Research Article

Characterization of Flammability and Low Stress Mechanical Properties (Compression and Shear) of Basofil® Fibers and its Blends

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Abstract

Basofil® fiber exhibits excellent fire protection and thermal stability along with resistance to chemical, hydrolysis and ultraviolet radiation. Open-end spun yarns were produced from Basofil® fiber and its blends, the necessary tensile properties were tested. 100% Basofil® yarns show less tenacity and breaking elongation due to fiber density, brittleness, and lower cohesion between fibers. Flammability characteristics of Basofil® fiber have enhanced in its blends. The compression and shear properties of the above mentioned fabric samples exhibit very high thermal dimensional stability. This study helps the yarn and fabric manufacturer to engineer the structures suitable for the development of Defence apparels, civilian apparels and Home furnishings.

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Key words: Basofil, Flame retardant, Compressional Property, Low stress Mechanical, Shear property.

1. Introduction

Conventional apparel clothing does not provide protection against flames and heat, thus the need for flame retardant apparel for civilians is on the rise because of increased incidents of fire accidents. Conventional flame retardant textiles through the application of flame retardant finishes are limited as the finish remains on the surface and it will not penetrate deeper into the fabric. However, the addition of flame retardant materials in the polymer forming stage makes the fiber inherently flame retardant.

In view of the above, chemically modified synthetic fibers like Kevlar, Nomex, Twaron, Trevira were developed. In light of this, Basofil® – an inherently flame retardant melamine based fiber was developed in the laboratories of BASF AG in the 1980s; it is relatively cheaper as compared to similar fibers.

An attempt has been made to study the flammability and low stress mechanical properties of the Basofil® and its blends with other commodity fibers, like Cotton to improve the comfort properties to produce yarns and knitted fabrics for the development of flame retardant apparels. It is believed that when Basofil® fibers are blended with cellulosic fibers, the former with the high heat of combustion supports the cellulose fibers, which have a relatively lower heat of combustion and thus the pyrolysis path of cellulose fibers is altered.

Tensile characteristics of Basofil® blended yarns were tested and the fabrics were also tested for the flammability, compression and shear properties understand their low stress mechanical properties. Studies have also been conducted to compare the flammability performance of basofil-cotton blends after the FR treatment on cotton component.

Safety of human beings has been an important issue all the time. A growing segment of the industrial textile industry has therefore been involved in a number of new developments in fibers, fabrics and Protective clothing. Major innovations in the development of heat resistant fibers and flame protective clothing for fire- fighters, foundry workers, military and space personnel, and for other industrial workers who are exposed to hazardous conditions have been carried out. For heat and flame protection, requirements range from clothing for situations in which the wearer may be subjected to occasional exposure to a moderate level of radiant heat as part of the normal working day, to clothing for prolonged protection, where the wearer is subjected to severe radiant and convective heat to direct flame. In the process of accomplishing flame protection, however, the garment may be so thermally insulating and water vapor impermeable that the wearer may begin to suffer discomfort and heat stress. Body temperature may rise and the wearer may become wet with sweat. Attempts have therefore been made to develop thermal and flame protective clothing, which can be worn without any discomfort [1, 2].

Basofil® fiber is a cost effective heat resistant fiber based on melamine chemistry, with a 400°F (200°C) continuous operating temperature. Melamine fibers are flame resistant, have outstanding heat/dimensional stability, and are self-extinguishing. EFT's WF series of melamine fibers have a fiber length distribution tailored for use in wet-laid Nonwovens. Typical fiber lengths are in the 1-12mm range, and they show excellent dispersion and formation in wet-laid processes. [3]

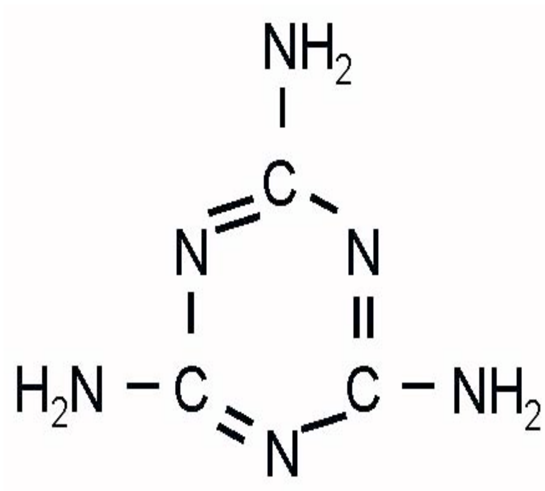

Figure 1 Structure of Melamine [4]

Concerning the environmental point of view, Horrocks et al. developed an analytical model for understanding the environmental consequences of using flame retardant textiles. An environmental rank value is given at each stage in the manufacturing process and product life of each flame retardant fiber and fabrics. The results show that each of the eleven generic fibers analyzed showed an environmental index value within the range of 32-51 % where 100 denotes the worst environmental position possible [3]. Open-end (OE) rotor spun yarns have certain characteristics which differentiate them from conventional ring-spun yarns. This is because of differences which can be noted between their production method and structure [5-11].

The concept of 'fabric hand', 'handle' or simply 'hand' is an important method of fabric assessment which was introduced by the apparel and textile industry. Fabric hand refers to the total sensation, experienced when a fabric is touched or manipulated with the fingers. The attractiveness of a fabric's handle depends on its end use [12], as well as on possible cultural and individual preferences of the wearer [13]. Fabric hand attributes can be obtained through subjective assessment or objective measurement [13], [14], [15], [16], [17] [18].

Fabric handle is defined as the overall aesthetic quality of the fabric perceived [24], which influences consumer priorities and their sense of the usefulness of the product, as well as the marketability of the fabric for retailers. Subjective evaluation of the handle has always been used as the fundamental aspect of communication for the development, production, quality control, specification and marketing of textile materials and garments before the development of objective measurement technology for fabric. The complex concept of fabric handle may be analysed as the interaction between simple attributes of fabric quality such as firmness, fullness, crispness and hardness, smoothness or sleekness [25].

From this perspective major research into the relationship between the mechanical properties of fabric and fabric handle was first conducted by Pierce [15] in 1930. His article "The Handle of Cloth as a Measurable Quality" was the first research on the relation between fabric mechanics and fabric handle. The handle of a fabric was investigated and then converted into numerical values. It is also known that fabric handle is related to many characteristics including flexibility, stiffness, compressibility, resilience, extensibility, the surface contour, mass per square meter, surface friction and thermal characteristics [26]. On the other hand, the quality, tailorability and performance characteristics of a fabric are related to its mechanical properties in a low stress region, as well as its surface and dimensional properties. These properties are tensile, shear, bending, compression, surface friction, hygral expansion and relaxation.

In the 1970's, S. Kawabata and M. Niwa [27 - 31] started to study fabric mechanics and handle in Japan. They aimed to build a model of the relationship between fabric mechanics and fabric handle. A research committee -The Hand Evaluation and Standardization Committee (HESC) - was then established in 1972 under the leadership of Mr. S. Kawabata, sponsored by the Textile and Machinery Society of Japan. The research on objective evaluation of fabric handle was accelerated by the foundation of this committee. The efforts of the HESC to seek an objective evaluation of fabric quality and handle, as well as constant studies on the mechanical properties of fabrics in Japan, enabled Kawabata to design the 'Kawabata Evaluation System for Fabrics' (KES-F) [32]. He defined this work as a need for quick and reproducible instrumentation for evaluating fabric handle. In 1973, the first KES-F instruments were introduced to the industry. These instruments were:

KES-F1: Tensile and Shear Tester

KES-F2: Bending Tester

KES-F3: Compression Tester

KES-F4: Surface-friction and Geometrical roughness Tester

The response of a fabric to applied forces, normal to its plane, is known as fabric compression behavior. The compressional property of a fabric handles closely related to fabric, i.e., the softness and fullness of the fabric and also to the fabric surface smoothness [28]. It also plays an important role in comfort. Fabric thickness and compressibility have a linear relationship with thermal conductivity [20]. The warmth of a fabric is largely a function of the airspace and its distribution in the structure [21].

During the virtual feel of fabrics, a certain material with its distinctive properties is simulated in a virtual environment. The user has then the possibility to interact in real time with the virtual simulated textile using a haptic/tactile device. However, the needed real time simulation of the fabric requires a simplified hand movement. Therefore a set of reasonable and feasible handling actions, which allow an adequate evaluation of the selected relevant textile mechanical properties, needs to be found. Simulated mechanical fabric properties are: Tensile properties, Shear properties, Bending properties, Compression properties, Surface properties, Weight property.

For the array of the haptic/tactile interface it was found that the optimal way of assessing different fabric properties without manipulating the material too much is by handling it with two fingers. Hereby, different kinds of stimuli to the user's fingertips are responsible for the various sensations [19].

Compressional behaviors' of fabrics, along with the bending, tensile, shear, and surface characteristics are closely related to fabric handling, drape, tailorability or making-up properties. The most commonly used instruments to measure compression properties of fabrics are the parts included in the KES-F (Kawabata Evaluation System for Fabrics) [14] and FAST (Fabric Assurance by Simple Testing) [22, 23] systems. These are static offline testing instruments that require operator interaction in sample preparation and mounting, which can introduce errors. The tests are generally time-consuming.

The ability to char in place rather than shrink or melt makes Basofil fiber of choice in critical applications. The advantage of this heat dimensional stability can easily be seen in the felt samples to the right, which have been exceeded to direct flame for the time indicated.

2. Experimental Procedure

2.1 Preparation of Yarn Samples

Yarn samples of 11 Ne are spun from pure Basofil® fiber and from the blends of Basofil®/Cotton (50/50) of 12Ne & 17Ne and pure cotton of 16Ne & 17Ne using rotor spinning. The yarn spin plan, process parameters and certain quality parameters are given in Table 1.

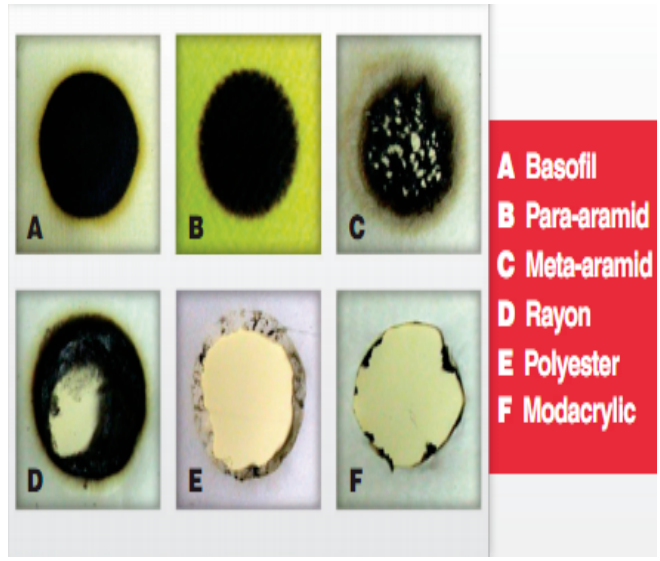

Figure 2 Heat Dimensional Stability of different fabrics [39]

2.2 Tensile Characteristics

The conditioned yarn samples were tested on Tensomaxx 7000 and Tensojet 4 for tensile characteristics, like breaking force, tenacity, breaking extension, breaking work. The yarn samples were tested at gauge length of 500mm, and at a constant strain rate of 5m/m in on Tensomaxx 7000 tensile tester. The strain rate of 5 m/min and gauge length of 500 mm is chosen as these are the commercially practiced test conditions in most of the spinning mills and conform to most test standards.

2.3 Production of Knitted Fabric Samples

The yarn samples were knitted on a laboratory model Fabric Analysis Knitter (FAK - Tube Knitter) of 3" diameter. The Basofil® and cotton yarns were knitted on an 18-gauge cylinder knitting machine using 160 needles and a single feeder running at a speed of 60 rpm to produce single jersey tubular fabrics.

2.4 Bleaching of fabric: Procedure

The following quantity of sodium silicate and hydrogen peroxide are mixed with a calculated amount of water. The fabric samples soak in the prepared solution for about 1 hour at 80°c in the jigger for uniform bleaching. The bleached samples were washed and dried.

- Hydrogen peroxide – 10%

- Sodium silicate – 4.8 gpl
- MLR – 1:20

Table 1 Particulars of Yarn Sample Preparation

Rotor spun Yarns	Yarn Count	Rotor Speed (r/min)	Opening Roller Speed (r/min)	Rotor DIA (mm)	CSP	TPM	Strength (lbs)
Basofil	11Ne	40000	8500	33	487	800	44
B/C (50:50)	12 Ne	65000	8500	41	1090	1000	81.47
B/C (50:50)	17 Ne	80000	8500	33	1135	900	58.92
Cotton	16 Ne	85000	8500	33	1400	975	110
Cotton	17Ne	85000	8500	33	1350	925	108.6

B/C: Basofil® / Cotton

2.5 FR Treatment of Cotton

The following quantity of phosphoric acid and Pekoflam DPN were mixed with water. The fabric samples were washed and rinsed in water. After rinsing in water, samples were soaked in the prepared finish solution for 30 minutes, after which dried at 100°c and curing is done at 120°c.

- Pekoflam DPN - 400 gpl
- Phosphoric acid 85% - 20 gpl
- MLR - 1:8

2.6 Flame Resistance of Knitted Fabric Samples

Flame resistance characteristics of conditioned knitted fabric samples were determined using the Vertical Flame Test (Method A) as described in the IS: 11871–1986 standard and flame resistance of fabric samples, in an inclined configuration, was determined using ASTM D 1230 – 1994. The flammability of all the

samples was also measured using a Limiting Oxygen Index method as per the procedure described in IS: 13501 – 199 method. Details of these test methods are described below:

A conditioned strip of fabric sample is kept at an angle of 45^{o} and ignited at the base by flame impinging on both sides in a standard manner. After igniting the specimen for a specific period of time, the char length, after-flame and afterglow characteristics were noted. Flammability tester with a separate timer capable of providing flame impingement on the specimen for 1 (0.05 seconds is used. The test specimens shall be 150mm x 50mm (length x width). Six such fabric samples, three in course and three in wale direction, were tested

The position of the flammability tester is adjusted with a holder and trial specimen in position, so that the tip of the indicator touches the face of the specimen. Place the specimen holder in the chamber so that the longest frame is on top. Adjust the burner and sample holder so that, with the indicator touching the face of the specimen, the flame is applied to the vertical center of the specimen, 19mm from the bottom of the specimen and with the burner face 8mm from the face of the specimen. Expose the test specimen to the flame within 45 seconds of the time it was removed from the desiccators. Place the stop cord 9.5 mm above and parallel to the lower surface of the top plate of the specimen holder. Close the door of apparatus and set up the clock at zero. Apply the flame to the specimen for a period of 1 second, using automatic timer and record the time of flame spread for each specimen.

2.7 Compression Tester - KES-FB3

KES-FB3 compression tester that can measure compression property such as fabric thickness, work of compression and recoverability of fabrics and films by applying compression load is used to test, the knitted fabric materials for compression property, before and after finishing.

2.8 Tensile & Shear Tester-KES-FB1

KES-FB1 Tensile and Shear tester is used to measure the tensile & shear properties of the fabrics before and after finishing treatments.

3. Results and Discussions

3.1 Tensile Characteristics of Yarns

From the literature, it is clearly understood that the the Basofil is not hazardous under the criteria of U.S. Occupational Safety and Health Standard 29 CFR, 1910 Subpart Z and United Nations GHS Parts 2, 3, and 4. The product is coated with finishes which do not present a significant health hazard in their normal use. If heated to elevated temperatures during processing, these finishes can degrade and generate off gases which may contain small amounts of chemicals. Local exhaust ventilation is recommended [34].

Table 2 shows that the breaking time required for 100% Basofil® yarn is less than that of 100% cotton and blended yarns. Among the 5 different samples tested, Basofil® has the lower breaking work, breaking elongation and breaking time while Cotton has the highest breaking force compared to other samples due to the effect of the structural arrangement of the fibers in the yarn. The yarn samples are showing variation in yarn count, it is due the selection of Basofil fiber with uncut length, the process-ability of the fiber was difficult in Airjet, Dref-3 Friction, and Ring spinning systems. Hence, it was planned to process in open end spinning system, the samples were developed from industry.

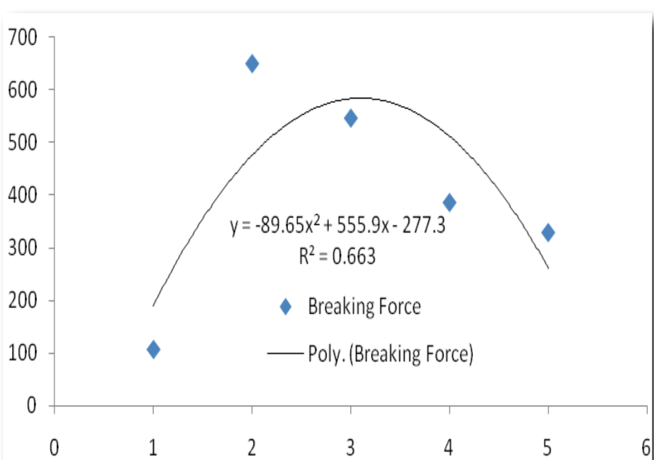

Figure 3 Breaking force of Baofil® and its Blends

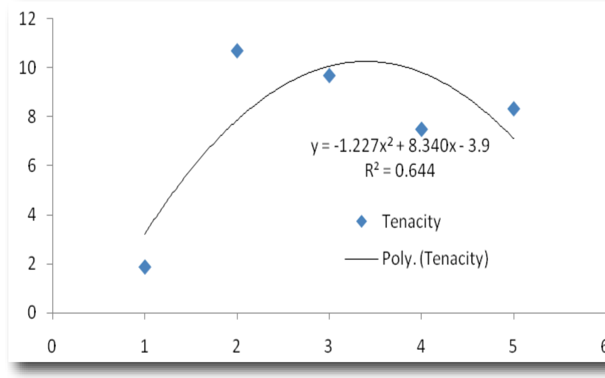

Figure 4 Tenacity of Baofil® and its Blends

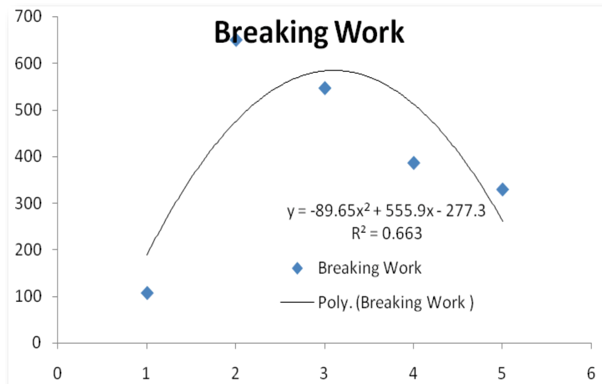

Figure 5 Breaking Work of Baofil® and its Blends

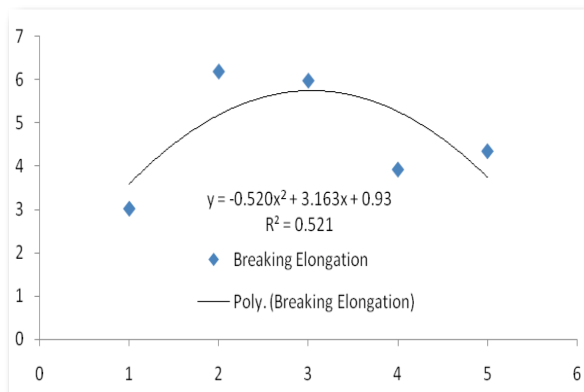

Figure 6 Breaking Elongation of Baofil® and its Blends

This can be attributed to the breakage of a higher proportion of fibers besides some contribution by wrapper fibers (which are expected to break due to application of a high instantaneous force). But in case of Basofil® it shows lower tenacity and energy to break due to its inherent characteristics; brittleness and less cohesiveness among the fibers. By blending the Basofil® with the cotton fiber, the tensile characteristics of the yarn increased significantly. The tensile characteristics of the yarns are plotted and their regression and coefficient of determinations were found. It shows that the tensile

Table 2 Tensile Characteristics of Yarns

Yarn Description (Rotor-spun)	Breaking Time (sec)	Breaking Force (gf)	Tenacity (g/Tex)	Breaking Elongation (%)	Breaking Work (kgf-m)
11 Ne Basofil®	0.2	99.90	1.86	3.03	107.98
16 Ne Cotton	0.3	394.70	10.70	6.18	650.22
17 Ne Cotton	0.3	336.50	9.69	5.97	546.88
12 Ne BC	0.2	388.50	7.49	3.93	386.73
17 Ne BC	0.3	289.20	8.33	4.35	329.77

BC-Basofil® Cotton Blend

characteristics of the yarns have 50% influence of these gauge lengths and strain rate as a function of polynomial functions. Even though the study was performed with constant gauge length and the strain rate it has got considerable influence in the tensile characteristics. From the study it was observed that the tenacity of the 12 Ne BC is lesser than 17 Ne BC, since, when the yarn becomes the finer the number of wrapper fiber present in the yarn is also increasing. Due to the increase in the number of wrapper fiber it contributes more for the strength of the yarn.

3.2 Flammability Values of Fabrics Samples

3.2.1 Inclined Strip Test Results

From the Table 3 it is observed that the Basofil® and its blends represent resistant to flammability characteristics. This is due to the characteristics of the fiber, chemical component (nitrogen) of melamine present in the fiber, the structure of the yarn and fabrics. When the cotton and cotton/Basofil® fabric is treated with the Pekoflam DPN flame retardant finish, flammability characteristics is proved significant at 95% significance level (Table value is greater than the calculated value, it is 9.75). From the study it was observed that the thermal dimensional stability of the Basofil fiber was showing excellent heat dimensional stability when compared to the finished Basofil fiber. When the fiber was burnt, it shows char in place rather than shrink or melt makes Basofil the fiber of choice in critical applications. It has clear evidence that there is good heat dimensional stability [33]

Table 3 Flammability Values of Fabrics

Fabric Description	Inclined Strip Test			
	Flammability (Without finishing)		Flammability (With finishing)	
	In Seconds	Char length in mm	In Seconds	Char length in mm
11 Ne Basofil®	1	3	1	0
16 Ne Cotton	18	0	1	8
17 Ne Cotton	17	0	1	13
12 Ne BC	1	7	1	5
17 Ne BC	29	0	1	6

BC-Basofil® Cotton Blend

3.3 Low Stress Mechanical Property Using Kawabata Evaluation System (KES)

3.3.1 Compression Properties (KES-FB3)

Table 4 Compression Properties Using Compression Tester (with and without finish)

Sample	LC		WC		RC	
	With Finish	Without Finish	With Finish	Without Finish	With Finish	Without Finish
BC 12'S Ne	0.324	0.345	0.629	1.070	34.66	40.56
BC 17'S Ne	0.349	0.384	0.701	0.663	32.24	33.94
Cotton 16'S Ne	0.301	0.340	0.575	0.768	24.7	32.29
Cotton 17'S Ne	0.314	0.301	0.319	0.383	31.03	35.77
Basofil® 11'S Ne	--	0.357	--	1.070	--	40.56

Linearity of compression – Thickness curve (LC); LC=1, Completely Linear; LC=0, Extremely Non Linear; Compressional Energy (WC gf.cm/cm^2); Higher value of WC corresponds to higher compressibility. Compressional Resilience (RC %); RC=100% Elastic; RC=0% Mean completely inelastic.

From the Figures 7-12, it is observed that the compression properties of the finished fabrics are different when compared to the non-finished fabric samples. An addition of the finish onto the surface of the fabric appears to modify the surface characteristics and ultimately the tensile properties of the fabrics.

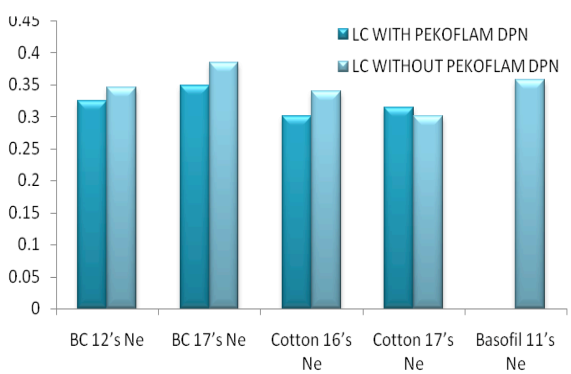

Figure 7 Comparative Graphs - Linearity of Compression-Thickness Curve

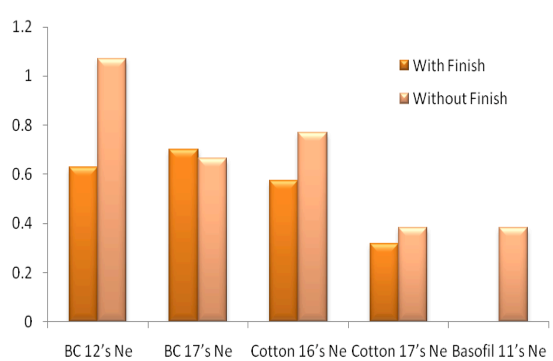

Figure 8 Comparative Graph Compression Energy, Compressional Resiliency

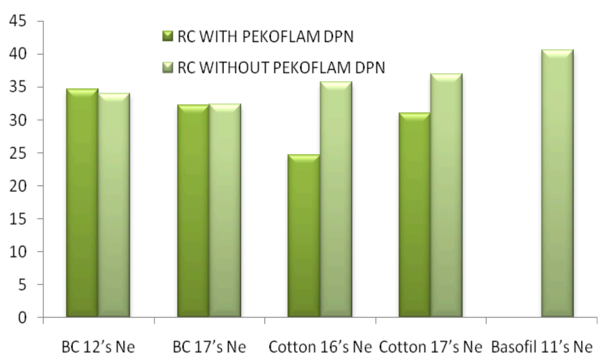

Figure 9 Comparative Graphs Compressional Resiliency

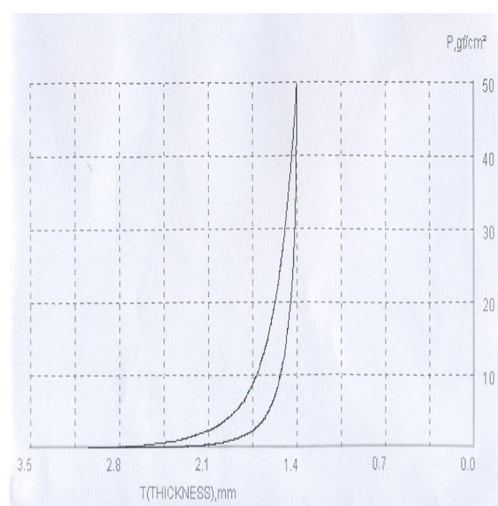

Figure 10 Compression Curve of 11 Ne Basofil® Fabric

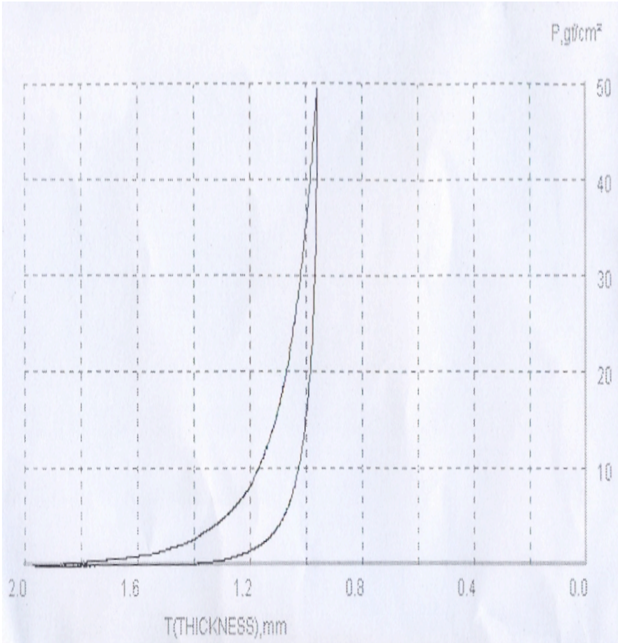

Figure 11 17 Ne Basofil® Cotton Blended Fabric without Finish

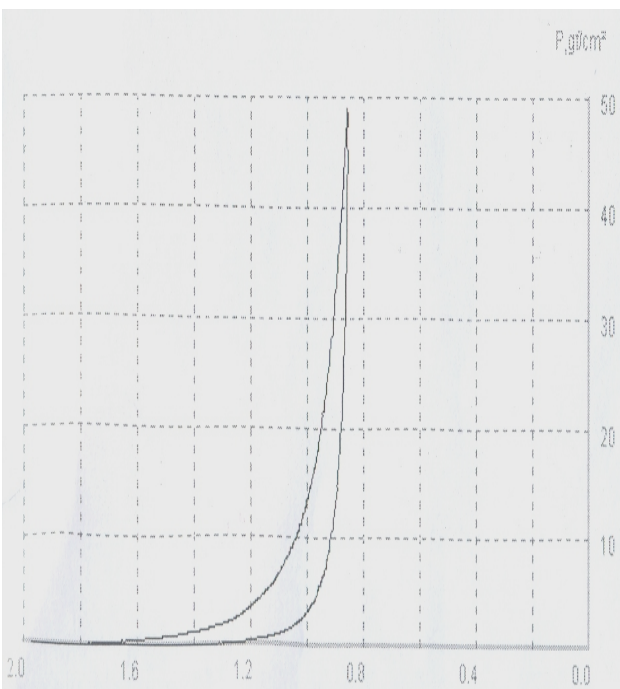

Figure 12 12 Ne Basofil® Cotton Blended Fabric without Finish

Fabric samples made using Basofil® yarn show high linearity of compression and compression resilience which means, the fabric exhibits good dimensional stability when an attempt is made to compress the fabric. While Basofil® blended fabrics show lower values because of the presence of the cotton fiber which is highly compressible. The very low compressibility of the Basofil® fiber is due to the bipartite structure of the yarn and brittleness of the fibers. Whenever the fabric is treated with Pekoflam finish the sheath fiber of the yarn gets finished and prevents the relative movement of the fibers and hence the fabric got a lower compressibility behavior. If we observe the LC of all samples, unfinished fabric samples show the LC higher LC value when compared to finished, since the unfinished fabric has more protruding fibers that resist the linear compressibility than the finished fabrics.

3.3 Shear Properties (KES-FB1)

Table 5 Shear Properties Using Tensile and Shear Tester

Sample		G	2HG	2HG5
	Wales	1.61	10.52	8.82
BASOFIL®	Course	1.85	9.42	9.10
	Mean	1.73	9.97	8.96

Shear Stiffness (G gf cm. Deg), Hysterisis of shear force at 0.5 Deg of shear angle (2HG gf/cm), Hysterisis of shear force at 5 deg of shear angle (2HG5 gf/cm)

From the **Table 5** it was identified that the wales of the yarn shows higher value when it is tested at 0.5 Degrees of hysteresis of shear force, which implies that the wale direction of the fabric has lower dimensional stability. When the fabrics were tested at 5 degrees, the structure of the fabric deformed to a higher extent due to the stress. If the yarn has higher twist and higher level of wrapper fibers lead to have lower dimensional stability, because the contribution of the core fiber is very less when compared to the sheath fibers.

4. Conclusions

1. 100% Basofil® yarn exhibit low tenacity, breaking work, breaking elongation and breaking time when compared to the cotton and basofil blended yarn yarn.
2. The cotton yarn shows more tenacity, breaking work, breaking elongation which is due to the

effect of the structural arrangement of the fiber in the yarn.

3. Cotton / Basofil® blend shows significant increase in the tensile characteristics due to the contribution of cotton fibers.
4. 100% Basofil® fabric exhibits high flame resistance compared to cotton fabrics while Cotton and cotton-Basofil® blended fabric show significant increase in the flame resistance characteristics when treated with Pekoflam DPN.
5. Basofil® fabric exhibits high dimensional stability with low compressibility when compared with cotton fabric
6. The Shear properties of Basofil® fabric show that it resists the shear force to a great extent, thickness and brittleness of the Basofil® fabric limit the ability of the fabric to be made and used as the apparel, which essentially require softer fibers to be blended.

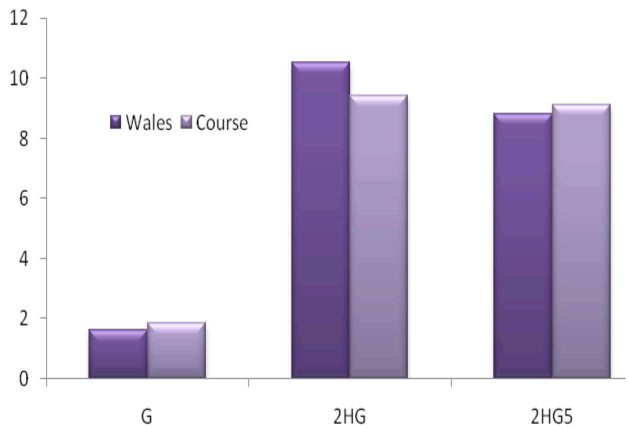

Figure 13 Hysteresis of shear force at 0.5deg, 5 deg of Shear angle and Shear Stress of the Basofil® Fabric (2HG gf/cm)

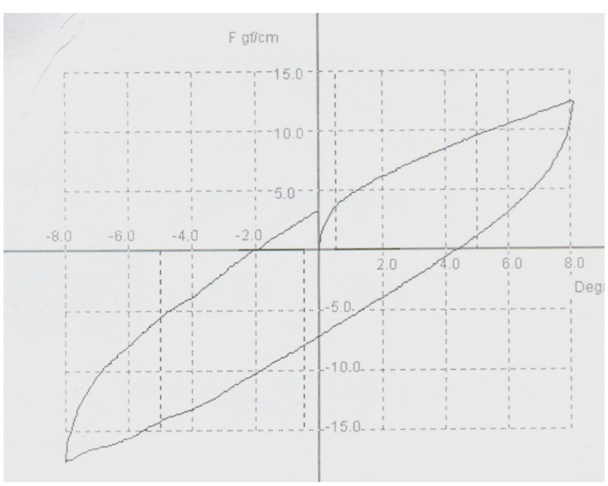

Figure 14 Hysteresis curve of the Basofil® 11s Ne Fabrics - Warp

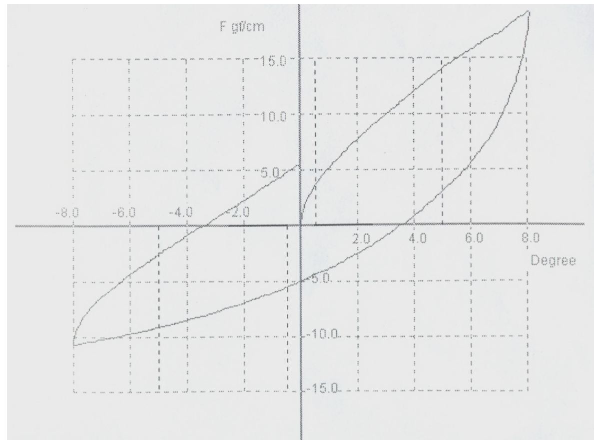

Figure 15 Hysteresis curve of the Basofil® 11s Ne Fabrics - Weft Directions

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