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Development and Analysis of the Thermal Behaviour of Non-Woven Fabric made with Cotton and Acrylic Blend

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ABSTRACT

Thermal insulators are composed of fibres that have greater resistance towards heat, light radiation, chemical resistance, and other related properties in their specified area of application. Major applications of thermal insulators in the form of non-woven fabrics are apparel, interlinings, blanket and sleeping rugs, automobiles, shoe covers, carpets, building insulators, and industrial packing equipment. In this research work, we have developed an engineered non-woven thermal insulator fabric from Cotton/Acrylic blend by stitch bonding process by the laying of fibres during web preparation. Here, we selected fibres cotton and acrylic for the production of non-woven thermal insulation because of their comparatively lower cost, availability, better thermal stability, for its attractive physical and mechanical properties. Different blending ratios, GSM and stitch density were taken into consideration as the main factors focused during sample preparation. Then, the non-woven fabrics were taken for laboratory testing of its GSM, stitch density, thickness, air permeability, and thermal conductivity tests. The thermal conductivity tests were carried out using static or gravitational method with WL 372 radial and linear heat conduction instruments. As per the test results, the thermal conductivity of the developed fabrics shows increment with the reduction of fabric weight, stitch density, air permeability and cotton fibre content in the blending composition.

Keywords: Thermal conductivity; thermal insulation; stitch bonded; nonwoven fabric; blending.

INTRODUCTION

Thermal properties influence performance in technical non- woven applications such as building insulation, automobiles, aircraft, and industrial process equipment [1]. A textile structure is mainly a mixture of fibers, air, and moisture, each having distinctively different thermal properties.

Thus, the thermal property of the system is the collective and interactive result of these three constituents. Non-woven materials because of savings in both space and cost are one of the most important products in textiles that are being used as thermal insulating materials [2]. They are formed by bonding textile fibers in the form of sheet, web, or batt structure either, mechanically, thermally or chemically [3]. However, the thermal insulation properties of the non-woven materials vary significantly depending on the type of different fibers in the composition [4]. Thermal insulation of non-woven fabric will be increased by increasing the weight, thickness, punch density and pressure on the fabric [5], [6].

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Acrylic, cotton and polyester fibers have been used in non- woven textile and clothing field due to their easy availability at a comparatively lower cost, and favourable physical and mechanical properties which may be suitable for thermal insulation material [6]. The heat setting properties and higher glass transition temperature of polyester and acrylic fibers can be employed with advantage in the manufacturing of better thermal insulating nonwoven fabrics by needle punching because more time is required to heat up and radiate energy [7]. In addition, the required fiber properties of cotton such as absorbency, lower electrostatic charge generation, superior comfort, ease of blending, disposability and sanitation value have been used to improve the nonwoven fabric properties in the blend ratios. These behaviours make cotton products feel comfortable and soft [8]. Due to its wide range of applications, attractive properties and its compatibility with technologies used to produce versatile products, cotton has long been one of the most preferable fibers [9]. The fibers are commonly blended or mixed in order to improve performance properties of nonwovens, such as strength, thermal insulation and other properties. The properties of nonwoven fabrics are mainly dependent on fiber properties and fabric structural geometry [10]. Therefore, the selection of fibers for this study depends on the cost-effectiveness, the ease of process ability, and the desired end-use properties [11], [12], [13].

Based on the above considerations, the stitch bonded nonwoven fabrics with different blend ratios, mass per unit area (web area density), and stitch density (course spacing) of cotton-acrylic blended nonwovens were developed in our research work. The developed nonwoven fabrics were investigated for their thermal behaviour of testing and characterization.

MATERIALS AND METHODS

Flow Process

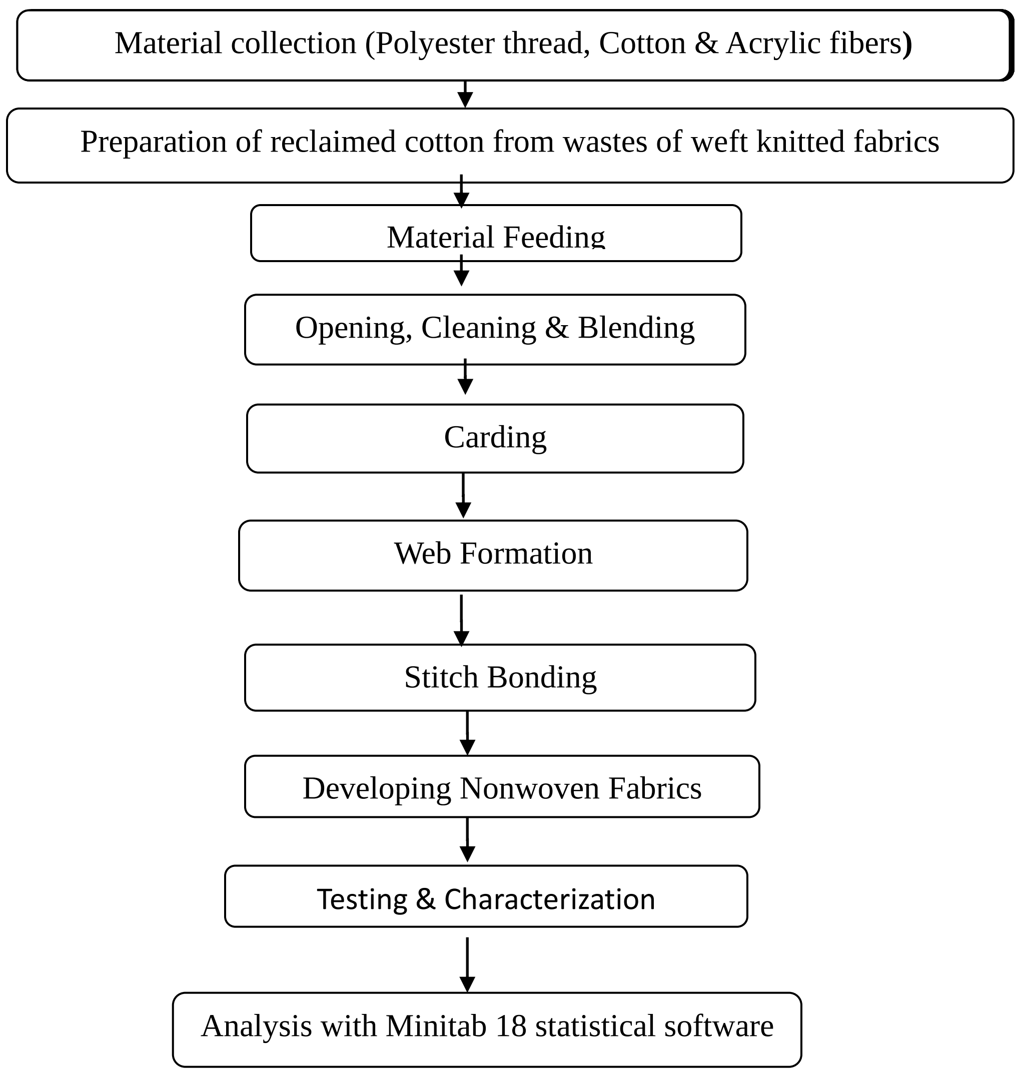


Fig.1 Experimental flow chart

Materials

Cotton fibers with 4.01mic. fineness and acrylic fibers (77 ‘s Ne) and polyester thread (18’s Ne count) for stitch bonding were used. The raw materials used for this study were chosen as reclaimed cotton, polyester thread and acrylic fibers due to widespread availability in market, cheap price and conformity of these fibers to the production method.

Preparation of Reclaimed cotton fibers

The cutting wastes from the garment industry have been collected in the form of fresh waste fabric. Cut pieces wastes were weft knitted fabrics by cotton fibers only. The raw clothing materials had to be converted in to yarn by tearing machines in the preparatory stage. The cut fabric pieces also passed through two nipped feed rollers that grip the textile while a rapidly rotating cylinder covered in sharp metallic pins opens the fabric into smaller fractions mechanically. Typically, the mechanical pulling consists of a mixture of individual fibers, yarn segments and smaller fabric pieces. The further separation stages were used to increase the reduction of the segments and pieces into fiber stage. The fiber is then collected on a vacuum assisted drum and fed out of the machine.

Optimization of fiber properties from the previous studies

The fibers like polyester and acrylic have been selected not only for their better heat setting properties but also with their greater glass transition (90 °c and 100 °c) and melting temperature (255 °c and 320 °c) respectively. These fibers have lower inherent thermal conductivity properties of fibers (0.157 w/mk and 0.172 w/mk) respectively because more time is required to heat up and radiate energy. The reclaimed fiber, extracted from fabric cut pieces of garment industry having 4.01 mic., which is finer than virgin cotton, and with better breathability behaviour also used as better thermal insulator. The properties of the component fibers in the fabric composition have been transferred to the properties of the developed nonwoven fabrics, which have been inserted by optimization of fiber properties from the previous studies in order to get better thermal insulation properties.

Preparation of samples

Functions of blow room, carding, and stitch bonding processes were carried out in a separate machine. The webs of required aerial density from the carding machines have been fed to Stitch bonding for the production of non-woven fabric samples during this research work. The raw materials of both reclaimed cotton and acrylic fibers have been blended manually in an intensive manner with different proportions as given in Table 1 below.

Table 1. Blend Ratio

	Cotton (%)	Acrylic (%)
X	70	30
Y	50	50
Z	30	70

The prepared web was formed by the carding machine. The cross laying of the web in the machine was carried out to produce the nonwoven samples. The feed speed, stroke frequency and the other parameters of the needle loom were arranged to get a stitching density of 18 and 34 stitches/inch accordingly. The depth of needle penetration was kept at 10mm and the delivery speed was adjusted to 0.96m/min. Twelve different samples were produced considering the number of blend ratios, the number of weights per unit areas and different needling densities for the experimental study (Table 2).

Table 2. Level of process factors

	Weight per unit area (g/m^2)		Stitch Density (Stitch/Inch^2)
1	550	1	18
2	650	2	34

Table 3. Experimental design for sample development

S.No.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
Sample Code	X12	X21	X22	Y11	Y12	Y21	Y22	Z11	Z12	Z21	Z22

Testing of nonwoven

The tests were performed to determine the air permeability, tensile strength, abrasion resistance and thermal conductivity of fabrics at standard atmospheric conditions.

The air permeability test of nonwovens was conducted on an SDL Atlas M021A Digital Air Permeability tester using the ASTM D 738-04. Martindale abrasion tester using ISO 12947-1 standard was used to test the resistance of the nonwoven fabric samples to the formation of abrasion on the textile fabrics. This test was carried out by cutting a small circular strip of fabric with an area of 3.8$m^2$and then adjusting to the Martindale abrasion tester machine with 5000 rotations for 2 hours. Then the samples were compared with the aid of grey scale.

Tensile strength and elongation tests were conducted by using Tenso lab universal tensile strength tester following ASTM D5035 fabric traction strip standard. In this test, five samples each having a size of 20cm×5cm were cut and tested for both machine direction and cross direction, and the average results were recorded.

The Thermal conductivity of the samples was performed by using WL 372 radial and linear heat conduction instruments.

RESULT AND DISCUSSION

Developed nonwoven fabric samples

Twelve different types of nonwoven fabric samples were developed from cotton/acrylic blend in different blend ratios, different web area density and different course spacing or stitch density in this research work. The best prediction model was selected and explained here.

Testing of non-woven fabric samples

The developed nonwoven fabrics were conditioned for 24 hours at standard atmospheric conditions (21$\pm$2^{o}C and 65$\pm$2% relative humidity). Then, the following tests were performed at standard atmospheric conditions:

Air permeability test result

All prepared nonwoven samples were tested for air permeability. The results were expressed ascm/s by taking the Unit Volume of Air (cm^3/s) that passed through 1cm^2 of fabric at a pressure difference of 200 Pa. Six different types of air permeability tests were investigated and the average result of each fabric was reported in Table 4.

Table 4. Air permeability test results

F. Code	X11	X12	X21	X22	Y11	Y12	Y21	Y22	Z11	Z12	Z21	Z22
Air per-meability (cm^3/s)	19.4	19.4	19.5	19.3	21.6	21.3	21.3	21.2	24.4	23.8	22.3	21.1

Effect of different factors on air permeability behaviour of nonwoven fabric

Analysis of the relationship between air permeability and different variables like blend ratios, stitch density and fabric weight or GSM of the fabric is shown in Fig. 2.

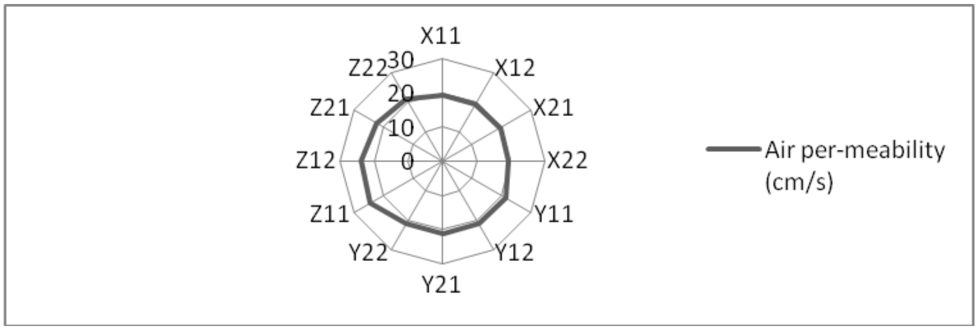
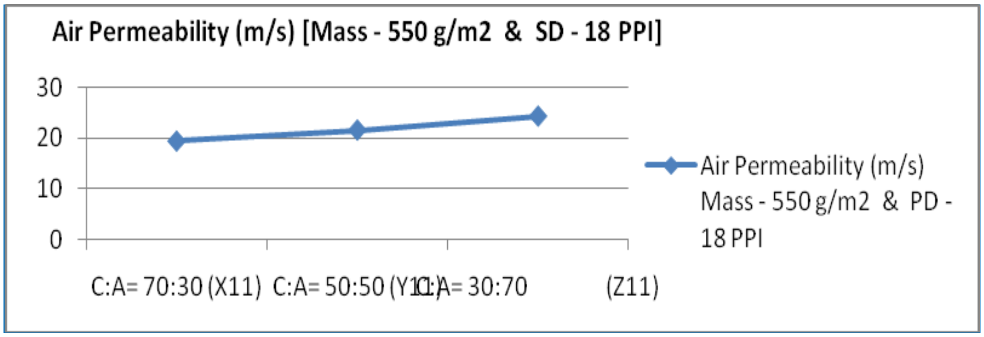
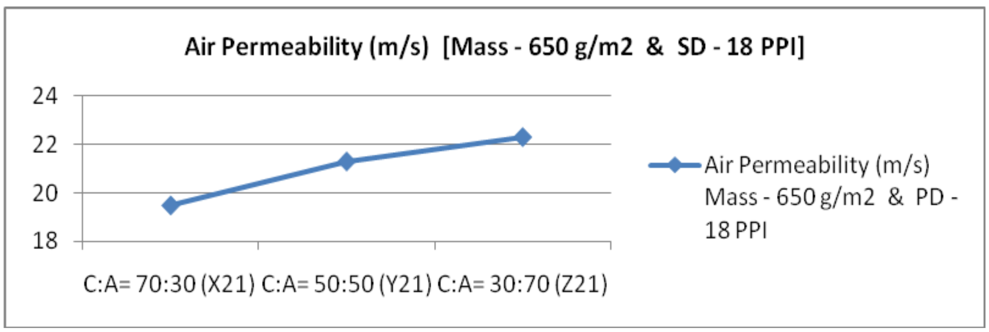


Fig.2 Effect of blend ratio on air permeability





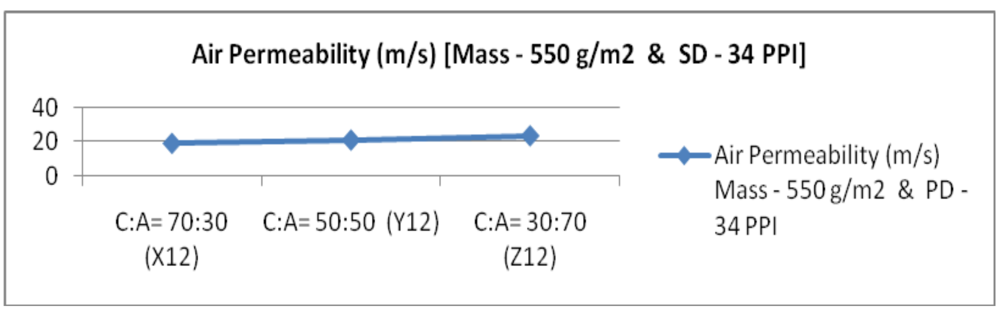


Fig. 3 Relationship between blend ratio and air permeability for different GSM and stitching density

Fig.2 and Fig. 3 shows that the air permeability was also increased as compared with the increase in acrylic% in the blend ratios of the fabric because acrylic fibers have been manufactured in course denier and high crimp, which in turn results in relatively higher mean free path or openings. The cotton fibers used in blending have been recycled from weft knitted fabric pieces in the tearing machine. In this process, the fibers were exposed to severe mechanical actions like stretching, rubbing, elongation, stress and strain. So, these cotton fibers would become finer, which results in the formation of more compact fabric structure with lower mean free path or lower porosity. On the other hand, fabrics having more amount of acrylic% in their blend ratios would have comparatively higher mean free path or porosity due to the loftiness or bulkiness of acrylic fibers in their inherent behaviour. The results showed that air permeability decreases with the increase in mass per unit area, thickness, amount of cotton content in blending ratios and density of the fabric.

Effect of Abrasion resistance:

The test results of abrasion of the nonwoven fabric samples to the formation of abrasion on the developed sample are shown in Table 4. This test was carried out by cutting a small circular strip of fabric and then adjusting to the Martindale abrasion tester machine with 5000 rotations for 2 hours. Then samples were pulled out and compared with the aid of greyscale.

Table 5. Abrasion resistance test results

Fabric Code	X11	X12	X21	X22	Y11	Y12	Y21	Y22	Z11	Z12	Z21	Z22
Abrasion Result	4	4/5	4	4	4/5	¾	4	4/5	3	4/5	¾	3

From the above results, the abrasion resistance of the nonwoven fabrics increases with the increase in cotton fiber content because cotton fibers have a greater tendency of higher abrasion resistance. However, fabrics with a higher amount of acrylic content in their blend ratios show a lower tendency of abrasion resistance because acrylic fibers have lower tendency of abrasion resistance in nature.

Effect of Tensile strength:

The tensile strength test is used to indicate the maximum amount of resistance force required for the rupture of fabric during its end use. From table 6 above, it was tabulated that the blend ratio versus tensile strength, it can be seen that both the longitudinal or machine direction and cross direction of tensile strength of the developed stitch bonded nonwoven fabrics increased with the increase in the amount of acrylic content in their fiber blending composition of the fabric. The longitudinal and crosswise tensile strength of the fabrics is increased for 12 samples. This is due to the higher tensile strength of acrylic fibers compared with other fabric samples having lower amount of acrylic content in their blending composition.

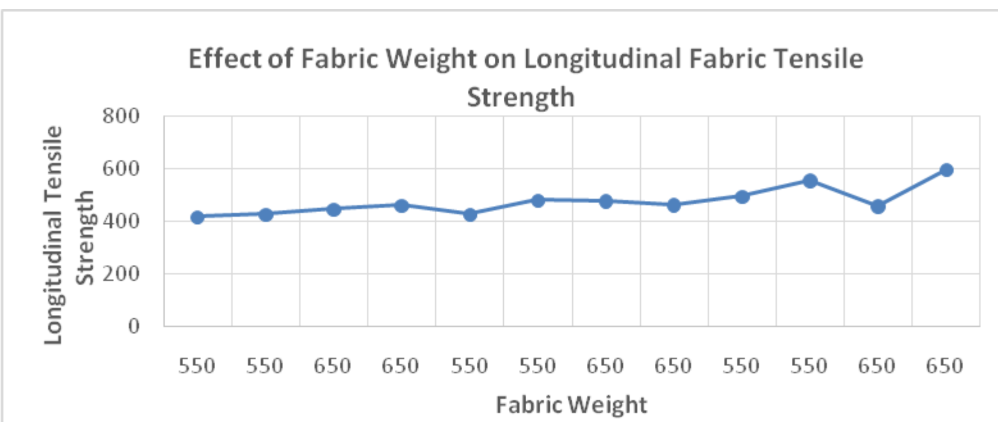


Fig. 4 Effect of Fabric Weight on Longitudinal Tensile Strength

Table 6. Tensile strength test results

Fabric Code	Fabric Direction	Maximum Force (N)	Elongation (%)	Time (second)
X11	Longitudinal	420	38.5	20
	Crosswise	210.4	95.4	55
X12	Longitudinal	429.8	44.7	26
	Crosswise	259.6	60	35
X21	Longitudinal	450.5	42.2	28
	Crosswise	196	83.21	50
X22	Longitudinal	466.6	65.5	10
	Crosswise	285.3	111.5	18
Y11	Longitudinal	428.6	38.5	20
	Crosswise	248	79.7	46
Y12	Longitudinal	483.3	49.9	28
	Crosswise	379	79.8	48
Y21	Longitudinal	480.5	60	10
	Crosswise	255	120.4	19
Y22	Longitudinal	468.3	48.5	27
	Crosswise	380	79. 3	47
Z11	Longitudinal	500	40.9	24
	Crosswise	226	77.3	45
Z12	Longitudinal	560.3	48.6	25
	Crosswise	418.33	97.1	18
Z21	Longitudinal	460.5	47.64	28
	Crosswise	249	84.76	50
Z22	Longitudinal	600.3	80.6	15
	Crosswise	289	113.7	19

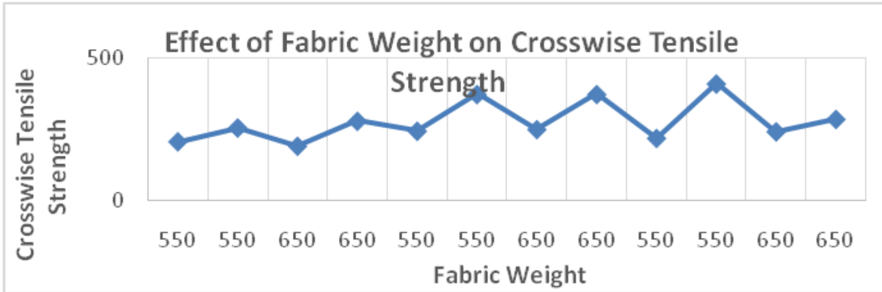


Fig. 5 Effect of Fabric Weight on Crosswise Tensile Strength

From Fig.4 and Fig.5 above, fabric weight against tensile strength shows that when the fabric weight increased, both the machine direction and cross direction of the tensile strength of the stitch bonded nonwoven fabric increased due to the increase in the number of fibers within a specified area of a fabric, which contributes a lot for the resultant final strength of the fabric. That means, we have exploited the strength of more individual fibers, which results in the formation of fabrics having greater strength in all directions. In general, the tensile strength of the nonwoven fabric in the machine direction is comparatively higher than in the cross direction due to the presence of uniformly distributed polyester warp yarns in the machine direction. That means the longitudinal tensile strength of the nonwoven fabric is a result of summation of the blended fibers strength and warp yarns strength.

Effect of thermal conductivity

The thermal conductivity measurement was carried out by using WL 372 radial and linear heat conduction apparatus. The procedure involves placing a nonwoven fabric between two metal plates and observing the increase in temperature with time. The procedure for using this thermal conductivity measuring apparatus involves placing of the samples in all experiments between heating and cooling metal cylinders with 30mm thickness and 25mm diameter. Several thermocouples were used in order to determine the exact temperature difference, ΔT, between the upper and lower surfaces of the sample. The samples were circles of the same diameter (25 mm) as the metal plate. The applied temperatures were 30 and 40 °C. Data was collected each 20 minutes until steady state was reached. With reference to the above modification, the sample arrangement should be considered as two conductors in series; one a standard of known conductivity (metal cylinder) and the other a sample whose thermal conductivity is to be measured (nonwoven sample). Based on the equation of a steady state conduction of heat through two solid slabs in series, the nonwoven samples thermal conductivity is calculated as follows:

$$\frac{K_1 \Delta T_1}{\Delta X_1} = \frac{K_2 \Delta T_2}{\Delta X_2} \quad \text{.......................... equation(a)}$$

Where, subscript 1 denotes the standard metal cylinder and 2 denotes the test sample.

Using T1, T2, T3, and T4 which are read from the apparatus and the temperature gradient diagram of the apparatus

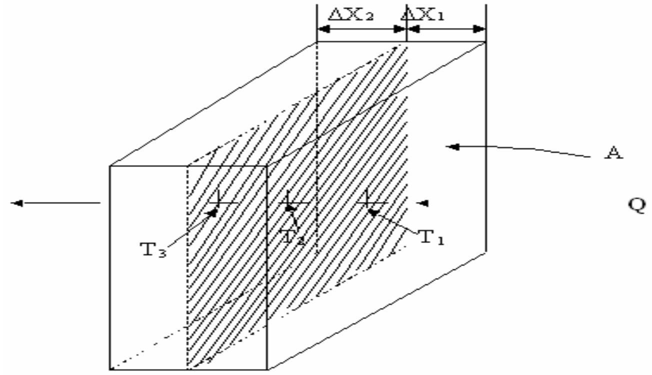


Fig. 6 Steady State Conduction of Heat through two Solid Slabs in series

Table: 7 Thermal conductivity test results

No. & Fabric code	**Thermal conductivity (w/mk)**	
1.	0.048487	X11
2.	0.042965	X12
3.	0.043645	X21
4.	0.028075	X22
5.	0.038467	Y11
6.	0.039567	Y12
7.	0.029350	Y21
8.	0.027685	Y22
9.	0.028475	Z11
10.	0.028587	Z12
11.	0.027957	Z21
12.	0.027865	Z22

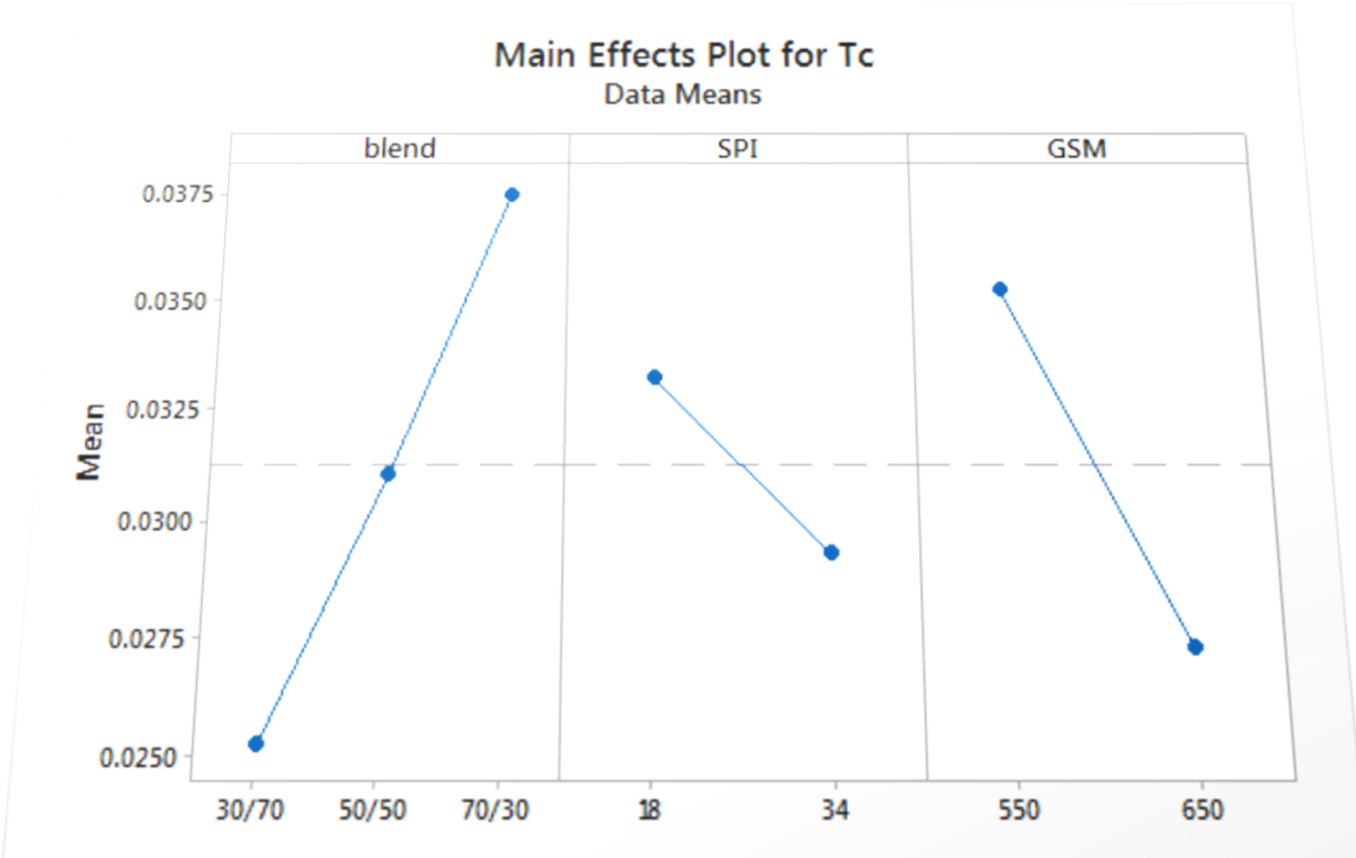


Fig. 7 Effect of blend ratio, stitch density and aerial density (GSM) on thermal conductivity

From fig. 7 above, graph of blend ratio vs thermal conductivity, it has been shown that with the increase in acrylic content in the respective blend ratio, the thermal conductivity of the nonwoven fabric decreases because of the higher glass transition and melting temperature of polyester fibers, which in turn results in more time to heat up and radiate energy. Finally, the thermal conductivity of the resulting fabric decreases. However, fabrics having more amount of cotton fibers in their blend ratios show greater degree of thermal conductivity because cotton fibers have higher tendency of thermal conductivity in their inherent behaviour compared with acrylic fibers.

From the graph of fabric weight vs thermal conductivity shown in fig. 7 above, when the fabric weight increases, the thermal conductivity of the nonwoven fabric decreases. With the increase in fabric weight the number of fibers per unit area of the fabric and number of pores increases. Due to this reason the fabric thickness and number of pores increases. As thickness of the fabric increases the thermal resistance increases so that the more number of pores acts as a heat barrier. Finally, the thermal conductivity of the fabric increases. The higher weight per unit area and thickness of these nonwoven fabrics leads to more still air in these fabrics. Still air inside the fabric geometry has the least thermal conductivity rate as compared to conductivity of fibers. So, air conveys a low quantity of energy via conduction, therefore; thermal conductivity of fabric decreases.

From the above graph of stitch density vs thermal conductivity in fig. 7, it has been shown that with increasing of punch density, the structure is being more packed, thus causing higher tortuosity or a lower mean free path, which generally results in more heat being blocked. The mean free path for movement of photons passing through the channels is greater in low web void fraction. For the structures discussed here, higher mean free path implies lower tortuosity or a more open structure, which in turn implies that the thermal conductivity is increased in the sample by reducing of stitch density.

CONCLUSIONS

In this research work, stitch bonded nonwoven fabrics were developed by considering blending of cotton and acrylic fibers in different composition, varying fabric weight, and course spacing which plays a major role in different levels for thermal insulation applications. After analysis of the individual and interaction effects of the above parameters on the air permeability and thermal conductivity behaviours, the following conclusions were drawn:

1. Air permeability of stitch bonded nonwoven fabrics decreases with the increase in thickness, density, and amount of cotton content in the blending composition.
2. The thermal conductivity of the stitch bonded cotton/acrylic blended nonwoven fabric decreases with the increase in fabric weight, stitch density, air permeability, and acrylic fiber content in the blending composition.
3. The thermal conductivity of this investigation was optimized from the previous studies by increasing the bulk density of the fabric, changing fabric structural geometry, decreasing fabric thickness, and optimization of fiber properties.
4. The thermal conductivity behaviour of the developed nonwoven fabrics was affected by the geometrical structure of the fabric, and with the variation of raw material properties.

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