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A Comparative Study of the Thermal Insulation Properties of Jute and Jute - Polyester fibre Blended Nonwoven Fabrics

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ABSTRACT: *Materials based on natural fibres are now becoming increasingly popular as thermal insulating material. Due to its low mass, density and cell structure, they show fairly good thermal insulation properties, often better and more advantageous than synthetic fibres. A great benefit of the insulation property based on natural fibres is not only a low value of thermal conductivity but also the natural character of these fibres. This paper delineatesto develop different blends of fibres comprising of jute and other fibres like recycled polyester (PET) and low melt bi-component fibres (PET) to produce needle punched nonwoven fabrics for using as thermal insulating material and to assess and compare the different functional properties of the developed nonwoven fabric samples for their suitability as thermal insulating material.*

Keywords: *Thermal Insulation, CLO value, Air permeability, gsm, Thickness*

I. INTRODUCTION

Thermal properties like thermal conductivity, thermal resistance, thermal insulation, etc. are important in many textile applications such as apparel, blankets, and sleeping bags, interlinings, building insulation, automobiles, aircraft and industrial process equipment [1]. In fact, these thermal properties are fundamental to determine the heat transfer through fabrics [2]. The thermal property of fabric is very important for both its thermal comfort and protection against challenging weather conditions [3]. The different types of textile materials which are generally used as thermal insulation media are mostly in nonwoven, woven and knitted forms. Thermal conductivity of needled nonwoven structures can be predicted with high accuracy using model with fabric thickness, porosity and structure along with applied temperature as was investigated by Mohammadi et al. [4]. Jirsak et al. concluded that thermal conductivity decreases with increasing material density [5]. Morris concluded that when two fabrics have equal thicknesses but different densities, fabric with lower density shows greater thermal insulation [6]. Abdel-Rehim et al. studied heat transfer through different fabrics made by polypropylene and polyester mass in a range from 400 to 800 g/m2 and they concluded that the investigated fabrics have high thermal performance and thermal response as insulators [7]. Saleh investigated properties of needled lining produced from polyester, cotton and recycled fibre and concluded that fabric thickness, mass and fibre type affect the thermal properties of the fabric [8]. In the same study the compressed linings show lower thermal insulation properties compared with non-compressed which was explained by a possible amount of trapped air of non-compressed nonwoven lining which provides greater thermal insulation. The calendering process gives a more compact structure of nonwoven fabrics, thus resulting in a controlled and predictable compressibility. With calendering needled polypropylene nonwoven fabrics the range of porosity becomes narrow when the characteristic opening sizes is reduced [9]. The influence of the calendering process of polypropylene nonwoven geotextiles on water permeability under different loads, as well as pore characteristics have been recently investigated and it has been concluded that additional bonding with calendering needled polypropylene nonwoven geotextiles provides a more controlled and predictable performance considering only needled geotextiles [10]. Debnath and Madhusoothanan have studied thermal resistance and air permeability of needle punched nonwoven fabric made from jute and polypropylene blends to observe the effect of fabric weight, needling density and blend proportion on thickness, thermal resistance, specific thermal resistance, air permeability and sectional air permeability [11]. They concluded that thermal resistance and thickness increase but air permeability and sectional air permeability decrease significantly with the increase in fabric weight at all levels of jute contents [12]. The reclaimed fibre based nonwoven materials, suitable for automotive application, was studied were authors founded that thermal conductivity of reclaimed fibre-based nonwoven materials varies significantly, depending on the type of reclaimed fibres and the resulting bulk density of the materials [13]. Determination of heat transfer by radiation in woven and nonwoven fabrics was investigated were authors concluded that nonwoven fabrics showed substantially higher increase of thermal conductivity with temperature than woven fabrics due to strong free convection effects caused by high temperature drop between the layers [14]. Nonwoven fabrics produced from polypropylene fibers are used in industry as thermal insulators. By development of its applications there is a need for thermal insulators of lower thickness. Tiwari M. [15] stated that clothing system must be able to control inward and outward flow of heat to maintain body temperature to avoid serious hazard to body. Slater K. [16] summarized that heat transfer between human and surrounding environment together with the movement of moisture constitutes the major thermal comfort maintaining mechanism. The resistance offered by fabric to the movement of heat through it is important to maintain its thermal comfort. Slater K. [16] also stated that the total thermal resistance to transfer of heat from the body to the surrounding has three effective components which are resistance to heat transfer from the material surface to surrounding, thermal resistance of clothing material itself and thermal resistance of the air trapped inside the fabric. Nonwovens have large number of air voids entrapped inside the fabric structure thereby giving better barrier against heat flow. Choi et al [17] concluded that nonwoven widely accepted as protective garment in medical and industrial areas due to enhanced and tailor-made thermal and comfort properties.

II. MATERIAL AND METHODS

2. Raw Materials

In order to fulfil the objectives of this project work three types of fibres have been procured, namely, jute 3rd drawing sliver (TD3 grade), stapled to 41 mm length, recycled polyester (PET)-in bale forms and low melt bi-component polyester (PET) fibre. The particulars of the above mentioned fibres after being tested and analyzed in the Textile Physics Laboratory, Department of Jute and Fibre Technology, Institute of Jute Technology, University of Calcutta are furnished in the table 1 below-

Table 1: Particulars of raw materials

Fibre	Fineness (denier)	Cut length (mm)	Tenacity (cN/ denier)	Elongation (%)	Work of rupture (Nmm)
Jute fibre	18	41	3.064	1.25	0.114
Recycled Polyester fibre	15	50	2.031	49.96	2.686
Low-melt Bi-component Polyester fibre	6	40	2.128	30.86	1.000

2.1 Manufacturing of the blended and non-blended fabric samples

Total twelve (12) numbers of fabric samples have been prepared in the Needle Punching Machine-laboratory model (specifications are furnished in table 3), which include ten (10) numbers of different blended fabric samples along with two (2) numbers of non-blended fabric samples. For easy understanding and smooth implementation of the project work, the samples prepared have been coded as provided in the table 2 below-

Table 2: Fibre Composition and Coding

SL. No.	Fibre composition	Coding
1	100% Recycled Polyester	S1
2	80% Recycled Polyester + 20% Low-melt Bi-component fibre	S2
3	80% Recycled Polyester + 20% Low-melt Bi-component fibre (Heat Treated)	S3
4	50% Jute + 30% Recycled Polyester + 20% Low-melt Bi-component fibre	S4
5	50% Jute + 30% Recycled Polyester + 20% Low-melt Bi-component fibre (Heat Treated)	S5
6	60% Jute + 20% Recycled Polyester + 20% Low-melt Bi-component fibre	S6
7	60% Jute + 20% Recycled Polyester + 20% Low-melt Bi-component fibre (Heat Treated)	S7
8	70% Jute + 10% Recycled Polyester + 20% Low-melt Bi-component fibre	S8
9	70% Jute + 10% Recycled Polyester + 20% Low-melt Bi-component fibre (Heat Treated)	S9
10	80% Jute + 20% Low-melt Bi-component fibre	S10
11	80% Jute + 20% Low-melt Bi-component fibre (Heat Treated)	S11
12	100% Jute	S12

Table 3: Specifications of Needle Punching Machine employed in this work

Name of the Instrument	DILO Machines GmbH, Germany (Laboratory Model)
Model No.	F7/6-10135/2012
Type	(1) One sided punching system (2) Double needle board (3) Chute feed with worsted card (4) Cross Lapper System controlled by electronic panel board
Dimension	(1) Working width:70 cm (2) Finished Fabric Width: 60 cm (max)
Density of needle per square inch in the needle board	17
Needle Punching Parameters	(1)Max punch per min.:1200 (2) Penetration of needle up to 10 mm. (3) Capacity of fibre length up to 10 cm
Needle Parameters	(1) Needle gauge: 40 (2) Needle cross-section: Triangular (3) No. of barbs per apex: 2
Needle Board Parameters	(1) Length: 26.5 inch (2) width: 7 7/8 inch (3) Effective length: 24.5 inch (4) Effective Width: 7 inch

III. RESULTS AND DISCUSSION

3. Results

In this project work total twelve (12) numbers of different nonwoven fabric samples have been produced in the DILO Needle Punching Machine (Laboratory Model) which include ten (10) numbers of blended fabric samples and two (2) numbers of non-blended nonwoven fabric sample.

Table 4: Test Methods followed for carrying out the tests of the properties of the nonwoven fabric samples

Sl. No.	Property tested	Test Method followed
1.	Determination of Mass per unit Area of the produced fabric samples expressed in gram per unit square metres (gsm)	ASTM D5261-10
2.	Determination of Nominal Thickness of the produced fabric samples expressed in mm	ASTM D5199-12
3.	Determination of shrinkage in machine direction, expressed in percentage, of the developed fabric samples.	Laboratory developed method
4.	Determination of shrinkage in cross-machine direction, expressed in percentage, of the developed fabric samples.	Laboratory developed method
5.	Determination of Apparent Opening Size (AOS) of the produced fabric samples.	ASTM D4751-12
6.	Determination of Air Permeability of the produced fabric samples.	IS 11056:1984
7.	Determination of Thermal Insulation Value, in terms of CLO value, of the produced fabric samples.	Niven's Hot Plate Method

Table 5: Mass per unit area of the nonwoven fabric samples

Sl. No.	Sample description with code	Mass per unit area (in gsm)
1.	S1 (100% Recycled Polyester)	282
2.	S2 (80% Recycled Polyester + 20% Low-melt Bi-component fibre)	267.6
3.	S3 (80% Recycled Polyester + 20% Low-melt Bi-component fibre) Heat Treated	281.2
4	S4 (50% jute, 30 % recycled polyester, 20% bi-component low-melt polyester)	268.4
5.	S5 (50% jute, 30 % recycled polyester, 20% bi-component low-melt polyester) Heat treated	304.8
6.	S6 (60% jute, 20 % recycled polyester, 20% bi-component low-melt polyester)	297.0
7.	S7 (60% jute, 20 % recycled polyester, 20% bi-component low-melt polyester) Heat treated	304.6
8.	S8 (70% jute, 10 % recycled polyester, 20% bi-component low-melt polyester)	230.6
9.	S9 (70% jute, 10 % recycled polyester, 20% bi-component low-melt polyester) Heat treated	249.8
10.	S10 (80% Jute + 20% Low-melt Bi-component fibre)	210.6
11.	S11 (80% Jute + 20% Low-melt Bi-component fibre) Heat Treated	219.6
12.	S12 (100% jute nonwoven fabric sample)	249.4

It has been observed from table 5, that nonwoven fabric samples, S5 and S7 shows maximum fabric weight of 304.8 gsm and 304.6 gsm respectively and sample, S10 shows the minimum fabric weight of 210.6 gsm. It has been observed that the treated fabric samples, S3, S5, S7, S9 and S11 shown comparatively high fabric weight values than that of the respective untreated fabric samples S2, S4, S6, S8 and S10. This is mainly attributed due to the shrinkage of the fabric sample causing an increase in mass of the total number of fibres per unit area. The compaction that accompanies shrinkage is useful in obtaining greater fabric weight and density, more bulk and improved properties. While nonwoven fabric sample S1 (100% recycled polyester) and S12 (100% jute), were not heat treated as there is no bi-component fibres in these samples.

Table 6 (a): Shrinkage of the nonwoven fabric samples in machine direction

Sample code	Length before heat treatment (cm)	Length after heat treatment in (cm)	Shrinkage % in length after heat treatment
S2 and S3	224	212.5	5.13%
S4 and S5	221	214.5	2.94%
S6 and S7	192	185.75	3.25%
S8 and S9	300	285.75	4.75%
S10 and S11	184	178.4	3.04%

Table 6(b): Shrinkage of the nonwoven fabric samples in cross machine direction

Sample Name	Width before heat treatment in (cm)	Width after heat treatment in (cm)	Shrinkage % in width after heat treatment
S2 and S3	39.0	36.5	6.41%
S4 and S5	40.0	37.0	7.50%
S6 and S7	40.0	37.0	7.50%
S8 and S9	40.0	37.4	6.50%
S10 and S11	39.5	37.0	6.30%

Tables 6 (a) and (b) show that shrinkage of the fabric samples S3, S5, S7, S9 and S11 after heat treatment shrink more in cross machine direction than that in machine direction

Table 7: Thickness of the nonwoven fabric samples

Sl.No.	Sample description with code	Thickness (in mm)
1.	S1 (100% Recycled Polyester)	4.45
2.	S2 (80% Recycled Polyester + 20% Low-melt Bi-component fibre)	4.46
3.	S3 (80% Recycled Polyester + 20% Low-melt Bi-component fibre) Heat Treated	5.01
4	S4 (50% jute, 30 % recycled polyester, 20% bi-component low-melt polyester)	3.67
5.	S5 (50% jute, 30 % recycled polyester, 20% bi-component low-melt polyester) Heat treated	4.54
6.	S6 (60% jute, 20 % recycled polyester, 20% bi-component low-melt polyester)	4.51
7.	S7 (60% jute, 20 % recycled polyester, 20% bi-component low-melt polyester) Heat treated	4.72
8.	S8 (70% jute, 10 % recycled polyester, 20% bi-component low-melt polyester)	3.53
9.	S9 (70% jute, 10 % recycled polyester, 20% bi-component low-melt polyester) Heat treated	4.13
10.	S10 (80% Jute + 20% Low-melt Bi-component fibre)	3.21
11.	S11 (80% Jute + 20% Low-melt Bi-component fibre) Heat Treated	3.39
12.	S12 (100% jute nonwoven fabric sample)	3.61

Table 7 show that treated fabric samples, S3, S5, S7, S9 and S11 are having comparatively high thickness values than that of the untreated fabric samples S2, S4, S6,S8 and S10 respectively. This is because during the heat stretching of the nonwoven fabric samples, the fibres align along cross machine direction of the web, therefore two controversial changing trends in the web structure influence on the change in thickness of the fabric samples. The nonwoven webs got stretched along machine direction meanwhile also shrink along cross machine direction. The shrinkage along cross machine direction dominated resulting into an increase in the web thickness (ref. Influence of Heat-Stretching Treatment on Structure and Properties of Bico MB Nonwoven Webs by Dong Zhang, Christine (Qin) Sun and Yanbo Liu, Textiles and Nonwovens Development Center (TANDEC), The University of Tennessee, Knoxville, TN 37996, http://www.jeffjournal.org/INJ/inj04_1/p42-48-zhang.pdf).

Table 8: Air Permeability values of the nonwoven fabric samples

Sl. No.	Sample description with code	Rotameter Reading (litre/hr.)	Air Permeability (m3/m2/min)
1.	S1 (100% Recycled Polyester)	8550	142.52
2.	S2 (80% Recycled Polyester + 20% Low-melt Bi-mponent fibre)	7500	125.025
3.	S3 (80% Recycled Polyester + 20% Low-melt Bi-mponent fibre) Heat Treated	7700	128.359
4	S4 (50% jute, 30 % recycled polyester, 20% bi-mponent low-melt polyester)	6937.5	115.64
5.	S5 (50% jute, 30 % recycled polyester, 20% bi-mponent low-melt polyester) Heat treated	8062.5	134.402
6.	S6 (60% jute, 20 % recycled polyester, 20% bi-mponent low-melt polyester)	7125	118.773
7.	S7 (60% jute, 20 % recycled polyester, 20% bi-mponent low-melt polyester) Heat treated	7175	119.607
8.	S8 (70% jute, 10 % recycled polyester, 20% bi-mponent low-melt polyester)	7500	125.025
9.	S9 (70% jute, 10 % recycled polyester, 20% bi-mponent low-melt polyester) Heat treated	7575	126.275
10.	S10 (80% Jute + 20% Low-melt Bi-component bre)	7037.5	117.315
11.	S11 (80% Jute + 20% Low-melt Bi-component bre) Heat Treated	8062.5	134.402
12	S12 (100% jute nonwoven fabric sample)	7725	128.775

Table 8 show that the air permeability values of the heat treated fabric samples, S3, S5,S7, S9 and S11 are higher than that of the fabric samples S2, S4, S6, S8 and S10 respectively. This increase in permeability is mainly associated with the non-random distribution of fibres, and this lack of randomness occurs because needled nonwovens have areas that have not been needled and where the fibers are still randomly oriented. However, the areas where the needle penetrates the fibers are not considered to be randomly distributed. In these areas, a channel may be formed that reduces tortuosity, that is the ratio of effective channel length and sample thickness and thus increasing the permeability of the nonwoven samples [*ref. Frontiers in Science 2012, 2(6): 226-234- Maity et. al.*].

Table 9: Apparent Opening Size (AOS) Values of the nonwoven fabric samples

Sl. No.	Sample description with code	Apparent Opening Size (AOS) in O_{95} micron
1.	S1 (100% Recycled Polyester)	440
2.	S2 (80% Recycled Polyester + 20% Low-melt Bi-component fibre)	420
3.	S3 (80% Recycled Polyester + 20% Low-melt Bi-component fibre) eat Treated	407
4	S4 (50% jute, 30 % recycled polyester, 20% bi-component low-melt lyester)	384
5.	S5 (50% jute, 30 % recycled polyester, 20% bi-component low-melt lyester) Heat treated	246
6.	S6 (60% jute, 20 % recycled polyester, 20% bi-component low-melt lyester)	389
7.	S7 (60% jute, 20 % recycled polyester, 20% bi-component low-melt lyester) Heat treated	370
8.	S8 (70% jute, 10 % recycled polyester, 20% bi-component low-melt lyester)	409
9.	S9 (70% jute, 10 % recycled polyester, 20% bi-component low-melt lyester) Heat treated	248
10.	S10 (80% Jute + 20% Low-melt Bi-component fibre)	396
11.	S11 (80% Jute + 20% Low-melt Bi-component fibre) Heat Treated	383
12.	S12 (100% jute nonwoven fabric sample)	419

It is observed from table 9, that the nonwoven fabric samples S3, S5, S7, S9 and S11 show a decreasing trend in their AOS values when compared with their untreated counterparts S2, S4, S6, S8 and S10 respectively. This is because "at a high heat treatment temperature, formation of the pore structure of the materials begins to be determined by the shrinkage properties of the bi-component fibres. With an increase in the temperature, the effect of the shrinkage properties of the bi-component fibres becomes determining, and this decreases the porosity of the materials"-E. K. Savel'eva et.al, Fibre Chemistry, Vol. 37(3), 2005, http://download.springer.com/static/pdf/944.

Table 10: Thermal Insulation Values (TIV) expressed in CLO and TOG of the nonwoven fabric samples

Sl. No.	Sample description with code	CLO Values
1.	S1 (100% Recycled Polyester)	3.06
2.	S2 (80% Recycled Polyester + 20% Low-melt Bi-component fibre)	2.9
3.	S3 (80% Recycled Polyester + 20% Low-melt Bi-component fibre) Heat Treated	3.1
4	S4 (50% jute, 30 % recycled polyester, 20% bi-component low-melt polyester)	2.3
5.	S5 (50% jute, 30 % recycled polyester, 20% bi-component low-melt polyester) Heat treated	2.5
6.	S6 (60% jute, 20 % recycled polyester, 20% bi-component low-melt polyester)	1.9
7.	S7 (60% jute, 20 % recycled polyester, 20% bi-component low-melt polyester) Heat treated	2.0
8.	S8 (70% jute, 10 % recycled polyester, 20% bi-component low-melt polyester)	1.8
9.	S9 (70% jute, 10 % recycled polyester, 20% bi-component low-melt polyester) Heat treated	1.9
10.	S10 (80% Jute + 20% Low-melt Bi-component fibre)	1.7
11.	S11 (80% Jute + 20% Low-melt Bi-component fibre) Heat Treated	1.75
12.	S12 (100% jute nonwoven fabric sample)	1.6

It is observed from table 10, that the CLO values of the fabric samples show a decreasing trend from S1 to S12. This may be probably due to high moisture content present in S12 (100% jute) fabric sample and the loss in insulation is proportional to the moisture content. The heat of the sorption of fibre increases with an increase in moisture content, and is generally high for fibres having high moisture content. This is an agreement with the observations made by Hollies and Bogaty [*Ref. Hollies N R S and Bogaty H, Text. Res J., 35(1965), pp 187*]. It is found that when the fibres absorb moisture, they become warmer and release the sum of heat of condensation of the water and heat of chemisorption [*Ref. Gupta N P et al. Indian J Fibre Textile Res., 23 (1998), pp 32*].

IV. DISCUSSIONS

The effectiveness of using nonwoven materials, for thermal insulation is basically determined by their basis weight (fabric weight), bulk density, compactness and porosity of the structure. The effect of shrinkage properties on heat treatment of the nonwoven materials which include blended products of low melt bi-component polyethylene terephthalate and jute fibres, recycled polyethylene terephthalate and jute fibres and non-blended 100% jute fibres respectively, on the fabric weight, thickness, air-permeability and porosity of the structures have been studied here. A comparison of the behaviour of the blended nonwoven fabric samples before and after heat treatment, along with that of the non-blended 100% jute nonwoven material is carried out here. The following conclusions are drawn from this work.

1) Heat treatment of the nonwoven fabric samples has shown that the fibres got shrinked both along machine direction and cross machine direction. The shrinkage of the produced nonwoven materials along cross machine direction dominated resulting into an increase in the web thickness.
2) The compaction that accompanies shrinkage resulted in obtaining greater fabric weight and density.
3) With an increase in the temperature, the effect of the shrinkage properties of the blended low-melt bi-component polyethylene terephthalate and jute fibres and becomes determining, and this decreases the porosity of the materials.
4) The air permeability values of the heat treated fabric samples, S3, S5, S7, S9 and S11 are found to be higher than that of the untreated fabric samples S2, S4, S6, S8 and S10 respectively. This increase in permeability is mainly associated with the non-random distribution of fibres, and this lack of randomness occurs because needled nonwovens have areas that have not been needled and where the fibers are still randomly oriented.
5) The thermal insulation value, determined in CLO value, show an decreasing trend of the nonwoven materials ranging from S1 to S12. This may be probably due to high moisture content present in S12 (100% jute) fabric sample and the loss in insulation is proportional to the moisture content. The heat of the sorption of fibre increases with an increase in moisture content, and is generally high for fibres having high moisture content.

Eventually, after analyzing the results obtained from this project work, it can be concluded that synthetic and natural fibre blended nonwoven materials offer better advantages as thermal insulation materials, at par with non-blended 100% natural fibre made nonwoven material like jute, exhibiting similar properties with respect to fabric weight, thickness, bulk density, compactness and porosity of the structure including their thermal insulation property.

V. CONCLUSION

It is found from the study that the gsm of fabrics containing bi-component fibre as a constituent increases on heat treatment due to fabric shrinkage as explained previously. The rate of increase is maximum between samples S4 and S5. This increment in gsm may be successfully utilized to manufacture fabrics at a lower gsm. It is also evident that the shrinkage is more dominant in the cross machine direction of the fabric samples. It can be concluded that the maximum increment in thickness takes place between the fabric samples S4 and S5. This property may be utilized in manufacture of thicker and bulkier nonwoven insulation bats at lower gsm. Samples S4 and S5 and samples S10 and S11 show remarkable increase in air permeability after heat treatment and the reason being increased tortuosity as discussed previously and the maximum reduction in AOS values. This property may be successfully utilized in manufacture of a fabric with reduced pore size. Fabric sample S3 shows the highest clo value followed closely by sample S1 whereas sample S12 displays the lowest clo value. From the above discussions it may be concluded that, use of 100% jute nonwoven as an insulating media is not at all recommendable.

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