Thermal Insulation Material Based on “Jute”

Abstract

Among the different natural fibres, jute is a less expensive fibre, annually renewable, and commercially available compared to other natural fibre crops. This jute is mostly cultivated in India and Bangladesh. More than a century, this fibre is well known as packaging (sacks), hessian, and carpet backing. Since 1950s, the synthetic fibres slowly took the market share of conventional jute textiles due to their low cost and high production speed. As far as suitability of the insulating material is concerned, it has high potential of using as three types of insulation (thermal, sound, and electrical). This present chapter gives emphasis on the basic methods of measuring jute based thermal insulation materials in different application areas. Apart from its evaluation methods, special attention has been made on the important factors affecting the thermal insulation behaviours of the jute-based textile materials. Focusing the needs of the industry, present chapter also covers the future aspects regarding the insulation application from jute-based materials.

Keywords

- technical textiles
- insulation materials
- jute textile material
- thermal insulation
- woven and nonwoven structures

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1. Introduction

Among the different fibre crops, jute is one of the oldest cultivated fibre crops in India. Jute is mostly cultivated in the eastern part of India, and stands highest production in the world, used popularly as technical textiles over the centuries. Jute fibre is used for reinforcement of rural mud house. Jute sacks are used as thermal insulating material [1], and for domestic animals like cattle, goat, pet dog, etc. Apart from these, it is the cheapest fibre crop available commercially in bulk quantities as of today. As far as the properties of jute fibre are concerned, it has both good characters as well as unwanted properties. Basically, this fibre is a mesh like structure which provides good coverage, good tensile strength, provides toughness and durability, less elongation at break, ensures dimensional stability, and natural colour which is ethnic in nature. Unlike any other fibres, the drawbacks of jute fibre crop are high surface roughness and prickliness, low extension at break, and coarseness, which restricts its use in textile garment.

Apart from these properties, jute-based materials have also properties like thermal, sound, and electrical insulation materials, out of which application in thermal insulation area is more popular [1, 2]. As per the usage of the material, insulation material can be classified as wearable textile and non-wearable textiles. Wearable textiles are those which are worn by any person either in direct contact with the skin or used as secondary clothing like jacket, protective clothing [3], gloves, etc. On the contrary, non-wearable materials are those that are not used directly by human beings, rather they are used in an indirect way like, insulation carpet, floor mat, insulation used in covering the electrical cable as protection material, roof top covering, wall coverings, etc. Now-a-days, jute-based materials are being used in the form of fibres, yarn, fabric, and composite media. There are researches where the method of measurement of insulation property, and the effect of such properties on different external parameters are demonstrated.

Keeping these in view, warm clothes have been designed and developed using jute-based fibres and yarns. Thermal insulation is one of the essential properties for any warm fabrics [3–6]. Judicious modifications on the fibre/yarn structure are one of the important parts as far as the thermal insulating material is concerned. The thermal insulation related properties mainly depend on the availability of amount of air pores in the textile structure. The static air trapped in fabric pores, makes the fabrics act as thermal insulating media [2]. As per the sound insulation is concerned, it mostly depends on the material surface morphology. Here, the morphology indicates the surface roughness, voids on the surface of the material, compactness of the material, intensity of the roughness, material structure (woven/nonwoven), etc.

Out of these three (thermal, sound, and electrical) basic types of jute-based insulation materials, major contribution has been documented in the area of thermal insulation. Hence, the major emphasis in this chapter has been imparted on the characterisation of the thermal insulation of the jute-based material factors affecting the thermal insulation of those materials and possible applications of jute based thermal insulation materials.

2. Evaluation of thermal insulation

The thermal resistance of textile material is generally defined as the ratio of the temperature difference between the two surfaces of the textile fabric material to the rate of flow of heat per unit area normal to the surfaces. This is analogous to the electrical resistance in case of current flow through electrical conductor. In Disc method, an application of Lee's disc apparatus to textiles has been used to evaluate thermal resistance of needle-punched nonwoven fabric samples. The material under test is kept between two metal discs surfaces from which, one has known thermal resistance. In a steady condition, the temperature drop across the metal disc with known value of thermal resistance and across the material under test is measured, and from the values obtained, the thermal resistance of the specimen is determined by the following techniques [4].

Let TR_k and TR_s be the thermal resistance of the known disc and the sample under test respectively. Let t_1 be the temperature registered by the lower surface of known disc, t_2 be the temperature registered by the lower surface of the sample under, and t_3 be the upper surface of the sample under test. Assuming constant rate of flow of heat at steady state condition, the TR_s is computed from the following formula in degrees Kelvin square metre per Watt:

$$\frac{t_1-t_2}{TR_k}=\frac{t_2-t_3}{TR_s},\ \text{or}\ TR_s=TR_k\times\frac{t_2-t_3}{t_1-t_2} \quad \text{E1}$$

Figure 1.

Instrument for measuring the thermal resistance of fabrics.

In this experiment, guarded two-plate thermal resistance instrument has been used to measure the thermal resistance of jute-based needle-punched fabrics (Figure 1) [4–6]. The thermal resistant instrument is based on a microprocessor and provides automatic results of thermal resistance value in 'tog'. The area of the test specimen used is 706.85 cm² (diameter 30 cm). The test is non-destructive and the process of sample preparation is free from human error. Thermal insulation of each fabric sample is measured randomly at five different places under a pressure of 0.3352 kPa. Average of five readings was considered and the coefficient of variation of the readings was <2%. All the fabric materials must be conditioned in the standard atmospheric condition prior to evaluation of the thermal insulation property [7].

Specific thermal resistance (STR_S) value is used to compare the thermal resistance of different nonwoven fabric samples. STR_S values of all the samples are determined using the following equation [4]:

STRs=TRsT0STRs=TRsT0E2

where STR_S is the specific thermal resistance in K m²/W; TR_S, the thermal resistance value of fabric in K m²/W; and T_0, the mean thickness in meter at 1.55 kPa pressure of the fabric sample.

3. Jute-based insulation materials and important factors affecting their insulation properties

Jute fibre has its inherent property of good thermal insulation. Different construction of jute-based textile materials further enhanced the performance and properties of insulation [8]. There are different applications where the jute based structures are used as insulating material like, warm garments, floor mat, carpet, soil temperature control in agricultural application, false ceiling, temporary partition wall, sound absorbing material in auditorium, etc. Depending upon the insulation requirement, different textile structures are being used like fibre, yarn, and fabric. Sometimes, composite structures are also used as particle board, and fibre reinforced board. Again in fabric, woven, nonwoven, and knitted structures are being used as insulation material. The following studies elaborate details on different possible insulation materials from jute-based textiles.

3.1. Thermal insulation behaviour of jute-based nonwoven fabrics

Different types of parallel laid and random laid needle punched and adhesive bonded nonwoven fabrics were prepared using blending of different fibre materials (polypropylene, acrylic, jute, woollenised jute, jute caddis, cotton, wool, ramie, pineapple leaf fibres, etc.). Two types of blending methods were used such as sandwich and homogeneous. Sandwich blending of polypropylene or acrylic with woollenised jute shows better thermal insulation compared to homogeneous blended materials as found by Debnath. They also found that nonwoven prepared out of woollenised jute-wool (2:1), woollenised jute-acrylic (2:1), and woollenised jute-pineapple leaf fibre (2:1) have better thermal insulation property. Air permeability and thermal conductivity of jute needle-punched nonwoven fabrics have been studied by Debnath et al. [3] and found that jute needle punched nonwoven has poor heat transmission. Furthermore, Box and Behnken factorial design was used to design and develop needle-punched nonwoven fabrics made from jute and polypropylene blends to study the effect of fabric weight, needling density, and blend proportion on thickness, thermal resistance, STR_S, air permeability, and sectional air permeability. Polypropylene fibre of 0.44 tex fineness, 80 mm length, and jute fibres of Tossa-4 grade were used to develop the jute-polypropylene blended needle-punched nonwoven. Some of the important properties of these jute and polypropylene fibres are presented in the Table 1.

Property	Jute	Polypropylene
Fibre fineness, tex	2.08	0.44
Density, g/cm^3	1.45	0.92
Moisture regain at 65% RH, %	12.5	0.05
Tensile strength, cN/tex	30.1	34.5
Breaking elongation, %	1.55	54.13

Table 1.

Properties of jute and polypropylene fibres [4].

3.2. Preparation of jute-polypropylene blended thermal insulation nonwoven fabrics

Initially, the jute reeds were opened through a roller and clearer card. This produces almost mesh-free opened stapled fibre. The woollenised jute and polypropylene fibres are then hand opened separately and blended at three different blend proportions as per the Table 2. Considering the fibre droppings in different stages of woollenised jute fibres taken is 2% higher than presented in Table 2 to maintain the target blend proportion. Then the blended materials were opened thoroughly by passing through one carding passage.

The blended fibres were then fed to the lattice of the roller and clearer card at a uniform and predetermined rate so that a web of 50 g/m^2 can be achieved. The fibrous web coming out from the card was fed to feed lattice of cross-lapper, and cross-laid webs were produced with cross-lapping angle of 20°. The web was then fed to the needling zone. The required needling density was obtained by adjusting the throughput speed.

As per the fabric weight (g/m^2) requirement, certain number of webs was taken and passed through the needling zone of the machine for a number of times, depending upon the punch density required. A punch density of 50 punches/cm^2 was applied on each passage of the webs, reversing the face of the web alternatively [4]. The fabric samples were produced as per the coded and actual levels of three variables (Table 2).

The depth of needle penetration was kept constant at 11 mm. For all webs, 15 × 18 × 36 × R/SP, 3½ × ¼ × 9 needles were used.

	Levels of variables					
	X_1 level		X_2 level		X_3 level	
Fabric code	Coded	Actual	Coded	Actual	Coded	Actual
1	−1	250	−1	150	0	60:40
2	−1	250	1	350	0	60:40
3	1	450	−1	150	0	60:40
4	1	450	1	350	0	60:40
5	−1	250	0	250	−1	40:60
6	−1	250	0	250	1	80:20
7	1	450	0	250	−1	40:60
8	1	450	0	250	1	80:20
9	0	350	−1	150	−1	40:60
10	0	350	−1	150	1	80:20
11	0	350	1	350	−1	40:60
12	0	350	1	350	1	80:20
13	0	350	0	250	0	60:40
14	0	350	0	250	0	60:40
15	0	350	0	250	0	60:40

Table 2.

Actual and coded values for three independent variables and the experimental design [4].

X_1 – Fabric weight, g/m^2; X_2 – Needling density, punches/cm^2; and X_3 – Blend ratio (polypropylene: woollenised jute).

3.3. Effect of fabric weight, needling density, and blend proportion of jute-polypropylene blended needle-punched nonwoven on thermal resistance

It is found that the thermal resistance increases with the increase in fabric weight [4] significantly (p <s 0.05000 and positive correlation, $r = 0.82$) as obtained from Table 3. There is more prominent increase of thermal resistance value of the fabric with the increase in fabric weight at 150 needling density than is obtained at 350 punches/cm². With the increase in needling density within the experimental range, the thermal resistance has does not have any significant effect even with varying jute component in the blend from 40% to 60%. Optimum thermal resistance value of 8.5×10^{-2} K m²/W found at fabric weight of 430 g/m², needling density of 150 punches/cm², and jute content of 40% in the blend. The number of fibres per unit volume of the fabric increases with the increase in fabric weight, which results in higher fabric thickness and larger amount of voids in the fabric structure obtained. These ultimately increase the thermal resistance of the fabric while increase in fabric weight. On the contrary, while needling density increases, thermal resistance decreases significantly ($p < 0.05000$ and negative correlation, $r = -0.67$) as depicted from correlation matrix (Table 3). This is due to higher degree of consolidation occurred, and hence reduces voids in the structure. Since the air act as thermal insulating material, the fall in air pocket in the fabric structure reduces the thermal resistance of the jute blended fabric.

Variables	*FW*	N_ρ	*J%*	T	TR_s	STR_s	*AP*	*SAP*
FW	1.00	–	−0.00	0.50	0.51	0.28	−0.93[3]	−0.75[3]
N_ρ	0.00	1.00	0.00	−0.49	−0.67[3]	−0.61[3]	−0.11	−0.33
J%	−0.00	0.00	1.00	−0.39	−0.26	−0.02	−0.19	−0.43
T	0.05	−0.49	−0.39	1.00	0.82[3]	0.29	−0.36	0.08
TR_s	0.51	−0.67[3]	−0.26	0.82[3]	1.00	0.78[3]	−0.37	−0.02
STR_s	0.28	−0.61[3]	−0.02	0.29	0.78[3]	1.00	−0.22	−0.11
AP	−0.93[3]	−0.11	−0.19	−0.36	−0.37	−0.22	1.00	0.89[3]
SAP	−0.75[3]	−0.33	−0.43	0.08	−0.02	−0.11	0.89[3]	1.00

Table 3.

Correlation matrix of variables [4].

FW – Fabric weight, g/m²; N_ρ – Needling density, punches/cm²; *J%* – Jute proportion, T_0 – Fabric thickness, cm; TR_s – Thermal resistance × 10^{-2}, K m²/W; STR_s – Specific thermal resistance, K m/W; *AP* – Air permeability, cm³/cm²/s; SAP – Sectional air permeability, cm³/s/cm.

*Correlations are significant at $p < 0.05000$.

Thermal resistance = $4.0520833 - 0.0114167X_1 - 0.0007917X_2 + 0.0558333X_3$ $0.0000079X_1^2 - 0.0000104X_2^2 - 0.0021979X_3^2 + 0.0000250X_1X_2 - 0.0002125X_1X_3 -$ $0.0001X_2X_3$ ($R = 0.9002$; $F_{9,5} = 15.04$)

3.4. Effect of fabric weight, needling density, and blend proportion of jute-polypropylene blended needle-punched nonwoven on specific thermal resistance

A study on specific thermal insulation behaviour of jute-polypropylene blended needle-punched nonwoven [4] show that the STR_S depends prominently on varying jute content levels of 20%, 40%, and 60% respectively (Figure 2). This study also reveals that with the increase in needling density, the STR_S decreases. They found that between needling density and STR_S, there is a significant ($p < 0.05000$) negative correlation ($r = -0.61$), shown in the correlation matrix (Table 3). Formation of consolidated structure occurs with the increase in needling density, as a result, the available air pockets reduces in the fabric structure. Again, with the increase in fabric weight, the number of fibres in unit area of the fabric increases, which increases the voids in the fabric structure. These ultimately influence the STR_S of the needle-punched nonwoven fabric. It is depicted from Figure 2a, that initially thermal resistance increases up to 375 g/m² of the fabric weight and later it decreases with further increase in fabric weight. Same trend has also been observed at 60% jute content level, but the decrease in trend of STR_S occurs at lower fabric weight (325 g/m²) as obtained from Figure 2b. This is due to reason that compared to polypropylene fibre, jute can easily form consolidated structure due to its poor resilience. Because of this, during higher level of needling and jute content levels, the fabric consolidation initially improves, and beyond certain fabric weight (325 g/m²) the bulkiness increases. Larger number of fibres available for each needle during needling with the increase in fabric weight means more number of fibres will be available to the needle barb during needling. Further increase from 325 g/m² of fabric weight, the incremental amount of fibres at needle barb is deficient to form better entanglement, which produce poor consolidation. Thus, with the increase in jute content (60%), the fabric consolidation occurs at 325 g/m² fabric weight (lower level) compared to that occurred at 40% jute content level (Figure 2c). Optimum STR_S value of 20.6 K m/W was obtained at 150 punches/cm² needling density and 400-450 g/m² fabric weight at lower jute content (40%) of jute-polypropylene blended needle-punched nonwoven (Figure 2b).

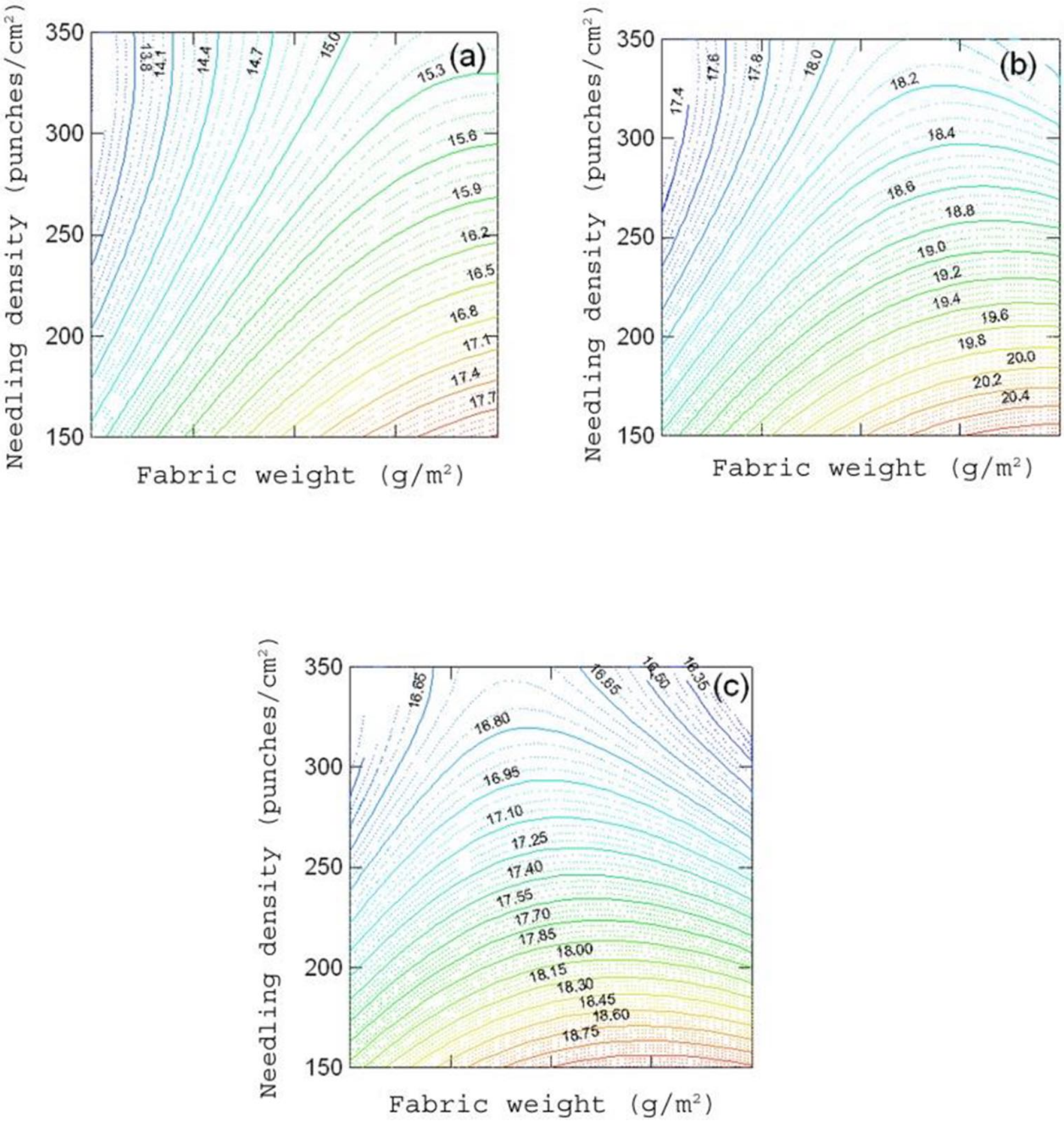

Figure 2.

Effect of fabric weight and needling density on specific thermal resistance at (a) 20% jute, (b) 40% jute, and (c) 60% jute content levels [4].

Specific thermal resistance= $-$ 2.3122917 + 0.0612292X_1 – 0.0160917X_2 + 0.5955833X_3 – 0.0000490X_1^2 + 0.0000452X_2^2 – 0.0056073X_3^2 – 0.0000365X_1X_2 ~ 0.0002725X_1X_3 – 0.0002163X_2X_3 (R = 0.9327; $F_{9,5}$ = 7.69)

Furthermore, Yachmenev et al. [9], have discussed the thermal insulation properties of biodegradable, cellulosic-based nonwoven composites for automotive application. This work is aimed to the development of bio-composite from jute-based material aiming for automobile application. They developed moldable, cellulosic-based nonwoven composites with excellent thermal insulation properties, which were fabricated from kenaf, jute, flax, and waste cotton using recycled polyester and substandard polypropylene. The composites of these fibers have excellent shape, stability, and high tensile and flexural properties coupled with economic and environmental benefits. Four different types of designs with varying different cellulosic fibers, manufacturing techniques, and various ratios of vegetable–synthetic fibers were manufactured on laboratory-scale equipment. A Steady-State Heat Flow meter was used for the measurement of thermal conductivity and thermal transmittance of the samples of composites. The research findings show that thermal insulation properties of the cellulosic-based nonwoven composites vary significantly, depending on the type of the cellulosic fibers, the ratio of cellulosic fibers to synthetic fibers, and the resulting density of the composite [9].

3.5. Measurement of thermal insulation value and comparative study of different jute based materials

A simple method can be used to measure the thermal insulation value (TIV) of different textile materials based on jute and cotton fibres [8, 10–14]. Methods that are commonly used for measurement of TIV are the disc method, the constant temperature method, and cooling method. Out of these three methods, cooling method is the simplest compared to other two methods. In this method of measurement of thermal insulation, a hot body is wrapped with the fabric, and its rate of cooling is measured. The outer side of the fabric is exposed to air. In this experiment, the time taken by a hot body covered with the fabric sample (t_c) and without the sample (t_u) to cool through a particular temperature range under identical atmospheric conditions. To measure the thermal insulation with this method, a brass cylinder (45 cm length, 5 cm external diameter, and 2 mm thickness) closed at one end with a cork was filled with distilled water heated to about 50°C. The mouth of the cylinder was closed with a cork through which a thermometer was inserted. To simulate the actual condition, a wire mesh has been wrapped on the surface of the cylinder to obtain a clearance of 2 mm between fabric sample and brass cylinder. A rectangular specimen of the fabric was used to cover the entire outer surface of the brass tube. The length-wise edges of the specimen were made to touch each other closely avoiding overlapping and kept in position by using cello-tape over the joint running parallel to the length of the cylinder [3].

The experiment was started when the temperature of the water was exactly 48°C. A stopwatch was used to find the time taken for the temperature fall at every 1°C. A cooling curve was drawn from these data and the time taken to cool from 48°C to 38°C was found. The TIV was calculated by using Marsh method, as follows [3, 5]:

$$TIV=\left[1-\frac{t_c}{t_u}\right]\times 100 \quad \text{E3}$$

where, (t_c) is time taken by the covered body to cool through a certain temperature range and (t_u) is time taken by the uncovered body to cool through the same temperature range. They found that TIV is related to the thickness of the fabric, the basis weight (fabric weight), and the number of layers of the fabric [1]. The intra fabric air spaces and inter space between fabric and body are also important. The TIV of the fabric is greater when a non-conducting mesh (polythene) is present between the cylinder and fabric instead of conducting metal mesh in the same position. Increase in any of these factors increases the TIV significantly. There has been marginal effect on TIV with varying fabric nature.

3.6. Thermal insulation behaviour of jute-based knitted fabrics

Fabric structure plays a very important role in thermal insulation property, which has been mentioned earlier. Further in the same line, Vigneswaran et al. have studied knitted jute-based fabric structure [15]. They studied the effect of thermal conductivity behavior of jute/cotton blended knitted fabrics. The thermal conductivity is the reciprocal of the thermal insulation. They established the relationship between fabric properties and thermal conductivity of various developed jute/cotton blended knitted fabrics. Experimental result obtained by them confirms that lower thermal conductivity is obtained at higher jute blend proportions. They concluded that the thermal conductivity reduces with increasing fabric thickness. This study also reveals that fabric air permeability and fabric tightness factor values influences the thermal conductivity of jute/cotton blended knitted fabrics. Higher TIVs are noticed with higher fabric tightness factor and lower air permeability [15]. Regression correlation coefficients between various fabric properties and thermal conductivity have also been discussed.

3.7. Thermal insulation behaviour of jute-based warm garments

It has been proven on evidences from the literature that jute-based fabrics are having equally good thermal insulation property when compared with synthetic acrylic and cotton shawl materials [11]. Jute and hollow polyester materials are used to prepare the weft yarns of the shawl and cotton yarn were used in warp direction to weave the shawl fabric. Apart from its thermal insulation property, other properties like air permeability, fabric cover factor is also better in case of the developed jute-polyester and cotton blended shawls. Furthermore, jute and polyester and cotton blended union fabric have been used to develop the jacket for winter season [8, 12, 13]. It has been found from this study that the jackets are comparable or better compared to commercial polyester jackets of the same jacket weight [9].

4. Conclusions and future prospects

It can be concluded from this study that jute-based material can be used effectively in different thermal insulating application. These applications are shawl, jacket, blanket, carpet, etc. Jute-based materials also have immense potential in other industrial applications as thermal insulation material.

Apart from these jute-based thermal insulation materials, electromagnetic shielding resistance, vibration resistance/insulation material, mechanical shock resistance/insulation, electrical insulation material, sound/noise insulation material, etc. are the future research directions. There are enormous scopes as insulation material from jute-based material for different domestic, industrial, and apparel applications. Jute-based textile as insulation material may be considered as green/sustainable material, which may replace a greater extent of synthetic material for the same application. Finally, it can be concluded that jute and jute-based allied fibres will get new avenue in future days as far as application of insulation material is concerned.