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Thermal and sound insulation properties of chiengora blended nonwoven fabrics

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A novel animal fibre chiengora has been explored for its potential application in textile. Chiengora fibres are made into nonwoven fabrics by blending with polyester fibre in different proportions for their better strength. Nonwoven fabrics are also produced from wool and polyester blends in different proportions for comparison. Hair of Lhasa Apso breed dog is chosen to blend with polyester to produce the nonwoven fabric and is analysed for its thermal and sound insulation characteristics. It is observed that 100% chiengora nonwoven fabric has thermal insulation value of 0.211 clo which is 42% higher than that of 100% wool nonwoven fabric (0.121 clo). The 70:30 chiengora/polyester fabric shows a thermal insulation values of 0.141 clo which is higher than 100% wool nonwoven fabric. The chiengora nonwoven fabrics also possess similar sound insulation properties like wool [noise reduction coefficient value (NRC) of 0.23 for chiengora and 0.22 for wool]. The increase in the chiengora and wool content in the blends reduces the tensile strength, tear strength and air permeability of the nonwoven fabrics. It is concluded that the chiengora blended nonwoven fabrics could be used as an effective padding material because of their better thermal insulation and sound absorption properties.

Keywords: Chiengora/polyester fabric, Noise reduction coefficient, Nonwoven fabric, Sound insulation, Thermal insulation, Wool/polyester fabric

1 Introduction

A novel and less explored specialty animal fibre is dog hair. The dog hair as clothing products were being used for centuries by individual artisans. However, they were not commercially produced. Before the usage of wool from sheep in North America, dog hair was one of the fibres spun by them[1]. The dog hair is commonly known as ‘Chiengora’. ‘Chien’ is the French word for dog, and ‘gora’ is derived from “angora” the soft fur of a rabbit. Similar to mohair, cashmere and angora, chiengora is considered to be a luxury fibre and it has similar appearance to angora[2]. Dog fibres are warm and fluffy in nature. Sweaters, scarves, home decors, mittens, hats, etc. are being made out of chiengora on order basis in countries like Canada[3]. It is imperative to deduce more usage for the dog hair as the dog population was close to 525 million in the year 2012[4]. In USA alone, there were 89.7 million dogs in 2017[5] and the combined population of top ten dog populous countries is 210 million[6] compared to the sheep in the world, which is approximately one billion[7].

The reason attributed to the non usage of chiengora fibres is that there is less understanding about their properties and on how it could be categorized along with commonly used protein fibres like wool and mohair[2]. Another reason for their lesser usage is that chiengora fibres may cause allergy to humans. However, it has been found that dog hair is not allergic and it is only the dander present in the hair that causes allergy[8]. Once the fibres are washed, allergy can be avoided[9,10]. All dogs shed hair, especially the ones with a denser hair coat. Dog grooming is also done by all pet owners to cut the unwanted hair. All these hairs are thrown as waste, leading to landfills[11]. If the hairs are collected, properly channelized and processed, beautiful textile products can be made out of it. The waste fibres can be converted into useful products. It can also become a suitable alternative for wool at least at a smaller scale as it is less costlier to manufacture, abundantly available, and also warmer and fluffier in nature.

The properties of the chiengora fibres have been studied by very few researchers. Suzanne *et al.*[1] has analysed the physical and mechanical properties of various breeds of dogs, like Collies, Shetland sheepdog, Chow, Newfoundland, Golden retrievers and Pomeranian. In an another study, the researchers found that the chiengora fibres have fur like appearance, circular cross-section, very less cohesion due to smoother surface with very finer scales unlike wool.

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The fibres are durable in nature and fluff when worn[2]. Rusinaviciute *et al.*[12] also studied the morphological structure of chiengora fibres confirming the presence of scales. They concluded that chiengora fibre differs from sheep's wool on the basis of type of scale shape, scale frequency and cross-section, as hairs of some of the breeds have medulla inside hair. Ragaisiene *et al.*[13] stated that their crystallinity degree differs from wool and it is also different in hairs of different dog breeds. They also performed FTIR analysis and found that chiengora fibre spectra are more intensive with bigger areal at all intensities, except at 2920 cm^{-1} and 2850 cm^{-1}, where it is intense for wool.

The abundant availability of fibres, better thermal insulation, better strength than other natural animal fibres, avoiding landfills by utilising the waste dog hair are the fundamental reasons behind the research. However, it can be clearly seen that the chiengora fibre application based researches have not been reported yet. The coarser nature of fibres may make yarn spinning challenging; however, the production of nonwovens would be possible. Hence, the possibility of exploring production of nonwovens has been carried out in this study. Nonwoven fabrics have been developed using chiengora and polyester blends in five different proportions. The properties of the developed fabrics are assessed and compared with the properties of the developed wool/polyester blend fabrics with respect to thermal and sound insulation behavior for industrial applications. This research study is possibly one of its kinds to provide evidence of quantitative values to chiengora fibre and further provide direction to the types of products that can be created using chiengora fibres.

2 Materials and Methods

2.1 Materials

The chiengora fibres were collected from local pet shops and groomers in and around Coimbatore, India. Five different dog hairs such as Golden Retriever, Lhasa Apso, Pomeranian, Labrador and German Shepherd were collected for the study. The dog hair were cut manually from dogs (average length of 32 mm) and then cleaned for further process. Wool fibres (average length 36 mm and linear density 5.4 denier) were procured from Excel Silks, Bengaluru, India and polyester fibres (cut length 32 mm and linear density 3 denier) were procured from Navamani Traders, Coimbatore, India. Sodium carbonate (anhydrous, ACS, 99.5% min, Sigma-Aldrich, India) was procured for fibre washing.

2.2 Methods

2.2.1 Washing of Fibres

The chiengora fibres of each breed were separately taken in a large cloth bag for washing, such that the fibres do not come out of the bag while rinsing in hot water solution. Fibre having a weight of 500 g was taken for cleaning at a time to avoid clumps during washing. The cleaning was done by immersing the fibres for 30 min at 70ºC using 2 g/L sodium carbonate, 0.5 g/L wetting agent and 1 g/L detergent with a 1:40 material-to-liquor ratio[2]. The fibres were then rinsed in hot water and shade dried for 24 h to make them free from excess water content.

2.2.2 Physical and Morphological Properties of Fibres

The fibres from five dog breeds were tested to select a suitable dog fibre for further processing of nonwoven. The strength and elongation of the fibers were determined based on ASTM D 3822-07 standard in an Instron tester. Fibre denier was analysed using Gravimetric method (ASTM D1577). Scanning electron microscopy (SEM) (Model JEOL-JSM-6396) was used to understand the surface morphology of the Lhasa Apso fibre. Prior to the test, the samples were coated with a thin layer of gold by a plasma sputtering apparatus. The observation was performed in high vacuum mode with secondary electron detector and accelerating voltage between 5 kV and 10 kV.

All the tests were carried out after conditioning the samples at the standard temperature (27° ± 2°C) and relative humidity (65±2%).

2.2.3 Nonwoven Fabric Production

Based on the characteristics of chiengora fibres (Table 1), hairs from Lhasa Apso breed were selected, considering their denier and tenacity for nonwoven fabric production. Polyester fibres were blended separately with chiengora and wool to make the nonwoven fabrics of different proportions. Polyester fibres were selected to blend with chiengora for their

Table 1 — Properties of wool polyester and chiengora fibres

Sample	Tenacity g/tex	Elongation %	Linear density den
Wool	1.64	43	5.40
Polyester	6.78	21	3.00
Chiengora			
Labrador	2.06	40.5	26.09
Lhasa Apso	2.28	47.2	5.50
Golden Retriever	2.12	42.3	18.69
German Shepherd	2.10	42.5	17.95
Pomeranian	2.22	46.31	8.23

better strength and thermal insulation behavior, and to facilitate easier nonwoven fabric production, as chiengora fibres are very coarser in nature. The sample code and blend proportions selected for making nonwoven fabrics are given in Table 2.

The miniature lab model carding machine (Trytex, India) with stationary flats was used to produce the webs. The fibres were mixed manually and each lot weighing 50 g was prepared with required proportion of fibres. The carded web was collected in the front of card by a drum. The different stages of production of carded sliver in miniature carding machine is shown in Fig 1. Four such webs were formed for each blend to get the required areal density in nonwoven fabric.

2.2.4 Fabric Formation using Needle Punching Machine

The needle-punched nonwovens were obtained by placing 4 webs of the same blend ratio on top of each other and feeding them into the needle punching machine (DILO, Germany) with 15 mm depth of penetration and at a speed of 120 strokes per min to achieve the areal density of around 400 g/m^2. The areal density of fabric was achieved by adjusting and needling the required number of layers of webs, considering the loss due to needling. The needle-punched nonwoven fabric is shown in Fig. 1(d).

2.2.5 Testing of Nonwoven Fabric

The basic properties for the produced nonwovens were tested to assess their performance for industrial applications using following standards: fabric weight (ASTM D 3776), thickness (ASTM D 5729), tensile strength (ASTM D 5035), tear strength (ASTM D 1424 – 96), air permeability (ASTM D 737 – 04) and thermal conductivity (ASTM D7340-07).

2.2.6 Thermal Insulation

The thermal transmittance and thermal resistance are calculated as per ASTM D 1518 using the following formula:

$$\text{Thermal transmittance } (U) = \frac{\text{Thermal conductivity } (K)}{\text{Thickness of fabric (mm)x 1000 (m)}}$$

$$\text{Thermal resistance } (R) = \frac{1}{U}$$

Thermal insulation of textile materials especially clothing may be expressed in clo units. The clo has the same dimensions as the *R* value, that is used to describe insulation used in residential and commercial construction. The clo value is also similar in magnitude to the *R* value, as shown below:

$$1 \text{ clo} = 0.88 \text{ R}$$

The thermal insulation value (*TIV*) is calculated using the following formula:

$$\text{Thermal insulation value } (TIV) = \frac{\text{R}}{0.88} \text{ clo}$$

Table 2 — Blend details, weight and thickness of nonwoven fabrics

Fibres	Sample code	Blend ratio	Fabric thickness, mm	Areal density, g/m^2	Bulk density, g/cm^3
Lhasa Apso	LA	100	3.15	405	0.129
Lhasa Apso /Polyester	LA/PES	70:30	3.1	403	0.130
Lhasa Apso /Polyester	LA/PES	50:50	2.95	400	0.143
Lhasa Apso /Polyester	LA/PES	30:70	2.9	395	0.136
Polyester	PES	100	2.8	392	0.133
Wool/Polyester	W/PES	70:30	3.1	405	0.131
Wool /Polyester	W/PES	50:50	3.0	402	0.134
Wool /Polyester	W/PES	30:70	2.9	398	0.137
Wool	W	100	3.2	408	0.128

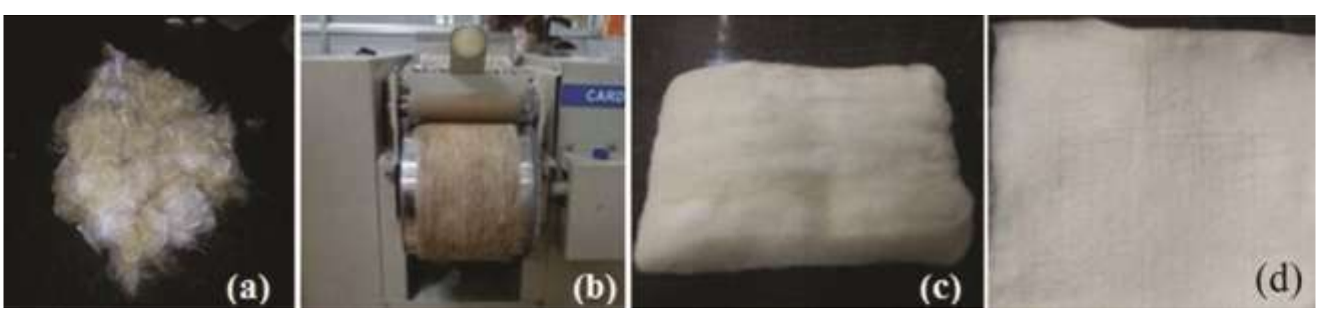

Fig. 1 — Carded web production (a) mixing of fibres, (b) web formation, (c) stacking of webs, and (d) needle-punched nonwoven fabric

It is the amount of insulation that allows a person at rest to maintain thermal equilibrium in an environment at 21°C (70°F) in a normally ventilated room (0.1 m/s air movement). Above this temperature, the person so dressed will sweat, whereas below this temperature the person will feel cold.

2.2.7 Evaluation of Sound Insulation

Impedance tube method is used to indicate the normal incidence sound absorption coefficient (NAC) by using plane sound waves that strike the material. The noise reduction coefficient (commonly abbreviated NRC) is a scalar representation of the amount of sound energy absorbed upon striking a particular surface. An NRC of 0 indicates perfect reflection and NRC of 1 indicates perfect absorption. It is the arithmetic average, rounded to the nearest multiple of 0.05, of the sound absorption coefficients for a specific material and mounting condition determined at the one-third octave band center frequencies of 250, 500, 1000 and 2000 Hz.

The experiment was set up according to ASTM E1050/ISO 10534-2 test method for impedance and absorption of acoustical materials by two microphone impedance tube. This test method is similar to ASTM C384 - 04 test method which used an impedance tube with a sound source connected to one end, and the test sample was mounted to the other end.

The test was conducted by taking four readings in each sample with two different sample sizes in different sound frequency range. From the test reading, the NRC value is derived based on the arithmetic average of the four sound absorbent values at 250, 500, 1000 and 2000 Hz and rounded to the nearest 0.05 (ASTM C 423-90A).

3 Results and Discussion

3.1 Chiengora Fibre Properties

The properties of hair fibres from five different breeds of dogs are given in Table 1. The denier of the various breeds varies widely between 5.5 and 26. Among the breeds, hairs of Lhasa Apso breed have a finer denier of 5.5, high tenacity of 2.28 g/tex and mean elongation of 47.2%. It is found that Labrador has 40.5% lesser elongation compared to other breeds. Pomeranian also has better tenacity due to its comparatively finer denier. This result shows that the chiengora fibres are much coarser than traditional animal hair fibres, except the Lhasa Apso and Pomeranian. These two breeds belong to the small and toy breed category of dogs respectively and have dense coat[14,15]. Based on the denier, tenacity and elongation values, Lhasa Apso fibre has been selected for further processing.

3.2 Surface Morphology of Lhasa Apso Fibres

SEM photographs of Lhasa Apso fibres are taken to understand their surface morphology and their similarity with wool. It shows the presence of scales (Fig. 2). The scales are present on the surface of Lhasa Apso chiengora fibres as reported earlier[12]. The scale patterning along the length of dog hair is regular and smooth. The distance between the cuticle scale margins is small and hence more frequency of scales is witnessed.

3.3 Nonwoven Fabric Properties

Chiengora and wool fibres are blended with polyester in different blend proportions and nonwoven fabrics are produced. Wool fabrics and wool/polyester blend fabrics are also produced to compare the thermal comfort and sound absorption properties of chiengora fabrics. Polyester fibre is chosen because of its thermal insulation property[16,17]. The polyester fibres are blended with chiengora fibres to produce better web with cohesion and thereby to increase the strength of the nonwoven fabric.

Table 2 shows the areal density and thickness of all fabric blends. Areal density of all the samples is within the range of 392–408 g/m^2. Areal density values of 100% chiengora and 100% wool fabric are more or less same at 405 g/m^2 and 408 g/m^{2}respectively. This difference in areal density can be owed to the difference in the fibre denier; however the difference is not very high and it would not have significant effect on the fabric properties. The average

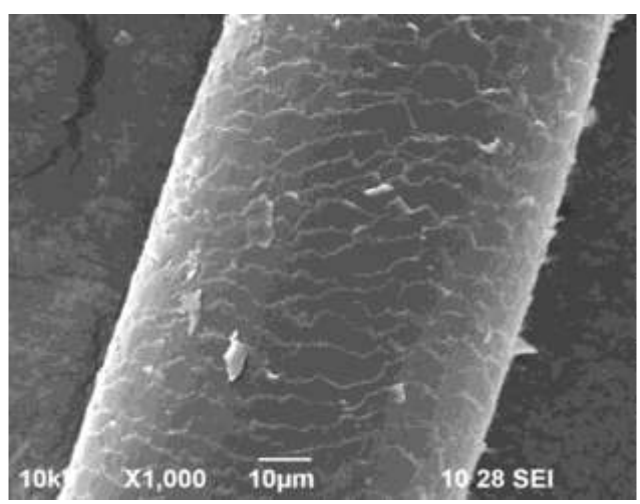

Fig. 2 — SEM photograph of Lhasa Apso fibre

thickness of all samples is found within the range of 2.8-3.2 mm with 100% chiengora and 100% wool fabrics having more thickness. The bulk density ranges between 0.128 g/cm^3 (for 100% wool) and 0.143 g/cm^3 (for 50:50 chiengora/ polyester fabric) with 100% wool and 100% Lhasa Apso having similar bulk density.

3.4 Tensile and Tear Strength of Nonwoven Fabrics

Tensile strength of the nonwoven fabrics is shown in Fig. 3. The higher tensile strength is observed for 100% polyester. The strength values of 100% chiengora (35 N) and 100% wool (36 N) fabrics are found very similar. It is observed that the increase in chiengora content leads to decrease in strength of fabrics. This could be due to the amorphous nature and relatively lower hydrogen bond formation in the chiengora fibre[18]. Tear strength results also show similar trend to the tensile strength results. Increase in chiengora content leads to reduced tear strength. The 30:70 chiengora/ polyester blend has higher tear strength of 46 N. Overall, the chiengora and its blends are found to have higher tear strength than wool and its blends.

3.5 Comfort Properties of Nonwoven Fabrics

3.5.1 Air Permeability of Nonwoven Fabrics

Air permeability is measured for all the samples (Fig. 4). From the above results, it is found that pure chiengora and wool have lower air permeability values of 52 and 55 cm^3/cm^2/s respectively. It is also

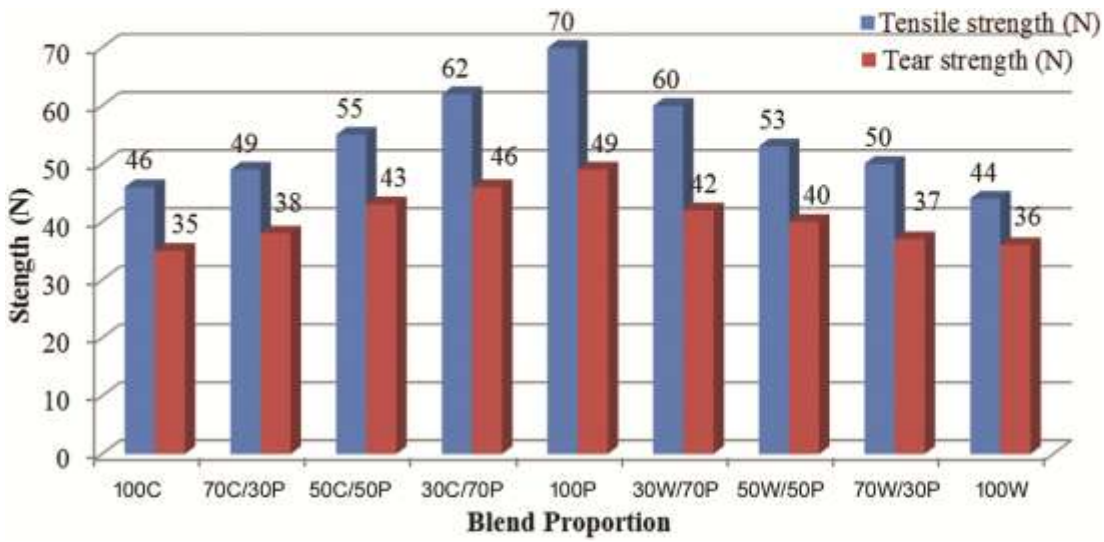

Fig. 3 — Tensile and tear strength of nonwoven fabric

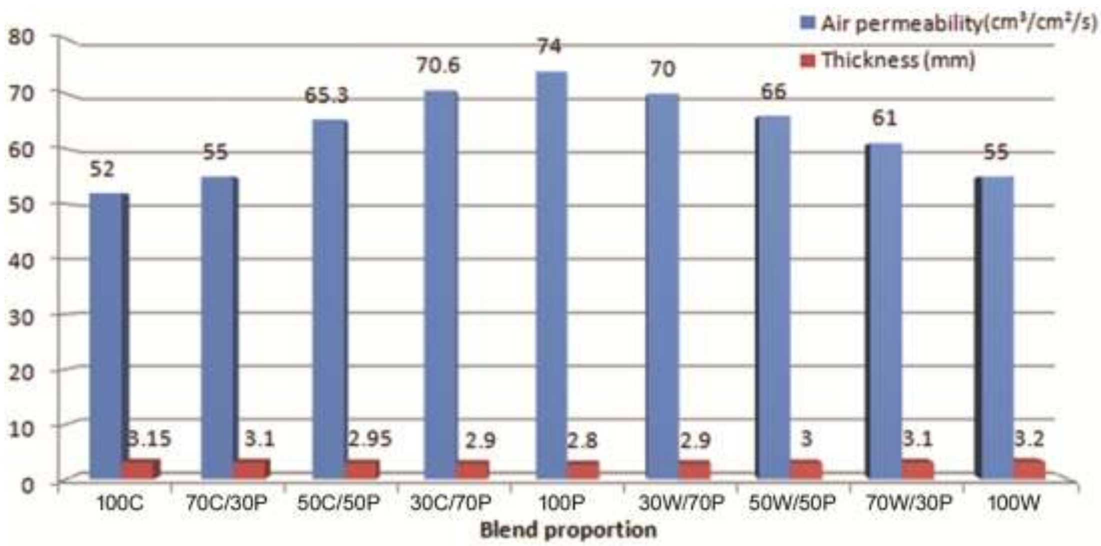

Fig. 4 — Air permeability and thickness of nonwoven fabric

observed that the reduction in chiengora and wool content increases the air permeability values of the nonwoven fabric. The higher air permeability values of 74 and 70 $cm^3/cm^2/s$ are observed for 100% polyester and 30:70 chiengora/polyester fabrics respectively. Wool/ polyester (30:70) fabrics are having 70.6 and 70 $cm^3/cm^2/s$ air permeability values respectively. The better performance of the above-mentioned nonwoven fabrics can be attributed to their thickness value[19]. Figure 4 shows that the increment in the polyester content reduces the nonwoven fabric thickness considerably from 3.15 mm to 2.8 mm in the case of chiengora blends and from 3.2 mm to 2.9 mm in the case of wool blends.

3.5.2 Thermal Insulation of Nonwoven Fabrics

The thermal conductivity of 100% chiengora is found to be lower than those of all the other blend proportions and 100% wool nonwoven. Hence, 100% chiengora fabric has higher thermal resistance and thermal insulation values. The polyester fabric has least thermal resistance of 0.049 m^2k/W and 100% chiengora fabric has the highest thermal resistance of 0.185 m^2k/W. Table 3 shows that the addition of polyester fibre in the nonwoven reduces the thermal resistance value. These findings are in line with the results of thickness reported in previous section, where the higher thickness is observed for 100% chiengora and wool fabrics. Fabric with higher thickness shows better thermal resistance than the thinner one. Even though both the nonwoven fabrics (wool and chiengora) have similar thickness (100% wool 3.2 mm and 100% chiengora 3.15 mm), the chiengora fibre fabric has higher thermal resistance which may be attributed to its fibre morphological structure. The SEM image of the chiengora fibre clearly shows the presence of more number of finer scales in fibre surface, which usually contributes to increased thermal insulation[20]. This structural difference in the chiengora fibres plays a vital role in their higher thermal resistance value over wool.

The 70:30 chiengora/ polyester fabric is also having higher thermal resistance than 100% wool, indicating that it can be used as a cheaper alternative for existing wool based fabrics. The thermal insulation values of chiengora and its blends are found to be higher than those of the wool and its blends[2,21]. Another reason for higher insulation value could be the lesser air permeability noticed in chiengora and its blends. The air permeability and thermal conductivity are directly proportional. The increment in air permeability value reduces the thermal insulation. From the air permeability results, it can be found that the 100% chiengora fibre nonwoven has lesser air permeability value than all the other fabric blends, including 100% wool. Hence, lesser air permeability indicates lesser conductivity and thus better thermal insulation[22].

For a better understanding of the elevated thermal insulation properties of chiengora fabrics, TIV value is expressed in the units of clo. Particularly, it is evident that pure chiengora has the highest TIV value of 0.211, which is 42% higher than that of 100% wool. These results confirm that the increase in chiengora content leads to an increase in thermal insulation value for similar fabric structures.

3.5.3 Sound Insulation

The sound insulation test has been done for all fabric samples and the results are given in Table 4. The table shows that there is no much difference in NRC among the samples. The NRC values are based on the fabric structure, areal density and porosity of the fabric. The results from Table 4 indicate that the NRC values of 100% chiengora and 100% wool fabrics are 0.23 and 0.22 respectively, indicating no

Table 3 — Thermal insulation value of nonwoven fabrics

Sample code	Thermal conductivity (K) W/mK	Thermal transmittance $\times 10^3$ (U), W/m^2k	Thermal resistance (R) m^2k/W	Thermal insulation (TIV) clo
LA	0.017	5.397	0.185	0.211
70:30(LA/PES)	0.025	8.065	0.124	0.141
50:50(LA/PES)	0.032	11.429	0.088	0.099
30:70(LA/PES)	0.04	13.793	0.073	0.082
PES	0.06	20.339	0.049	0.056
70:30(W/PES)	0.036	11.613	0.086	0.098
50:50(W/PES)	0.042	14.000	0.071	0.081
30:70(W/PES)	0.045	15.517	0.064	0.073
W	0.03	9.375	0.107	0.121

Table 4 — Sound insulation of non woven fabric

Frequency, Hz	Noise reduction coefficient (NRC)								
	LA	70:30 (LA/PES)	50:50 (LA/PES)	30:70 (LA/PES)	PES	70:30 (W/PES)	50:50 (W/PES)	30:70 (W/PES)	W
250	0.14	0.11	0.09	0.08	0.07	0.1	0.09	0.07	0.13
500	0.17	0.15	0.13	0.13	0.12	0.14	0.13	0.12	0.17
1000	0.25	0.23	0.2	0.18	0.15	0.23	0.22	0.17	0.23
2000	0.36	0.34	0.34	0.33	0.3	0.33	0.35	0.29	0.36
Average	0.23	0.20	0.19	0.18	0.16	0.2	0.19	0.16	0.22
Fabric thickness, mm	3.15	3.1	2.95	2.9	2.8	3.1	3.0	2.9	3.2

major difference in sound insulation property. In general, the NRC value of more than 0.2 indicates the presence of sound insulation property, and the material with NRC value of < 0.2 is considered as sound reflecting material[23]. Normally, wool has higher sound insulation[24] and better sound insulation behaviour than any other fibre, surprisingly the chiengora fibre is also possessing the same level of sound insulation value. The average NRC values indicate that 70:30 chiengora/ polyester blended nonwoven also possesses higher sound insulation property (NRC 0.207). The major reason for the sound insulation behaviour of the chiengora fibre is its similar morphological structure and higher fabric thickness to wool as mentioned earlier. It is also noted that specifically the sound absorption is not up to the expected levels at lower frequency range, and at higher frequencies the sound absorption is better. These results suggest that the selected chiengora fibres and their blends with polyester can be used as a potential alternative to the wool fibre in the higher frequency sound insulation requirements. However, the performance of the chiengora fibres and their blends at different environmental conditions is yet to be studied in the future research.

4 Conclusion

In this work, the scope of a non-traditional animal protein fibre chiengora, for textile use has been identified. The Chiengora fibres are made into nonwoven fabrics by blending with polyester fibres at different proportions for its better strength, thermal insulation behaviour and cost effectiveness. Hair of Lhasa Apso breed dog are chosen to blend with polyester based on its comparative finer denier of 5.5 and high tenacity value of 2.28 g/tex, to produce the nonwoven fabrics. Out of the developed nonwoven fabrics, the 100% chiengora fibre fabric shows more thickness; the thickness values range from 2.8 mm to 3.2 mm for all fabrics. The highest bulk density of 0.143 g/cm^3 is noted for 50:50 chiengora/ polyester fabric. The 30:70 chiengora/ polyester shows higher tear strength of 46 N. The chiengora and its blends are found to have higher tear strength than wool. The higher air permeability values of 74 and 70 cm^3/cm^2/s are noted for 100% polyester fibre fabric and 30:70 chiengora/ polyester fabrics respectively.

The 100% chiengora nonwoven fabric shows thermal insulation value of 0.211 clo which is 42% higher than that of 100% wool fabric. The 100% wool nonwoven fabric has thermal insulation value of 0.121 clo which is also lower than 70:30 chiengora/ polyester fabric with 0.141 clo. The chiengora nonwoven fabrics also possess similar sound insulation properties when compared with wool and its blends. The noise reduction coefficient (NRC) of 100% chiengora and 100% wool fabrics is 0.23 and 0.22 respectively. The 70:30 chiengora/ polyester fabric (with NRC value of 0.207) can also be used as an alternative to wool, thereby reducing the consumption of wool and the cost by utilizing the chiengora fibre which is thrown as a waste in many countries. The research findings indicate that the chiengora fabrics can be used for thermal and sound insulation purpose effectively for textile and industrial applications.

References

1 Suzanne G, Banks P & Jones M, *AATCC Rev*, 9 (2007) 42.
2 Suzanne G, *Evaluation of Non-traditional Animal Fibres for use in Textile Products*, MSc thesis, North Carolina State University, USA, 2003.
3 *Chiengora Fibres*, www.chiengorafibres.com (accessed on 20 September 2017).
4 Coren S, *How Many Dogs are there in the world?* https://www.psychologytoday.com/blog/canine-corner/201209 /how-many-dogs-are-there-in-the-world (accessed on 18 February 2018).
5 Statista, *Number of Dogs in the United States from 2000 to 2017*. https://www.statista .com/statistics/198100/dogs-in-the-united-states-since-2000/ (accessed on 18 February 2018).
6 Worldatlas, *Countries with the Most Dogs Worldwide*. https://www.worldatlas .com/articles/countries-with-the-most-dogs-worldwide.html (accessed on 18 February 2018).

7 *Dollars and cents*, www.sheep101.info/farm.html (accessed on 18 February 2018).

8 Veterinary and Aquatic Services Department, *Human Allergies to Dogs*, http://www.pet education.com/article.cfm?c=2+2111&aid=145 (accessed on 20 September 2017).

9 Crolius K & Montgomery A, *Knitting With Dog Hair* (St. Martin's Griffin, New York), 1994.

10 Hodson T, Custovic A, Simpson A, Chapman M, Woodcock A & Green R, *J Allergy Clin Immunol*, 103(1999) 581.

11 Czinski R, *Eco-friendly Options for Dog Waste Containment.* http://www.simpleecology.com/eco/dog-waste-containment (accessed on 20 September 2017).

12 Rusinaviciute J, Ragaisiene A & Binias W, *J Nat Fibers,* 13(2016) 585.

13 Ragaisiene A, Rusinaviciute J, Milasiene D & Ivanauskas, *Fibres Text East Eur,* 5(2016) 21.

14 Pomeranian, http://dogtime.com/dog-breeds/pomeranian#/slide/1 (accessed on 20 September 2017)

15 Lhasa Apso, http://dogtime.com/dog-breeds/lhasa-apso#/slide/1 (accessed on 20 September 2017).

16 *Textiles for Cold Weather Apparel*, edited by J T Williams (Woodhead Publishing, UK), 2009.

17 Zeinab S, Abdel-Rehim, Saad MM, El-Shakankery M & Hanafy I, *Autex Res J,* 6(2006) 148.

18 *Protein Fibre*, http://nptel.ac.in/courses/116102026/protein%20fiber-m5/wool%20polyme r.htm (accessed on 20 September 2017).

19 Debnath S, *Indian J Fibre Text Res,* 36 (2011) 122.

20 Shekar RI, Kasturiya N, Raj H & Nigam S, *Indian J Fibre Text Res,* 26 (2001) 287.

21 Asis Patnaik, Mlando Mvubu, Sudhakar Muniyasamy, Anton Botha & Rajesh Anandjiwala, *Energ Building*, 92 (2015) 161.

22 Ajmeri J R & Bhattacharya SS, *Int J Text Fash Technol*, 3(2013) 1.

23 Asdrubali F, *Int Proceedings of Euronois*, 30(2006) 1.

24 Michaud A, *Silence is Golden: Optimizing the Acoustic Environment*. https://www.price industries.com/content/uploads/assets/literature/technical-papers/silence-is-golden-optimi zing-the-acoustic-environment.pdf (accessed on 20 September 2017).