# EFFECT OF MECHANICAL CRIMP OF JUTE FIBRE ON THE THERMAL PROPERTIES OF WOVEN FABRICS

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***Abstract:*** *The aim of this paper is to find the effect of mechanical crimp of jute fibre on the thermal properties of woven jute fabrics. In this study, crimp box and gear crimping method were used to impart mechanical crimp into jute sliver. Crimps were divulged to enhance the cohesion between fibres that make it suitable for spinning. Jute yarns were produced by inserting a different number of crimps and woven fabrics were produced by using these yarns. Fabric thickness, porosity, air permeability and thermal conductivity tests were done according to standard method and found that fabric porosity, air permeability and thermal conductivity of the fabric decreased and fabric thickness increased with the increased number of crimps and fabrics from gear crimping method showed better effect than that of crimp box method. The study on jute woven fabric will provide quantitative experimental data for potential applications with advantages of lightweight, cost-effective, easy to manufacture, biodegradable and excellent mechanical properties.*

***Keywords:*** *Mechanical crimp, crimp box method (CBM), gear crimp method (GCM), fabric porosity, air permeability and thermal conductivity.*

## 1 INTRODUCTION

The heat and air transferring properties of textiles, which are fundamental factors related to clothing comfort, are affected by the mechanical characteristics of the fabrics, yarns and also fibre properties. The mechanical properties can be depended on the yarn's physical properties and fabric structures [1]. Jute is a technical fibre with some special properties. Nowadays, jute woven fabrics are widely used for thermal issues and composite materials for its functional properties [2]. Functional properties are sometimes involved with yarn properties which are greatly related with fibre crimp. Jute is a natural fibre having no natural crimp. So, mechanical crimp is imparted into jute fibres in order to enhance the cohesion between fibres and to make it suitable for subsequent processes like spinning and weaving [3]. Nowadays, mechanical crimp is imparted into jute sliver during drawing in the 2nd and 3rd draw frame machine. The CBM is widely used for jute crimping. In the CBM, the sliver leaves the nip of the drafting rollers and passes down the sliver plate into the nip of a pair of fluted delivery rollers, the upper one of the pair is spring-loaded and positively driven.

A lid is used in the crimping box. Some weight is applied to the lid and it creates a pressure or load on the sliver in the crimp box. As a result, fibre is compressed under pressure and irregular crimp is produced into jute sliver. The length of time on any particular place of sliver remains in the crimp box can be controlled by means of small weights which can be added to the lid. If different weight is used, then crimp produced into sliver also gets changed. A heavy weight causes a greater mass of sliver in the box to lift it up and develops more crimp in the fibres [4]. This crimp creates inter-fibre cohesion which is very important for jute processing. In CBM, crimps produced with irregular size and shape. As a result, the number of crimps per inch or per unit length also becomes irregular [3]. On the other hand, for GCM, two crimping rollers are used to impart crimp into sliver. After passing the nip of the drafting rollers, it passes over the sliver plate into the nip of a pair of fluted delivery roller, then passes between the nips of the gear crimping rollers, then crimp is formed in the sliver which is regular in size and shape. The lower crimp roller is positively driven and the upper crimping roller is spring-loaded. The pair of crimping rollers should be changed to change the number of crimps in per unit length.

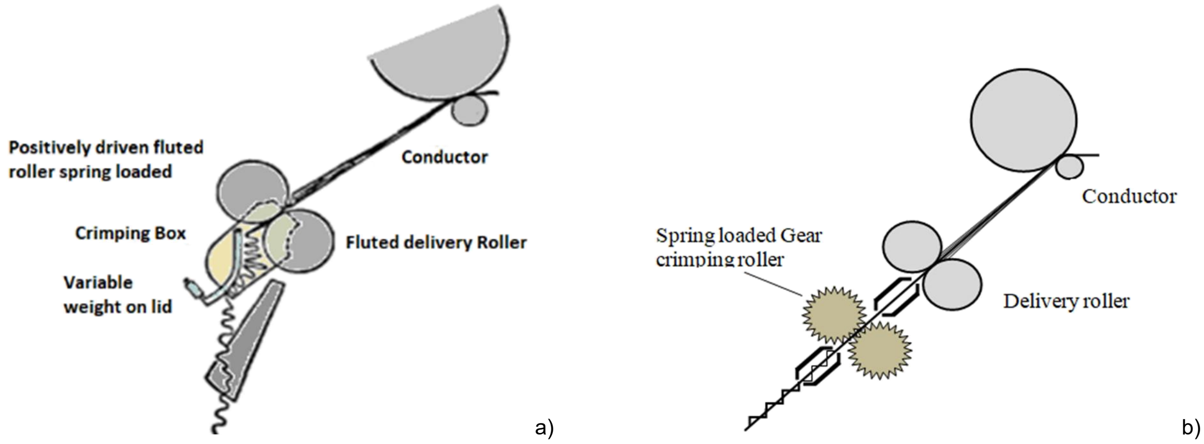


**Figure 1** a) Crimp Box Method (CBM) [4] and b) Gear Crimp Method (GCM)

The crimps affect the fabric thickness, fabric porosity, air permeability and thermal conductivity of the fabric. Air permeability and thermal conductivity of the fabric are related to fabric thickness and porosity [5, 6]. Thermal protective clothing contains an inner layer, middle layer and outer layer. The inner layer provides next to skin comfort by wicking the sweat at the skin surface for better evaporative cooling and quick drying. The middle layer normally provides insulation. The outer layer aims to protect people against environmental conditions [7]. Heat transfer by conduction depends on thermal conductivity and thermal resistance of the material. Heat transfer portent can help in accepting the fabric used as thermal obstacle with lower thermal conductivity, hence understanding the concept of mode of heat transfer through textile material becomes essential [8]. Heat transfer in porous materials occurs from high to low temperature section. Hence, a temperature difference has to occur between the two sections for transfer of heat. Mostly, heat is transferred through conduction, convection, and radiation from high temperature to low temperature. The total thermal conductivity decreases when material density increases and conduction is the main source of heat loss at higher mass such as gram per square meter (GSM) and thickness of fabric. Thermal conductivity of a material increases with a given temperature gradient. The more a material absorbs thermal energy, the more it acts as a thermal conductor, and also the total thermal resistance of the material is a function of the actual thickness of the material [9, 10]. However, various studies are conducted on preparation of multilayer fabric by using fibers such as cotton, wool, normal polyester and hollow polyester of varying fineness [11-13], but jute fiber is not reconnoitred as raw material for multilayer fabric. In this research work, jute fibre was used with an increased number of crimps to evaluate the thermal conductivity of the jute woven fabrics.

## 2 MATERIALS AND METHODS

### *2.1 Materials used*

100% jute fibre was used for this research work. CBM and GCM were used to impart crimp in the sliver. Different yarns were produced with various numbers of crimps in the jute sliver. In CBM, crimps are irregular in size, shape and number. But in GCM, crimps are regular in size and shape. The number of crimps is also regular in per unit length. Woven jute fabrics were produced with plain structure by using these special yarns with 16 ends and 12 picks per inch in CCI loom. Sample details are given in Table 1.

**Table 1** Sample details for different crimping method

| Crimping method | No. of crimps per unit (2.54 cm) | Structure of fabric | Construction of fabric |
|---|---|---|---|
| Crimp Box | 2.5 | $\frac{1}{1}$ Plain weave | $\frac{6.3\ x\ 4.7}{210x210}$ X 45.72 cm |
| | 3.5 | | $\frac{6.3\ x\ 4.7}{214x214}$ X 45.72 cm |
| | 5.0 | | $\frac{6.3\ x\ 4.7}{298x298}$ X 45.72 cm |
| Gear Crimp | 3.0 | | $\frac{6.3\ x\ 4.7}{218x218}$ X 45.72 cm |
| | 4.0 | | $\frac{6.3\ x\ 4.7}{258x258}$ X 45.72 cm |
| | 5.0 | | $\frac{6.3\ x\ 4.7}{311x311}$ X 45.72 cm |

### *2.2 Methods used*

Fabric porosity test was done by using PMI. Air permeability testing was carried out with Air Permeability Tester following ASTM D 737-96 standard. Fabric thickness and thermal conductivity testing was carried out with Fabric Touch Tester following ASTM D1776 standard. For every test, five observations or measurements were taken.

Fabric porosity test: Capillary Flow Porometer, Porous Materials Inc. PMI was used to test the fabric porosity. Machine parameters for the test were as: Tortuosity factor 0.715, fluid used Galwick, surface tension 15.9 dynes/cm, bubble point pressure 0.015 PSI. The density of the fabric was less, so bubble point pore diameter was considered for measuring the fabric porosity.

*Factors affecting the test results:* Flat textile materials like woven fabrics, are porous materials which permit the transmission of energy and substances and are hence interesting materials for different applications. Porosity of the woven fabrics depends on some factors such as type of material, warp and weft yarn count, warp and weft density, twist of yarn, type of weave, fabric weight and fabric thickness.

Air permeability test: Air permeability tester was used to test the air permeability of jute fabrics. Test specimen dimensions vary considerably depending on the requirements and are described in related section in the ASTM book of standards. Samples were conditioned using standard procedures. The recommended test conditions were 23±2°C as a standard laboratory atmosphere and 65±5% relative humidity. Supplied air pressure was 100 Pa and test pressure was 20 Pa. The test area for the test was 38 $cm^2$ and the test pressure was 100 Pa. A circle of fabric of the above area was clamped into the tester and through the use of vacuum; the air pressure is made different on one side of the fabric. Airflow will occur from the side with higher air pressure, through the fabric, to the side with the lower air pressure. From this rate of air flow, the air permeability of the fabric is determined.

*Factors affecting the test results:* Air permeability is a function of the thickness, tightness factor and porosity of the woven and knitted fabrics. The type of fabric structure, the design of weave, the number of warp and weft yarns per cm or inch, the amount of twist on yarn and the size of yarn and the type of yarn structures affected the air permeability of the woven fabric.

Thermal conductivity test: Fabric Touch Tester (FTT) [14] was used to measure the thermal conductivity of the fabric. It is used to measure simultaneously physical properties related to touch feels of textiles such as knitted and woven fabrics in four modules as follows. FTT can measure all these four modules including warp and weft directions as well as face and back sides with in five minutes. Thermal conductivity was tested using the ASTM D1776. The samples should be conditioned in the standard atmosphere for testing which are 21±1°C (70±20°F) and RH 65±2% for at least 24 hours prior to testing. The test samples should be cut in the shape of a letter 'L' with 200 mm arms in two sides. Face-side up specimens (A) should be tested first and then back-side up specimens (B) should be tested. Fabric thickness was also tested with this machine.

*Factors affecting the test results:* Thermal conductivity is not always constant. The rate of heat flow between the fabric and the skin is strongly determined by the fabric property, which is called thermal inertia. Thermal inertia is defined as the product of thermal conductivity and a combination of thermal conductivity of the fibre substance and that on the air contained within the fabric. The fibre properties also affected the thermal conductivity. The tightness factor of the fabric significantly affects thermal conductivity [15]. For tighter structures, the density of fibre and fabric increased, so that heat loss decreased. Finally, the main factors which affect the thermal conductivity of fabrics were fibre types, density of the material, moisture of the material and ambient temperature.

## 3 RESULTS AND DISCUSSION

Woven jute fabrics are widely used as technical and non-technical textiles like geo-textiles, composite materials and many diversified products for thermal issues. In this research work, some properties of jute woven fabrics were analysed to introduce jute fibre as thermal insulation material. Confidence intervals and standard deviation for all test results were also calculated to understand the better comparison of two crimp methods. Different test results of fabrics for various crimp methods and standard deviation are shown in Tables 2 and 3.

**Table 2** Yarn count and different fabric properties for different number of crimps for various crimp methods

| Crimping method | No. of crimps (2.54 cm) | Yarn count [tex] | Fabric thickness [mm] | Fabric porosity [μm] | Air permeability [cc/cm²/s] | Thermal conductivity [W/m/K] |
|---|---|---|---|---|---|---|
| Crimp box | 2.5 | 210.9 | 1.454 | 565.2002 | 321.4 | 0.062 |
| | 3.5 | 214.1 | 1.606 | 439.2359 | 224.4 | 0.053 |
| | 5.0 | 298.9 | 1.616 | 177.1085 | 193.0 | 0.037 |
| Gear crimp | 3.0 | 218.6 | 1.622 | 539.3081 | 238.2 | 0.055 |
| | 4.0 | 258.9 | 1.634 | 219.3566 | 213.2 | 0.045 |
| | 5.0 | 311.6 | 1.688 | 95.6007 | 171.8 | 0.033 |

**Table 3** Standard deviation for different test of fabrics for various crimp methods

| Series | Type of test | Standard deviation CBM | | | Standard deviation GCM | | |
|---|---|---|---|---|---|---|---|
| 1 | No of Crimp (2.5 cm) | 2.5 | 3.5 | 5.0 | 3.0 | 4.0 | 5.0 |
| 2 | Fabric thickness [mm] | 0.0594 | 0.0611 | 0.0853 | 0.0712 | 0.0568 | 0.0277 |
| 3 | Fabric porosity [μm] | 0.4083 | 0.7475 | 0.5228 | 0.7871 | 0.6358 | 0.5807 |
| 4 | Air permeability [cc/cm$^2$/s] | 11.2606 | 8.1731 | 7.7136 | 5.2631 | 6.2209 | 5.7184 |
| 5 | Thermal conductivity [W/m/K] | 0.00130 | 0.00114 | 0.00158 | 0.00158 | 0.00187 | 0.00130 |

*Fabric thickness*

Fabric thickness is one of the important parameter or properties to determine some other properties of fabric like air permeability and thermal conductivity. When fabric thickness is greater, the thermal insulation property is also changed. In this research, it is found that fabric thickness is affected and improved by the increased number of crimps. Though all the technical parameters of the production process were remained same, the count of the yarn changed due to the increased number of crimps per unit length. Yarn count and the thickness of fabrics are changed due to the increased number of crimps per unit length (2.54 cm) and it is shown in the Table 2. It was found that thickness of fabric produced from GCM method is slightly higher than that of CBM, as more fibre is compressed in the yarn and yarn diameter is also higher for GCM [3].

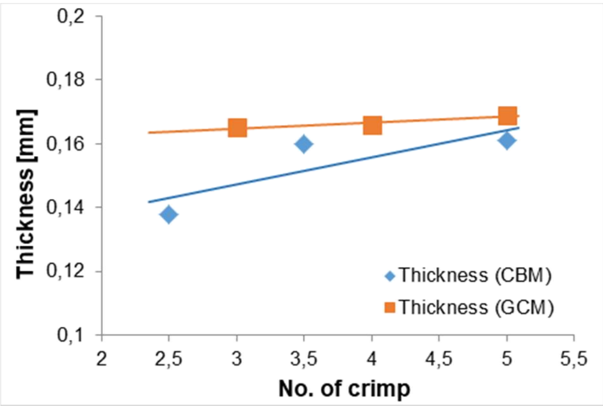


**Figure 2** Thickness vs number of crimps for different crimp methods

It is seen from the Figure 2 that fabric thickness increased in every step of increased crimp and it is also exposed that thickness of fabric is slightly more for GCM than that of CBM. Confidence intervals are seen from Figure 3 and 4 for fabric thickness for various crimp methods and it is found that confidence intervals overlap which indicate the differences in values for thickness are hence statistically insignificant.

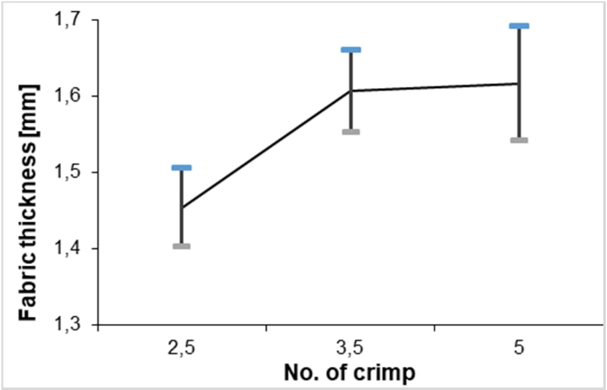


**Figure 3** Confidence interval of fabric thickness of CBM with upper and lower limit

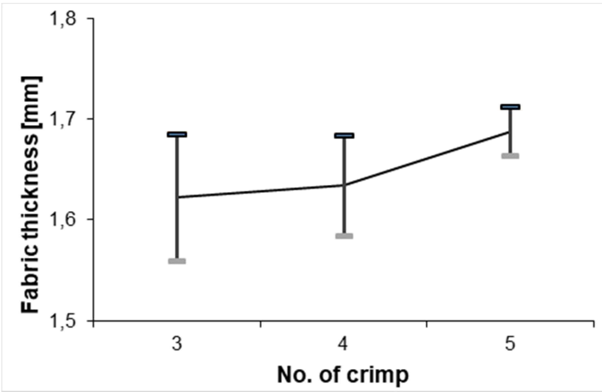


**Figure 4** Confidence interval of fabric thickness of GCM with upper and lower limit

*Fabric porosity*

The porosity of the fabrics is the voids between weft and warp yarns in the fabrics. The pore diameter of the fabric defines the void space available in the fabric. The air and other fluids pass through the pores from the surface of the fabric. It is seen from the Figures 5, 6 and 7 that, porosity of the fabrics produced from GCM showed fabrics with lower pore size than that of CBM. As, yarn counts and fabric thickness were increased for more number of crimps, so pore size of the fabrics gradually becomes small, which affects the permeability of the fabrics.

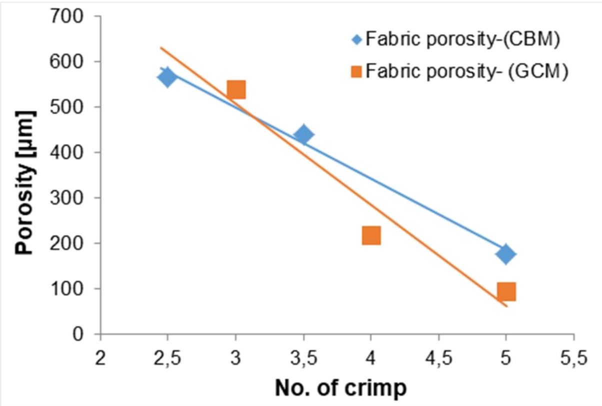


**Figure 5** Porosity vs number of crimps for different crimp methods

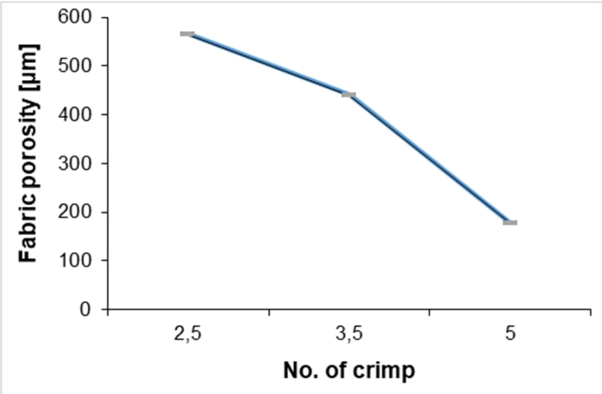


**Figure 6** Confidence interval of fabric porosity of CBM with upper and lower limit

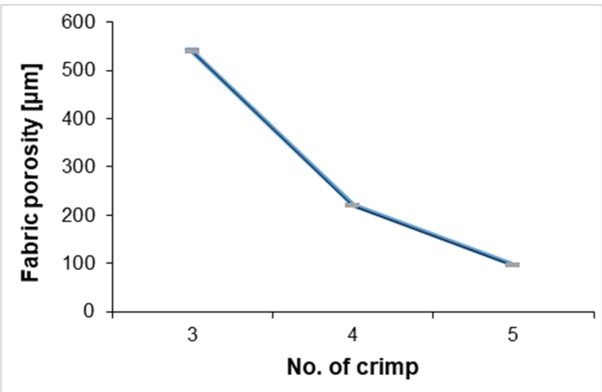


**Figure 7** Confidence interval of fabric porosity of GCM with upper and lower limit

*Air permeability*

Air permeability property of fabrics is almost dependent on the fibre and yarn properties. It also depends on the fabric structure. The air is subjected to a higher resistance in fabrics with yarns produced with more number of crimps due to the smaller inter-yarn pores, more cohesion and more thickness of fibres. Figures 8, 9 and 10 show air permeability of fabrics produced from GCM and CBM. It is seen from the figures that air permeability of the fabric was decreased for higher number of crimps due to more diameter of yarn and more thickness of fabric. The porosity of the fabric also affects the air permeability and due to the smaller pore size of fabric having more crimp, hence the air permeability decreases gradually.

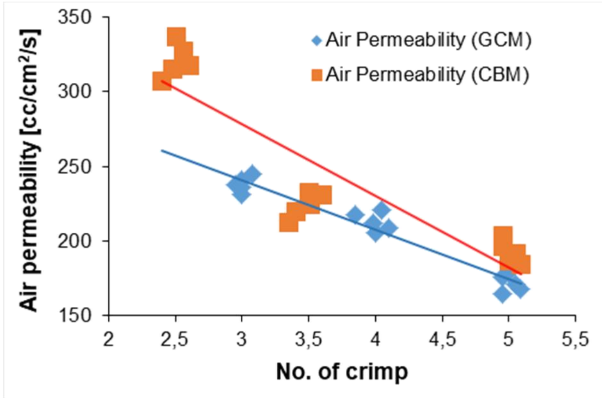


**Figure 8** Air permeability vs number of crimps for different crimp methods

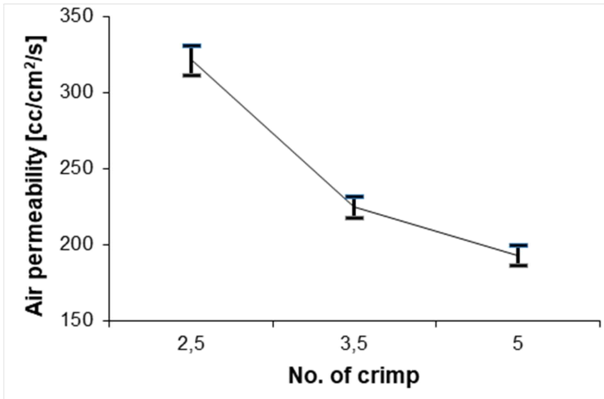


**Figure 9** Confident interval of air permeability of CBM with upper and lower limit

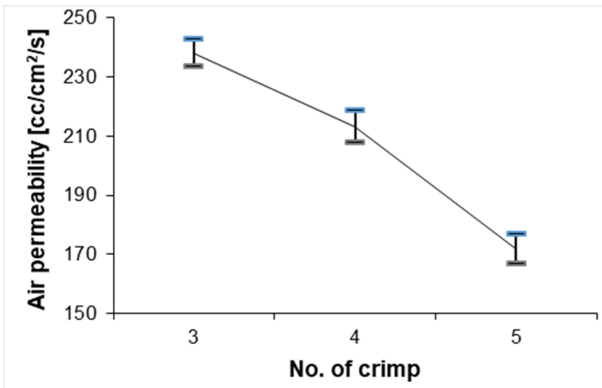


**Figure 10** Confident interval of air permeability of GCM with upper and lower limit

*Thermal conductivity*

The mechanical properties of fabrics are depended on the physical properties of yarns and fabric structures. It is seen from the Figures 11, 12 and 13, where thermal conductivity decreases with the increase of number of crimps and for both cases, it decreased.

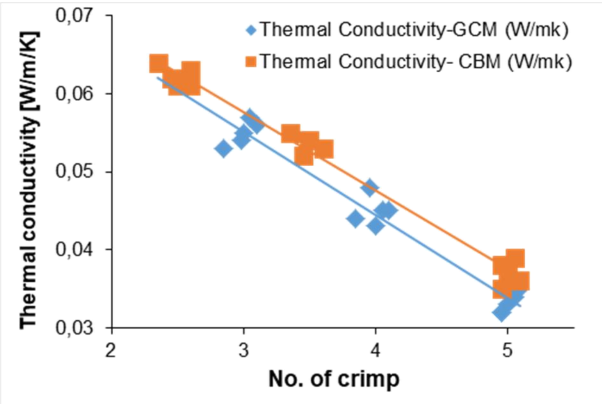


**Figure 11** Thermal conductivity vs number of crimps for different crimp methods

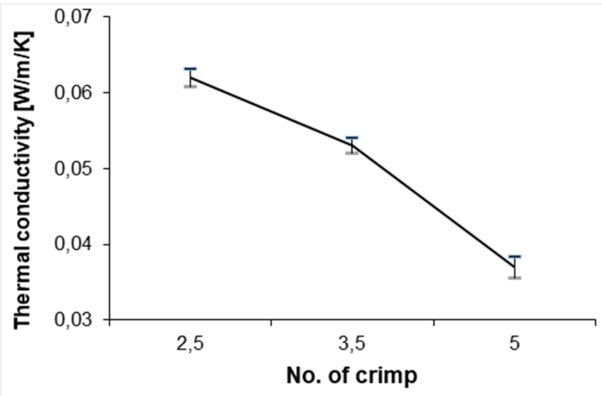


**Figure 12** Confident interval of thermal conductivity of CBM with upper and lower limit

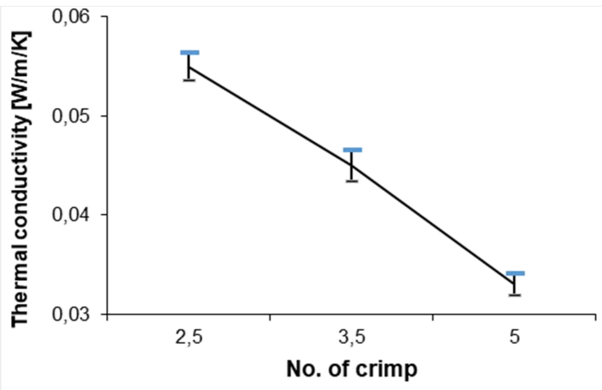


**Figure 13** Confident interval of thermal conductivity of GCM with upper and lower limit

Because, crimp effect results in the increase in thickness and inter-fibre cohesion, which has lower thermal conductivity. Thus the thermal resistance of fabrics produced with higher number of crimps [16]. Thermal conductivity of fabrics with GCM is less than the fabrics produced with CBM. Comparatively, fabrics of GCM shows better insulation property than that of CBM, as GCM imparts more regular size and shape of crimps which accumulate more fibres in the unit length.

## 4 CONCLUSION

The jute is a very technical fibre and the demand of this fibre for diversified end uses is increasing day by day. Jute fibres can be used as winter cloth or as insulation layers for multilayer fabric. In this research, it is found that yarns produced from GCM is more bulky and thick compared to yarns produced from CBM because of symmetries and higher number of crimp. The porosity of the fabric becomes also lower for amplified cross-section of yarn. Moreover, the fabrics show better insulation, such as air permeability is decreased with the increased number of crimps per unit length. Again thermal conductivity of fabric is also decreased for higher number of crimps. Therefore it can be concluded that GCM exhibits better results for the fabric and this is a new era to use jute fibre as winter cloth for their better thermal insulation property.

## 5 REFERENCES


1. Jahan I.: Effect of fabric structure on the mechanical properties of woven fabrics, Advance Research in Textile Engineering 2(2):1018, 2017, pp. 1-4
2. Ghosg S., Singh S., Maity S.: Thermal insulation behavior of chemically treated jute fibre quilt, Journal of Natural Fibre 18(4), 2021, pp. 568-580, https://doi.org/10.1080/15440478.2019.1636744
3. Akter S., Helali M.M.: The effect of mechanical crimp on the basic properties of jute yarn, Materials Today: Proceedings 46(1), 2021, pp. 425-432, https://doi.org/10.1016/j.matpr.2020.09.431
4. Atkinson R.R.: Jute Fibre to Yarn, Iliffe, 1964, pp. 105-126, ISBN: 978-0592063317
5. Huang C., Cui L., Xia H., Qiu Y., Ni Q-Q.: Influence of crimp and inter-yarn friction on the mechanical properties of woven fabric under uniaxial/biaxial tensile loading, Fibres and Textiles in Eastern Europe 6(144), 2020, pp. 43-52, DOI: 10.5604/01.3001.0014.3797
6. Bhattacharjee D., Kothari V.K.: Heat transfer through woven textiles, International Journal of Heat and Mass Transfer 52(7-8), 2009, pp. 2155-2160, DOI: 10.1016/j.ijheatmasstransfer.2008.09.035
7. Morrissey M.P., Rossi R.M.: Clothing System for Outdoor Activities, Textile Progress 45(2-3), 2013, pp. 145-181, https://doi.org/10.1080/00405167.2013.845540

8. Gnanauthayan G., Rengasamy R.S., Kothari V.K.: Heat insulation characteristics of high bulk nonwovens, The Journal of The Textile Institute 108(12), 2017, pp. 2173-2179, https://doi.org/10.1080/00405000.2017.1316697
9. Pac M.J., Bueno M.A., Renner M., Kasmi S.: Warm-cool feeling relative to tribological properties of fabrics, Textile Research Journal 71(9), 2001, pp. 806-812, https://doi.org/10.1177/004051750107100910
10. Ukponmwan J.O.: The thermal insulation properties of fabrics, Textile Research Journal 24(4), 1993, pp. 1-54, https://doi.org/10.1080/00405169308688861
11. Ghosh S., Das R., Maity S.: Optimization of material and process parameters of fibrous quilt for comfortable heat loss from human body, The Journal of The Textile Institute 110(6), 2019, pp. 873-881, https://doi.org/10.1080/00405000.2018.1531742
12. Naylor G.R.S.: The determination of the thermal resistance of continental quilts, Journal of The Textile Institute 81(2), 1990, pp. 175-84, https://doi.org/10.1080/00405009008658344
13. Naylor G.R.S., Wilson C.A., Laing R.M.: Thermal and water vapor transport properties of selected lofty nonwoven products, Textile Research Journal 87(12), 2017, pp. 1413-1424, https://doi.org/10.1177/0040517516654104
14. Hu J.Y., Hes L., Li Y., Yeung K.W., Yao B.G.: Fabric touch tester: Integrated evaluation of thermal – mechanical sensory properties of polymeric materials, Polymer Testing 25(8), 2006, pp. 1081-1090, https://doi.org/10.1016/j.polymertesting.2006.07.008
15. Sari H, Berger X.: A new dynamic clothing model, Part 2: Parameters of the underclothing microclimate, International Journal of Thermal Sciences 39(5), 2000, pp. 646-654, https://doi.org/10.1016/S1290-0729(00)00212-X
16. Das A., Alagirusamy R., Shabaridharan K., Kumar P.: Study on heat transmission through multilayer clothing assemblies under different convective modes, Journal of The Textile Institute 103 (7), 2012, pp. 777-786, https://doi.org/10.1080/00405000.2011.607570