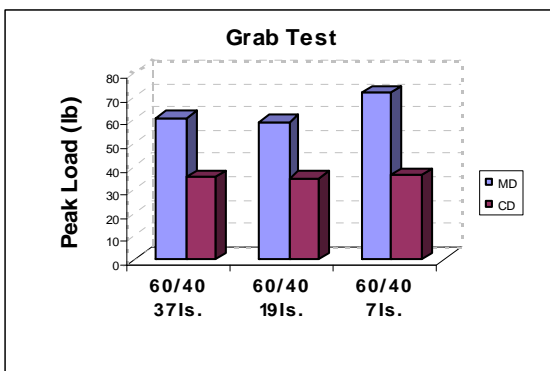
(a) Peak Load Chart



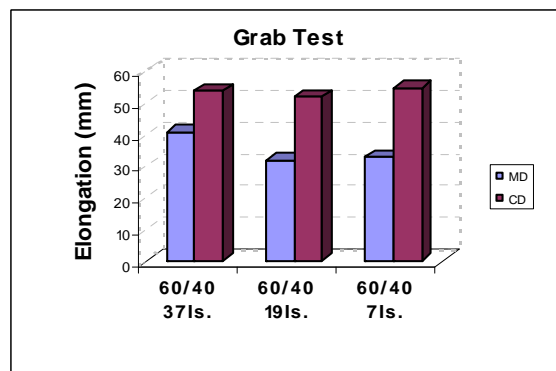
(b) Strain Chart

Figure 4.42: Tensile Test for Segmented Fibers

Figure 4.43 shows peak load and elongation of all three, 37 islands, 19 islands, and 7 islands fabrics in machine and cross directions. It is evident that the peak load and elongation of 7 islands fabric in machine direction is the greatest. 19 and 37 islands fabrics have almost the same peak load and elongation. Unlike the segmented fibers where the weakest fibers made the strongest fabric structures, the strongest Islands-in-the-Sea fibers make the strongest fabric structures.



(a) Peak Load of Fabrics

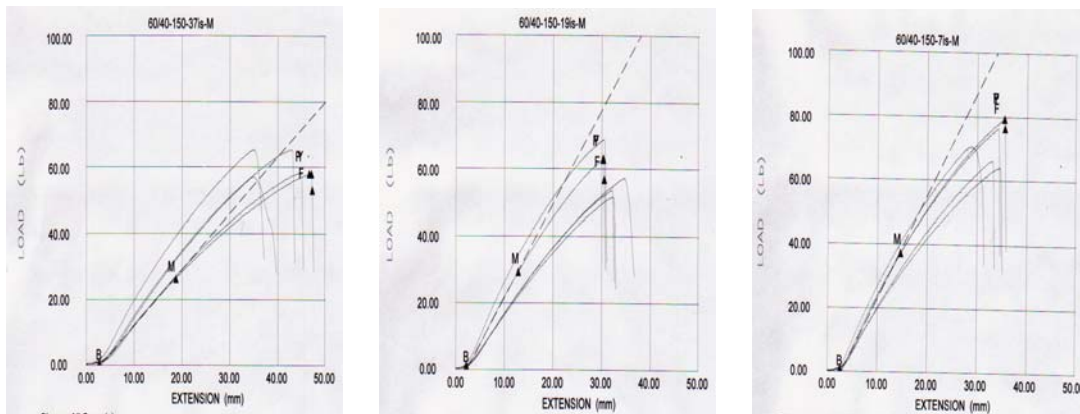


(b) Elongation of Fabrics

Figure 4.43: Grab test of Fabrics with Island in the Sea Fibers (150 gsm)

The results of the grab test suggest that 7 islands blend fibers were split better than 19 islands and 37 islands blends. As mentioned for segmented fibers, the better the Islands-in-the-Sea fibers split, the better they entangle in the hydroentangling bonding process. The abraded tests results confirm this assumption.

Figure 4.44 depicts the Load-Elongation curves for all three blends in this group. As it is shown in 4.44(c) the initial modulus of 7 islands fabric is the greatest, followed by 19 islands and the 37 islands fabrics, in that order. These results indicate that initial modulus of these fabrics depends on the strength of the fibers. The stronger the fiber is, the higher the initial modulus.



(a) 60PET/40N-37 islands

(b) 60PET/40N-19 islands

(c) 60PET/40N-7 islands

Figure 4.44: Load (lb)-Extension (mm) Diagrams of Fabrics with Island in the Sea Fibers

Abraded Results

Figure 4.39 (abrasion after 2000 cycles) shows the differences in the size and density of pills that were formed on the surface of fabrics. The 37 islands blend has a higher tendency to pill compared to other blends, followed by 19 islands. Although, not easily seen, the sizes of the pills on the 7 islands fabric are very small. This is because the 7 islands fibers were better split than the 19 and 37 islands fiber. Figure 4.45 (optical rating) and 4.46 (visual rating) confirm this.

From Figure 4.40 (abrasion after 6000 cycles), it is observed that the incidence of pills in 19 and 37 islands fabrics decreases as compared to abrasion after 2000 cycles. However, the pills become larger after 6000 cycles of abrasion. There is no clear difference in 7 islands when comparing 2000 and 6000 abrasion cycles. As fibrils in 7 islands blend were entangled strongly the anchor pull-out didn't occur.

As Figure 4.41 shows (after Random test), non-split fibers in 37 islands and 19 islands blends, after 30 minutes of random abrasion, entangled together. But on the surface of 7 islands fabric only a few small pills were formed. Random test also verified the assumption that 7 islands fibers were split better and make a stronger fabric structure.

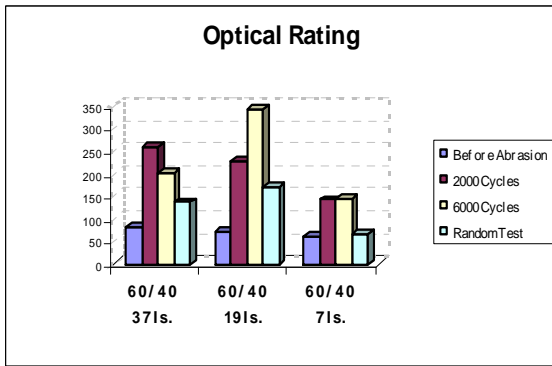


Figure 4.45: Optical Rating

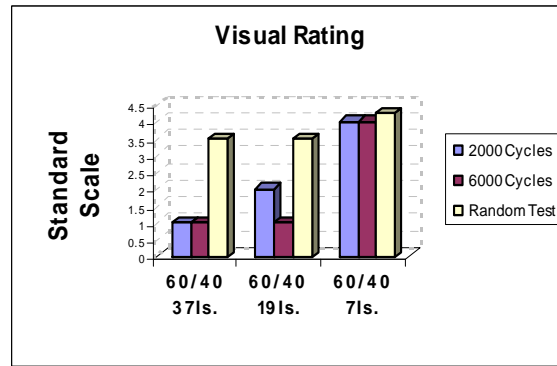


Figure 4.46: Visual Rating

Figure 4.47 (loss weight) shows that 37 islands blend lost more weight than 19 islands and 7 islands blends.

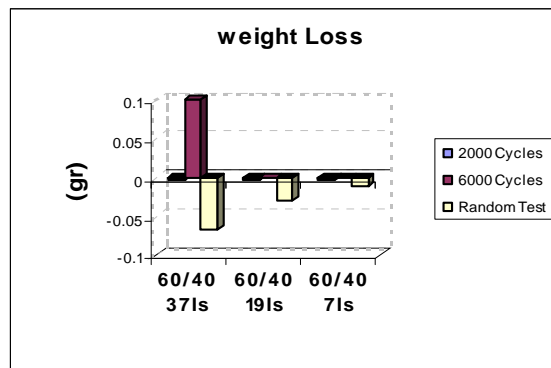


Figure 4.47: Weight loss for Fabrics with Islands-in-the-Sea Fibers

Grab test and abrasion test results of this group (60PET/40N66-37 islands-150gsm, 60PET/40N66-19 islands-150gsm and 60PET/40N66-7 islands-150gsm) suggest that the number of islands is the main factor for the mechanical properties of fabrics. The 7 islands blend gives the best appearance index because of blend uniformity and it has the strongest structure, so pills do not develop suddenly and spontaneously.

The 37 islands blend fibers is the weakest and made the loosest fabric structure. These features assist more pill formation in the 37 islands fabric.

4.4.3 Trilobal Fibers

4.4.3.1 50PET/50N66

Figure 4.48:

Before Abrasion

Figure 4.49:

Martindale:
After 2000 Cycles

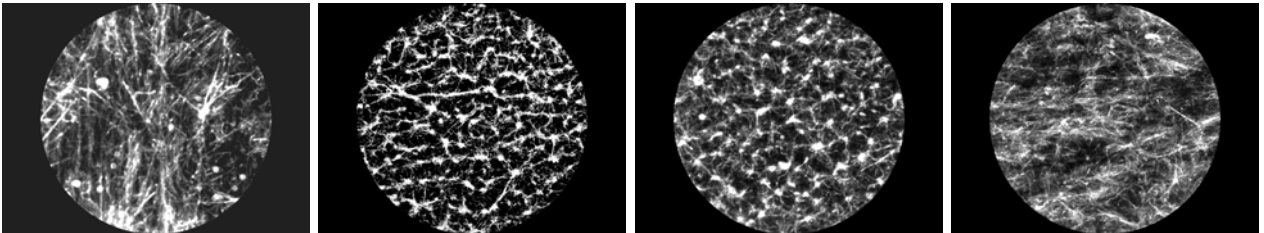
Figure4.50:

Martindale:
After 6000 Cycles

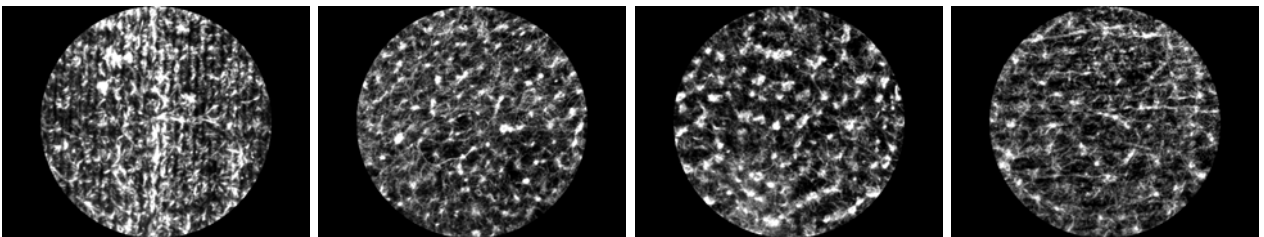
Figure 4.51:

Random Test
After 30 min.

50PET/50N-NCore



50PET/50N-PCore

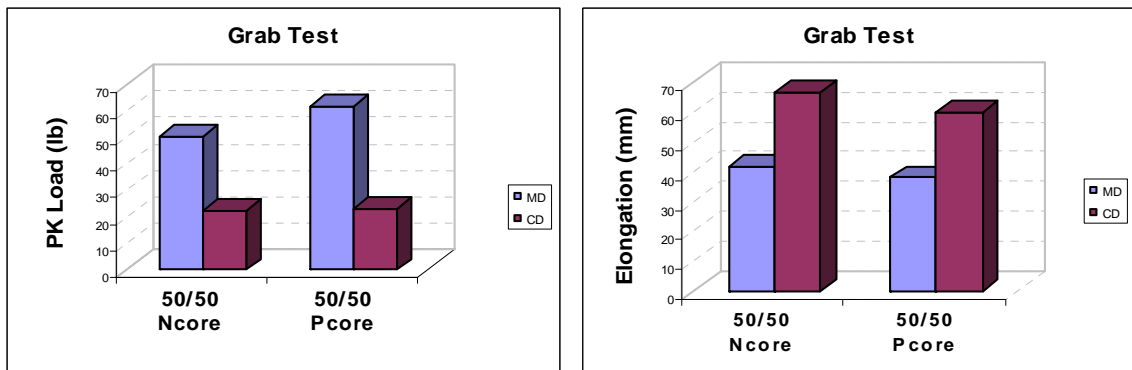


Figures 4.48-4.51 show samples of fabrics with Trilobal fibers prior to and after specific abrasion. Figure 4.48 shows the samples before abrasion. Figure 4.49 and 4.50 show the samples after 2000 and 6000 cycles on the Martindale abrasion tester. Figure 4.51 shows abraded fabric after 30 minutes on the Random tester.

Properties of Initial Sample Material

Figure 4.48 (before abrasion) shows the texture of the two fabrics. Hydroentangled lines are clear in the 50PET(core)/50N blend fabric but not obvious in the 50PET/50N(core) blend. Nylon(core) blend fabric has a lot of free standing fibers on the surface which were not entangled in the bonding process. As is evident the percentage of polyester (50%) and nylon (50%) are the same in both blends. The only difference between their fibers is that in the 50PET/50N(core) blend nylon is in the core of the fibers and in the 50PET(core)/50N blend polyester is in the core.

From Figure 4.52 it can be seen that the peak load of PET(core) blend in both MD and CD directions is greater than Nylon(core) blend, but elongation of Nylon(core) is greater.



(a) Peak Load of Fabrics

(b) Elongation of Fabrics

Figure 4.52: Grab test of Fabrics with Trilobal Fibers (150 gsm)

The results of the grab test and fabric appearance suggest that PET(core) blend fibers were split better than Nylon(core) blend fibers. This is suggested because PET(core) blend fibers made a stronger fabric structure and had a less fuzzy appearance.

Figure 4.53 shows the Load-Elongation curves for both blends. As can be seen in 4.53(a), the initial modulus of Nylon(core) blend is greater.

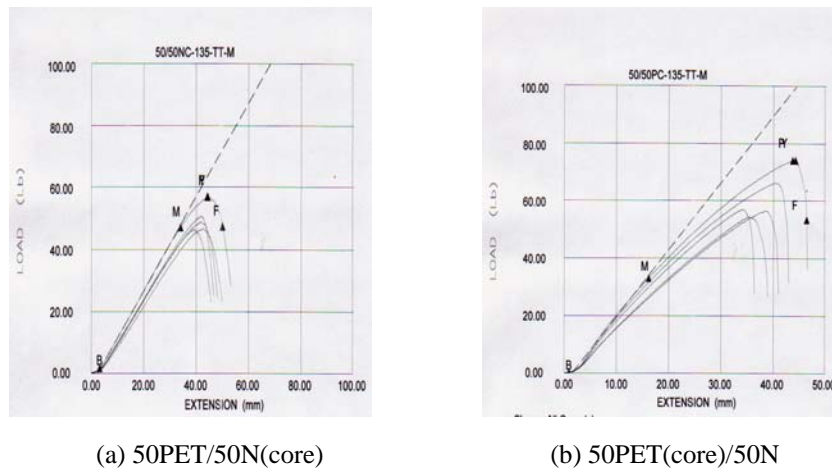


Figure 4.53: Load (lb)-Extension (mm) Diagrams of Fabrics

The Load-Elongation curve results indicate that Nylon(core) fibers are stronger, because the initial modulus of fabric depends directly on the strength of fibers. So like segmented fibers, weaker fibers made a stronger fabric structure. Again this occurs because weaker fibers split better.

Abraded Result

Figure 4.49 (abrasion after 2000 cycles) shows the differences in the shape and size of pills that were formed on the fabrics surface. Non-entangled free fibers on the surface of Nylon(core) fabric tied together and formed a lot of connected pills. But lots of small pills covered the PET(core) sample. Examination of the fabric surface revealed that the higher optical rating of N(core) fabric is due to fuzzier surface and not for more pills. As was mentioned before, the difference between the results of optical rating (Fig. 4.54) and visual rating (Fig. 4.55) is because the optical rating is sensitive to both pills and fuzzes, while visual rating just counts pills.

From Figure 4.50 (abrasion after 6000 cycles) it can be seen that the size of pills on both samples become larger and the total numbers of pills are unchanged. It seems reasonable to assume that anchor pull-out occurred more often. Figure 4.54 (optical rating) and 4.55 (visual rating) also indicates little difference between 6000 cycles and 2000 cycles.

As Figure 4.51 depicts (after Random test), a lot of free fibers, and no pills are seen on the surface of the Nylon(core) sample. Non-split fibers in Nylon(core) blend became free after 30 minutes randomly abrasion. But on the surface of PET(core) blend very small pills were formed. Random test also verified the claim that PET(core) fibers were split and make a stronger structure fabric. Figure 4.54 (optical rating) shows the same rate for both samples because Nylon(core) is fuzzy and PET(core) has pills. Figure 4.55 (visual rating) depicts that the PET(core) sample has more pills than the Nylon(core) sample.

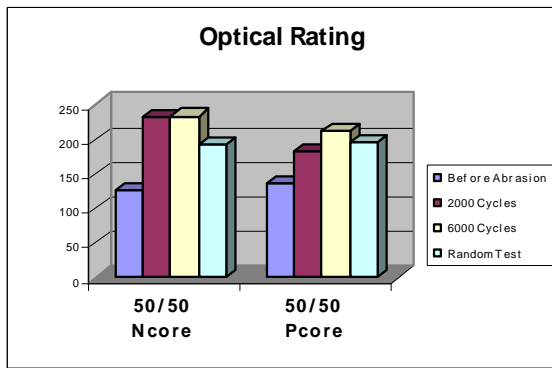


Figure 4.54: Optical Rating

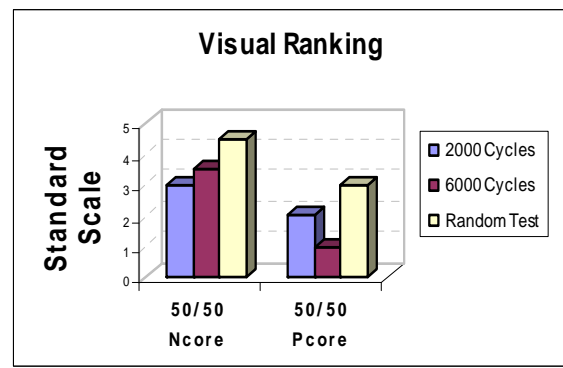


Figure 4.55: Visual Rating

Figure 56 shows the weight loss after Martindale and Random tests. After the Martindale test, fabrics gained a little weight, but after the Random test, Nylon(core) blend fabric lost significant weight (0.025g) while PET(core) lost only a little weight.

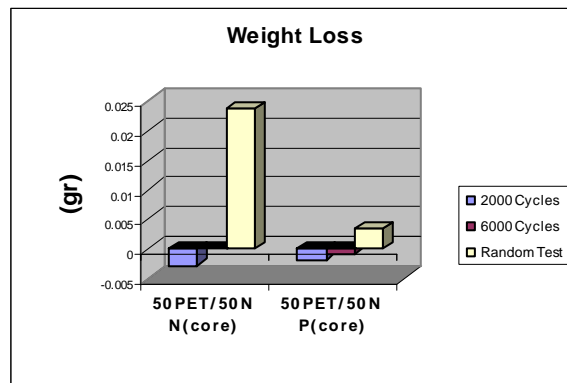


Figure 4.56: Weight loss for Fabrics with Trilobal Fibers

In this group, PET(core) blend has the strongest structure because fibers were split more. Also PET(core) blend has the highest pill formation. The reason for these results is because non-split N(core)fibers have nylon in the core, they have higher modulus and bending rigidity, so they have less tendency to pill.

5 Conclusion

This research was focused on the pilling and abrasion properties of a series of nonwovens fabrics made from bicomponent fibers. The results clearly indicate that fiber type (segmented, islands-in-the-sea, and trilobal) and the percentage of component fibers plays a large part in determining the fabric's structure and pill resistance. The pilling tendency of the test samples and their resistance to abrasion was evaluated with Random and Martindale abrasion testers, respectively. In addition, an extensive SEM examination was used to study the effect of fiber splitting on both fiber structure and pilling development for nonwovens fabrics produced from segmented fibers.

This study ranks the contribution of various bicomponent fibers' attributes to the structure and abrasion resistance of nonwovens fabrics. Although many factors have been identified, the degree of influence of each effect on pilling propensity is largely unknown. At the same time, it is illustrated that the interaction of various factors, including fiber properties (type, percentage of component, cross section, and strength) and fabric construction (structure, compactness) determines the rate and extent of pill formation.

This study indicated that the most important factor in pill development for nonwoven fabrics made from bicomponent fibers is fibers splitting. How bicomponent fibers split explains the tightness of fabric structure. As it was shown in chapter four, for segmented and trilobal fibers, the weakest fibers made the strongest fabric structure, since fibers were better split than stronger fibers.

Then each fiber produces lots of fibrils that have much lower modulus than non-split fibers. Those fibrils get involved in the hydroentangling bonding process better than non-split fibers. These fibrils entangle strongly into the fabric structure to the point that the fibers end are not protruding on the surface and are therefore not available to form pills.

The second factor that influences the abrasion and pilling resistance of nonwoven fabrics is the physical properties of non-split fibers or separate fibrils. After fibers protrude from the surface of fabrics, their own characteristics preordain whether they form pills, wear off from the fabric, or just make fuzz. In this study the percentage of polyester/nylon; number of segments; and number of islands in the sea; play a very important role in determining the fabric tendency for forming pills. In segmented fibers, by increasing the number of segments the strength of the fibers increased but the strength of the fabric decreased, since fibers split less. For islands in the sea fibers, by decreasing the number of islands the strength of fibers and fabric increased. In trilobal fibers, the strength of the fiber changes depending on what component is in the core. As the results showed, having the same percentage of polyester/nylon, the trilobal fiber which has polyester in the core is stronger.

Our experience indicates, however, that pilling of a fabric during abrasion process should not be judged merely by the number of pills since other factors, including the size of the pills, the degree of color contrast between pills and fabric, and the amount of fuzz, all contribute to the acceptability of the fabric.

It is clear that the design of the pilling tester has a significant effect on test result as well. Findings show that different testers may give different pilling results for the same fabric.

Tests on the Martindale resulted in worse pilling grades than test on the Random Tumble tester. Another important result of this research is that different pilling testers have different sensitivities for various fibers, and fabric parameters. Martindale test results indicate that this apparatus is sensitive to the fiber count and initial modulus of fabrics.

6 Suggesting for Future Work

Martindale is most widely accepted tester. However, present study shows in consistencies that it is recommended that a more extensive study be specifically carried out using this apparatus. Such a study could include:

Critical analysis of Martindale:

- ▶ Fiber transfer (quantify: visually or weight)
- ▶ Chemically remove wool from abraded sample
- ▶ Evaluate weight loss of abradant fabric
- ▶ Collect debris & analyze for sample and abradant
- ▶ Is “scale” appropriate for Nonwoven!

7 References

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