Compression Properties of Polyester Needlepunched Fabric

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ABSTRACT

In the present paper, a study of the effects of fabric weight, fiber cross-sectional shapes (round, hollow and trilobal) and presence of reinforcing material on the compression properties (initial thickness, percentage compression, percentage thickness loss and percentage compression resilience) of polyester needle punched industrial nonwoven fabrics is presented. It was found that for fabrics with no reinforcing material, the initial thickness, compression, and thickness loss were higher than fabrics with reinforcing material, irrespective offiber cross-section. Compression resilience data showed the reverse trend. Initial thickness for trilobal cross-sectional fabric sample was highest followed by round and hollow cross-sectioned polyester needle punched fabrics. The polyester fabric made from hollow cross-sectioned fibers showed the least percentage compression at every level of fabric weights. The trilobal cross-sectioned polyester fabric sample showed higher thickness loss followed by round and hollow cross-sectioned polyester fabric samples respectively. The hollow cross-sectioned polyester fabric samples showed maximum compression resilience followed by round and trilobal cross-sectioned polyester samples irrespective of fabric weights. The initial thickness increases, but percentage compression, thickness loss and compression resilience decreases with the increase in fabric weight irrespective of fiber cross-sectional shapes.

KEY WORDS

Compression, Compression resilience, Fiber cross-section, Needle-punched nonwoven, Polyester, Reinforcing material, Thickness loss.

INTRODUCTION

Compression property is one of the important properties of needle punched nonwoven fabric used in the area of carpet, geotextile and other industrial applications. Kothari *et al* [1] studied the effect of rate of compression and recovery, number of compression-recovery cycles and size of the pressure foot on the compression behavior of nonwoven fabrics. It was observed that as the rate of deformation increases, the compressibility and energy loss of the nonwoven fabrics decrease due to frequent and brisk compression. The compressibility, initial thickness and energy loss decreases sharply after the first cycle but after a few cycles, these parameters remain unchanged in case of cyclic loading. If the needled fabric is consolidated well it is expected to have better compression characteristics.

Fabric consolidation can be improved either by increasing the depth of needle penetration or needling density [2-5]. Dynamic loading characteristics of jute and polypropylene shows that the thickness loss increases with diminishing rate up to a certain limit and thereafter does not change [6]. Midha *et al* [7] studied the compression behavior of hollow polyester needle-punched fabric using the Box-Behnken experimental design wherein fabric weight, depth of penetration and punch density were considered. They reported that cross-laid structures show higher compressibility and lower recovery compared to parallel laid fabrics. It was found that finer denier and parallel laid webs led to more consolidation in the fabric. Debnath *et al* [8] studied the effect of polyester fiber cross-sectional shapes on fabric thickness, bending length, tensile, thermal insulation value and air permeability polyester of needle punched nonwoven. The Box-Behnken experimental design was used to study the effect of fabric weight, needling density and blend proportion on compression behavior such as initial thickness, compression, thickness loss of jute and polypropylene blended needle punched fabric [9, 10]. But, the effect of the fiber cross-section shape on compression properties has not been studied in detail.

The present study highlights the effects of fabric weight, fiber cross-sectional shapes (round, circular hollow and trilobal) and presence of reinforcement martial on the compression properties of initial thickness, percentage compression, percentage thickness loss and percentage compression resilience of polyester needle punched industrial nonwoven fabrics.

EXPERIMENTAL

Materials

Polyester fibers of 0.33 tex at three different cross-sections and light weight cotton fabric as reinforcing material were used in this study. The properties of the polyester fibers and reinforcing material are given in *Table I* and *Table II* respectively.

TABLE I Properties of Polyester fibers

FS	FL mm	LD tex	CF	T cN/tex	BE %	C %
Round	51	0.33	12.8	34.83	51.00	18.0
Circular hollow	51	0.33	12.0	38.43	21.05	17.0
Trilobal	51	0.33	13.0	37.53	50.28	18.0

FS - Fiber cross-sectional shape, FL – Fiber staple length, LD - Linear density, CF – Crimp frequency, T – Tenacity, BE – Breaking extension, C - Crimp

TABLE II Properties of cotton reinforcing material

Warp yarn	14.77 tex (40.00^s Ne)
Weft yarn	17.96 tex (32.88^s Ne)
Ends/cm	23.62
Picks/cm	18.90
Weight/unit area	76.25 g/m^2
Thickness	0.31 mm
Breaking extension	17.25 %
Tenacity at break	6.23 cN/tex

Methods

Experimental Design

The *Table III* identifies the fifteen sets of needle-punched nonwoven fabric samples prepared from polyester fiber having three different cross-sectional shapes namely. round, circular hollow and trilobal. Four fabric samples were prepared from each cross-sectioned polyester nominal weights of 415, 515, 680 and 815 g/m^2 with the reinforcing material. The needling density and depth of needle penetration were kept constant at 300 punches/cm^2 and 11 mm respectively. For all these samples the reinforcing material was kept at the centre of the web. In order to investigate the effect of reinforcing material, needle-punched fabrics without reinforcing material of 415 g/m^2 with a needling density of 300 punches/cm^2 were also produced The depth of needle penetration was 11 mm.

Nonwoven Fabric Production

The needling was done alternatively on each side of the fabric. For all the fabrics 15 x 18 x 36 x R/SP 3½ x ¼ x 9 needle made by Torrington Felting Needle USA) as illustrated in *Figure 1* were used. With reference to *Fiugre 1*, 15 swg (standard wire gauge) is the butt position of the needle, the intermediate area is 18 swg, the needle blade area is 36 swg, the distance between two protrusion is ¼″, the length of the total needle is 3½″, the total number of barbs present on the needle is 9, SP represent standard protrusion of needle barb and R indicate regular spacing of barbs as shown in *Figure 1* [11, 12].

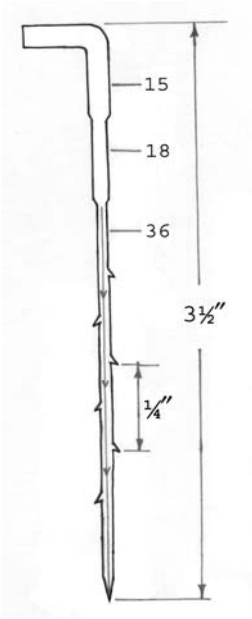

FIGURE 1 Diagram of a felting needle (dimensions are not to scale)

The cross-section of the needle blade position is equilateral triangle. The blade gauge selected is 36 swg for better needling and to avoid fiber damage [12]. *Table III* gives the constructional details of fabric samples. The depth of needle penetration was also kept constant at 11 mm in all the cases.

TABLE III Constructional details of experimental fabric samples

Fabric code	FS	FW g/m^2	ND punches/cm^2	RM
R1	Round	415	300	Yes
R2	Round	515	300	Yes
R3	Round	680	300	Yes
R4	Round	815	300	Yes
H1	Circular hollow	415	300	Yes
H2	Circular hollow	515	300	Yes
H3	Circular hollow	680	300	Yes
H4	Circular hollow	815	300	Yes
T1	Trilobal	415	300	Yes
T2	Trilobal	515	300	Yes
T3	Trilobal	680	300	Yes
T4	Trilobal	815	300	Yes
R5	Round	415	300	No
H5	Circular hollow	415	300	No
T5	Trilobal	415	300	No

FS – Fiber cross-sectional shape, FW – Nominal fabric weight, ND – Needling density, RM – Presence of reinforcing material

Measurement of Initial Thickness, Percentage Compression, Percentage Thickness Loss and Percentage Compression Resilience

The initial thickness, compression, thickness loss and compression resilience were calculated from the compression and decompression curves [9] [10]. The compression properties were studied under a pressure range between 1.55 kPa and 51.89 kPa. The compression and decompression curves were plotted from the correspondent thickness at a certain compression pressure as shown in *Figure 2*

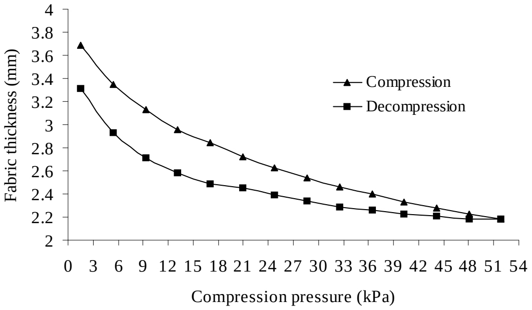

FIGURE 2 Typical compression and decompression curves of needle punched polyester fabric

The percentage compression, percentage thickness loss and percentage compression resilience [9, 13] were estimated using the relationship as given in Equations 1 - 3.

Compression (%) = $[(T_0 - T_1) / T_0] \times 100$ (1)

Thickness loss (%) = $[(T_0 - T_2) / T_0] \times 100$ (2)

Compression resilience (%) = $(W_c' / W_c) \times 100$ (3)

Where, T_0 is the initial thickness; T_1, the thickness at maximum pressure; T_2, the recovered thickness; W_c, the work done during compression; and W_c', the work done during recovery process.

RESULTS AND DISCUSSIONS

Effect of Reinforcing Material on Compression Properties

It can be observed from the *Table IV* that the initial thickness, percentage compression and percentage thickness loss is higher in the case of fabrics made without reinforcing material compared to that of fabric with reinforcing material, irrespective to the fiber cross-sectional shapes.

TABLE IV Effect of reinforcing material on compression properties

Fabric code	IT mm	C %	TL %	CR %	Presence of reinforcing material
R1	3.54	42.93	9.89	54.33	Yes
R5	4.67	50.91	18.98	49.76	No
H1	3.17	31.66	8.33	60.46	Yes
H5	4.98	56.65	19.55	46.76	No
T1	3.57	42.27	11.44	53.27	Yes
T5	5.82	60.50	24.82	46.28	No

IT – initial thickness, C – compression,
TL – thickness loss, CR – compression resilience

This clearly indicates that fabrics made without the support of a reinforcing material are much bulkier in nature, and can be compressed easily under the same pressure range to a much higher extent. When needled fabrics were produced with reinforcing material, better entanglement among the fibers and reinforcing material was achieved. This condition results in minimising fiber-to-fiber slippage during the process of compression and helps the deformed fibers to easily come back to their earlier position. A similar finding was also concluded by Sengupta *et al* [14] for jute needle punched nonwoven.

It is also clear from the *Table IV*, that irrespective of fiber cross-sectional shape the fabric with reinforcing material posses better compression resilience in comparison with fabric made without reinforcing material. As there are more fiber-to-fiber slippages during compression [15] in the fabric without reinforcing material this condition results in higher energy loss reducing the percentage compression resilience.

Effect of Fiber Cross-sectional Shapes and Fabric Weight on Compression Properties

Table V presents the effect of fiber cross-sectional shape on fabric initial thickness, thickness loss percentage compression and compressive resilience. The maximum thickness and close to highest value of % compression in fabrics is obtained with trilobal fibers followed by round and hollow cross-sectioned polyester fibers.

TABLE V Effect of fiber cross-sectional shapes and fabric weight on compression properties

Fabric Code	Fabric weight g/m^2	IT mm	C %	TL %	CR %
R1	415	3.54	42.93	9.89	54.33
R2	515	4.14	37.00	8.36	56.69
R3	680	5.13	28.35	6.19	54.21
R4	815	5.62	23.78	6.65	53.85
H1	415	3.17	31.66	8.33	60.46
H2	515	3.60	24.36	6.51	60.55
H3	680	4.69	18.09	5.53	59.28
H4	815	5.53	16.13	4.56	58.27
T1	415	3.57	42.27	11.44	53.27
T2	515	4.37	37.93	10.17	54.11
T3	680	5.58	25.43	6.97	53.83
T4	815	6.58	23.19	7.41	51.80

IT – initial thickness, C – compression,
TL – thickness loss, CR – compression resilience

The trilobal cross-section polyester has higher surface area than other types of cross-sectional polyester fibers used in this study, which results in thicker fabrics. The fabrics made with hollow fiber, have better consolidated structure than those made with round cross-section polyester fiber, though the surface area of hollow cross-sectioned polyester is much larger than round cross-sectional polyester fiber. This is probably due to hollow structure of the fiber, and fine denier of the hollow fiber used in the study. The fabric is more consolidated as well and the percentage compression and resilience is also less for hollow cross-section fiber compared to other cross-section polyester samples due to higher stiffness of hollow polyester fiber. Midha *et al* [7] also reported that hollow polyester of finer denier will help in producing a better consolidated fabric structure.

Among the fibers considered, trilobal polyester fiber produces fabrics with higher thickness loss and compressive resilience. With the trilobal cross-section fibers during compression, due to pressure all the fiber lobes gets compressed and these ribs or lobs on the fiber outer surface probably gets trapped to each other which will restrict its recovery when the load is released. This may be the reason that the percentage thickness loss is much higher in the case of trilobal polyester samples. With hollow cross sectional polyester fibers the fabric is in a reasonably consolidated state, which can be substantiated by the fact that the initial thickness is least among the three groups of samples. With compression the fabric with hollow cross-sectional polyester gets denser. This results in better recovery after the compression pressure is released. This is also reflected by the trend with compression resilience percentage.

A better consolidated structure can also be achieved with the use of more solid round fibers of the same fineness instead of using hollow cross-sectional fibers. In such condition the fabric with the higher percentage of solid round fibers would be heavier. It has been reported in the literature that fabrics made from coarser fibers show higher compressibility and lower recovery compared to fabrics made from finer fibers [16, 17]. This was attributed to the fact finer fibers can bend easily leading to compact structure and higher surface area resulting in better interlocking of the structure. With hollow fibers the same effect we will yield higher fiber surface area and more bending of fibers resulting in better consolidation in the structure. This condition results in lower % compression and better resilience.

As shown in *Table V* , the percentage compression decreases with the increase in fabric weight for all three cross-sectioned polyester samples. With the increase in weight the amount of fibers per unit area of the fabric increases, and the compressive load will be shared by a greater number of fibers. Hence, a decrease in percentage compression is observed with the increase in fabric weight. The thickness loss initially decreases rapidly with the increase in fabric weight. Further, with an increase in fabric weight the thickness loss value remains unchanged [9] irrespective of fiber cross-section. Most likely, better entanglement of fibers results in a reduction in fiber-to-fiber slippage during the comprression phase. These factors bring about better compression recovery.

CONCLUSIONS

If needle punched nonwoven fabrics are manufactured for end uses wherein compressional characteristics are of paramount importance, it is better to produce them with some reinforcing material. Under such circumstances the cross section of the fiber used has no influence on the compressional properties. If fabrics are produced without reinforcing material and better fabric resilience is required it is suggested that hollow fibers be used.

ACKNOWLEDGEMENT

One of the authors (S D) is grateful to the Director of National Institute of Jute and Allied Fiber Technology, Kolkata, India, for encouragement and valuable support and is also thankful to CSIR, New Delhi, India for awarding Senior Research Fellowship during this project work.

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