Thermal insulation studies on leather clothing: Relevance to structure – property relationship

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Abstract

Understanding the performance of leather in the final product form (apparel) provides valuable inputs for the design and fabrication of the leather apparel. Primarily, leather apparels are used for protection against cold conditions. However, the total comfortability of the apparel on wearing depends on many other factors. In this work, an attempt has been made to study one of the prime comfort parameter "thermal insulation". Measurement of thermal insulation under simulated conditions has been carried out for garments made out of different leathers and also for different designs of the garment construction. Customized experimental set up was developed for calculating thermal insulation values by measuring the heat supply after bringing equilibrium between the environment (cold chamber) temperature and heat source temperature. The above values were calculated for different samples at different environment temperatures. It is evident from the study that the heat supply required to keep the source temperature at 34˚C increases when environment temperature decreases. Also, it is shown that all the samples tested have more than the required minimum thermal insulation for protection against cold as specified in international standards. Insulation values for all the samples and constructions are in the range of 0.402 to 0.692 m^2˚C/W. It has also been shown that there is a strong structure property relationship for all the leather types when viewed under microscope. Thermal insulation values quantified in this study can be used to design leather apparels with appropriate thermal insulation according to the place of use.

Introduction

Leather garments are widely used as protective clothing against cold environment. Designing of leather garments plays a major role in providing comfortability and ergonomics to the wearer. More accurate and specific inputs in the design stage leads to ergonomically designed garment. Measuring a material's reaction to conditions of use provides information that can be used to predict product performance. The relationship between clothing comfort and clothing materials lies on the ability of a material to retain or conduct body or environmental heat, absorb or repel moisture and feel next to the skin. Clothing comfort has two main aspects namely thermophysiological and sensorial that combine to create a subjective perception of satisfactory performance[1]. Thermal insulation is one of the prime parameter to provide thermophysiological comfort[2]. Optimal thermal comfort on wearing apparel is achieved by balancing the rate of heat transfer by human body, insulation value of the apparel and environment temperature. Heat transfer is concerned with the determination of the rate at which energy is transferred as heat by virtue of temperature difference between two bodies[3]. The thermal situation of an apparel as a protective layer between the human body and the environment is very complex and largely depends on human factors (activity, individual factors), clothing (material, fit) and environment factors (temperature, wind, radiation)[4]. In order to remain comfortable, the human body must maintain a skin temperature of 34˚C and in thermal equilibrium with the environment[5]. Human body generates heat even during sitting at rest. Among the total heat generated, a small portion is lost to evaporation, insensible perspiration and respiration. The major portion of heat generated is lost through radiation, convection and clothing[6,7]. This is otherwise called as dry heat loss due to temperature gradient between skin and environment. Many studies were carried out to quantify the thermal insulation values of textile fabrics and other synthetic clothing material[4,8-10]. To the best of the authors' knowledge no studies were found in literature regarding the thermal comfort measurements on leather apparel. In this study, an attempt was made to measure thermal insulation for garments at different simulated conditions. Thermal insulation of an apparel can be calculated by measuring the inside body temperature, atmospheric temperature and the quantity of heat supplied to maintain inside body temperature at 34˚C. The thermal insulation was measured and analysed for garments made of different leathers and also for different designs of the garment construction.

Experimental

Materials: The samples (leather apparels) for the study were prepared using various types of leathers with different types of garment construction. The leathers used were sheep nappa (0.8 mm thick), goat nappa (0.8 mm thick), cow nappa (0.8 mm thick), goat suede (0.6 mm thick), and fur sheep nappalon (1.4 mm thick excluding fur). Commercially available top grade leathers were procured from different sources with uniform size and thickness. The construction types chosen were based on front opening in a garment namely "zipped" and "buttoned". Apart from the leather, all the accessories like lining (poly satin), wadding (60 GSM), thread (ticket no. 24, cotton-glace finished) etc. were of same specification for all the garments (except in fur garment where no lining or wadding was used). Pfaff 1245 model single needle flat bed unison feed lockstitch sewing machine and Schmetz needle model 134-35 LR point was used and the stitch length was maintained at 3 mm for fabricating the apparel samples. The garment samples fabricated for the experiment were of children size and the average outer area of the apparel ranges between 0.23 to 0.26 m^2.

Methods: To test the thermal insulation on functional clothing, thermal mannequin is often used in the textile clothing comfort studies[8]. Thermal mannequin is very sophisticated and expensive equipment. Hence in this study, a customized experimental setup was designed and fabricated. To simulate the thermal condition, an infra red bulb was used as a heat source. Cold chamber capable of producing temperatures from -30 to +20˚C was used to simulate the atmospheric temperature. The cold chamber was equipped with a thermocouple to maintain any desired temperature over a period of time. A typical test setup to measure the heat supply is given in Fig. 1.

Temperature controller comprising digital wattmeter, voltage regulator, digital thermometer and thermocouple was designed and fabricated. The voltage regulator controls the power supply to the heat source. The temperature inside the sample garment (body temperature) was measured by a temperature sensor near the heat source. Using the temperature controller the inside temperature (simulating the body temperature of 34˚C) can be maintained by controlling the voltage regulator according to the feed back from the digital thermometer. During the experiment, the cold chamber was set for a desired temperature simulating the atmospheric temperature using the temperature controller provided in the cold chamber. To be in equilibrium with the chamber temperature a constant power supply is needed to maintain inside temperature of the sample. The power supplied to the heat source to maintain the inside temperature was measured and used for calculation.

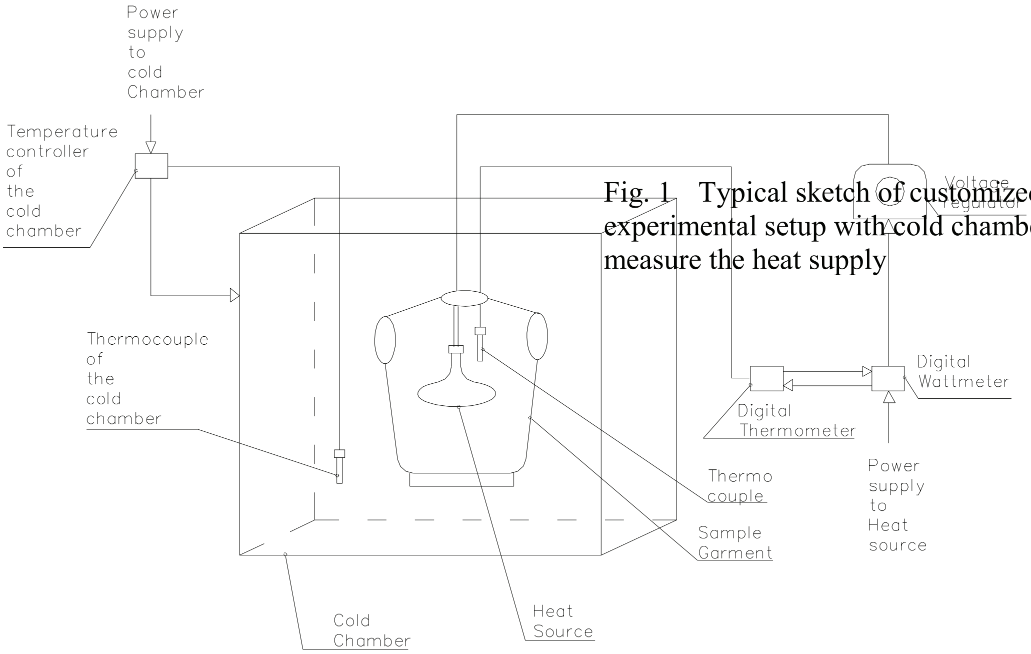


Fig. 1 Typical sketch of customized experimental setup with cold chamber to measure the heat supply

Measurements and Calculations: The principle used in determining thermal insulation is to measure the heat supply per unit area required to maintain a thermal equilibrium between the heat source placed inside the garment and the external environment. In the above measurement the area of the garment through which the heat transfer takes place has to be calculated. The area of the garment was calculated by measuring the area of individual patterns and it is 0.26 m2 for zipped garment and 0.23 m2 for the buttoned garment. The opening at the neck, sleeve armholes and the bottom were plugged using thermocole material during the experiment. The temperature of the cold chamber was maintained from +10 to -10˚ C for nappa and suede garments and from +10 to -20˚C for fur garment in steps of 5˚C. At a preset cold chamber temperature, each test sample was measured for the power supplied to the heat source to maintain inside temperature at 34˚C. The test duration was half an hour after the equilibrium is reached.

The thermal insulation was calculated using eq. (1)

$$Thermal\ Insulation(TI) = \frac{t_s - t_a}{H} \qquad (1)$$

Where

ts = inside temperature (˚C)

ta = environmental temperature (˚C)

H = heat supply per unit area (W/m2)

TI = Thermal insulation (m^2 ˚C/W).

Scanning Electron Microscopic (SEM) Analysis:

It is expected that the thermal insulation values would be different for various types of leather. This may be due to the variations in the compactness of the fiber structure as well as the grain patterns. Hence the selected leather samples were analysed using scanning electron microscopy. The cross section as well as the surface morphology were analysed for the various leather samples. Specimens from selected experimental leathers were cut. In the case of fur (sheep-nappalon) leather, the cut samples were shaved to remove wool. All specimens were then coated with gold using a Polaron SC500 sputter coater. A Leica Cambridge Stereoscan 440 scanning electron microscope (SEM) was used for the analysis.

Results and discussion

The heat supply per unit area of the test samples for different simulated atmospheric temperatures is given in Table 1. The values have been corrected based on the efficiency of heat source (the IR heat source used in this study had 90% efficiency). It is evident that the energy (heat) required to keep the source temperature at +34˚C increases when the environmental temperature decreases. Generally, the buttoned garments require lower energy compared to zipped garments. Among the various nappa garments, cow nappa requires less energy compared to goat and sheep. The heat supplied per unit area for various samples was plotted against the simulated atmospheric temperature as given in Fig. 2a - e. The plots show a linear fit for all the samples. The line equation and correlation co-efficient are given in Table 2. Heat supply values are analyzed over the whole range of simulated temperatures and it is found that for the goat and cow nappa leathers, the variation in heat supply is low and for fur and sheep nappa the variation in heat supply is moderate and for goat suede it is very high. Suede garment requires more heat supply compared to nappa and fur leather garment. Fur leather requires lower heat supply compared to all other leather types.

Table 1
Heat supplied to the source and thermal insulation values of different leathers garments for various simulated atmospheric temperatures

Leather type	Temperature of the cold chamber	Zipped garment		Buttoned garment	
		Heat supply* (W / m²)	Thermal insulation# (m² ˚C/W)	Heat supply* (W/ m²)	Thermal insulation# (m² ˚C/W)
Sheep Nappa	-10	94.74 ± 3.26	0.464	93.83 ± 3.22	0.469
	-5	85.96 ± 5.25	0.454	82.10 ± 4.43	0.475
	0	66.67 ± 5.02	0.510	70.37 ± 6.24	0.483
	5	59.65 ± 2.45	0.486	60.60 ± 4.38	0.479
	10	52.63 ± 7.10	0.456	54.74 ± 5.70	0.438
Goat Nappa	-10	87.72 ± 4.77	0.502	87.97 ± 2.83	0.500
	-5	73.68 ± 6.70	0.529	78.19 ± 4.23	0.499
	0	64.91 ± 3.34	0.524	66.46 ± 3.01	0.512
	5	59.65 ± 1.68	0.486	58.65 ± 3.22	0.495
	10	56.14 ± 7.25	0.428	54.74 ± 5.89	0.438
Cow Nappa	-10	77.19 ± 5.08	0.570	78.19 ± 5.44	0.563
	-5	66.67 ± 4.42	0.585	70.37 ± 7.91	0.554
	0	59.65 ± 5.55	0.570	62.55 ± 6.66	0.544
	5	52.63 ± 5.98	0.551	54.74 ± 4.43	0.530
	10	42.11 ± 4.23	0.570	44.96 ± 2.39	0.534
Goat suede	-10	108.77 ± 6.24	0.405	97.74 ± 8.26	0.450
	-5	94.74 ± 10.11	0.412	82.10 ± 7.61	0.475
	0	77.19 ± 7.35	0.441	70.37 ± 6.25	0.483
	5	66.67 ± 6.73	0.435	62.55 ± 2.98	0.464
	10	59.65 ± 5.92	0.402	56.69 ± 5.57	0.423
Fur sheep nappalon	-20	87.72 ± 6.26	0.616	97.74 ± 7.21	0.553
	-15	77.19 ± 4.59	0.635	86.01 ± 5.54	0.570
	-10	70.18 ± 6.43	0.627	74.28 ± 4.57	0.592
	-5	63.16 ± 2.32	0.618	66.46 ± 2.91	0.587
	0	49.12 ± 4.44	0.692	54.74 ± 5.88	0.621
	5	42.11 ± 5.56	0.689	46.92 ± 7.63	0.618
	10	35.09 ± 2.87	0.684	35.19 ± 4.81	0.682

* The values are average of four measurements along with standard deviation
# Thermal insulation values are calculated from the average heat supply values

Table 2
The line equation and correlation coefficient (R) for the plot of heat supplied per unit area against simulated atmospheric temperature

	Zipped	Buttoned
Sheep nappa	y = -2.2x + 71.9 R = -0.98	y = -1.99x + 72.3 R = -0.99
Goat nappa	y = -1.54x + 68.4 R = -0.96	y = -1.7x + 69.2 R = - 0.99
Cow nappa	y = -1.68x + 59.7 R = -0.99	Y = -1.64x + 62.2 R = -0.99
Goat suede	y = -2.5x + 81.4 R = -0.99	Y = -2x + 73.9 R = -0.98
Fur Sheep nappalon	y = -1.78x + 51.8 R = -0.99	Y = -2x + 55.7 R = -0.99

Fig. 2 **Heat supply per unit area Vs simulated atmospheric temperatures for (a) sheep nappa (b) goat nappa (c) cow nappa (d) goat suede and (e) fur sheep nappalon garments.**

Fig. 2a

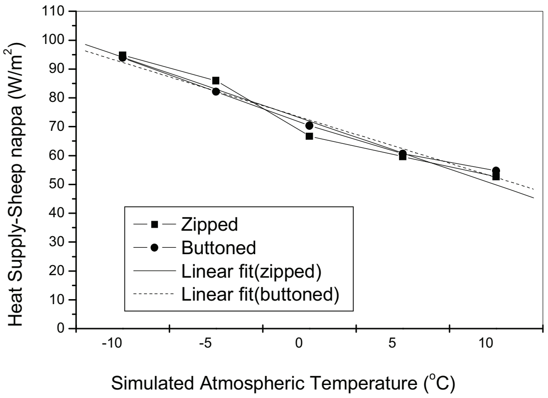


Fig. 2b

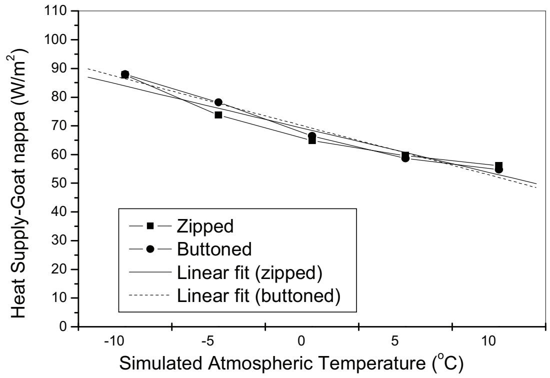


Fig. 2c

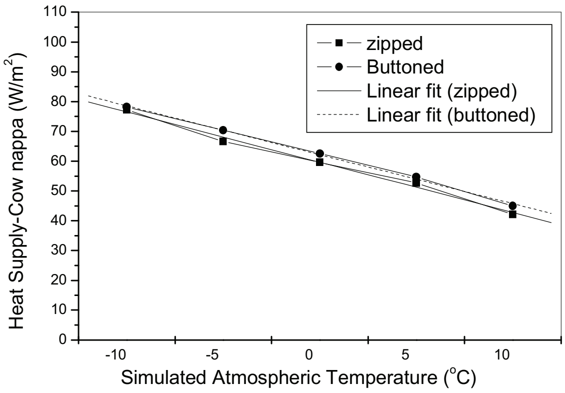


Fig. 2d

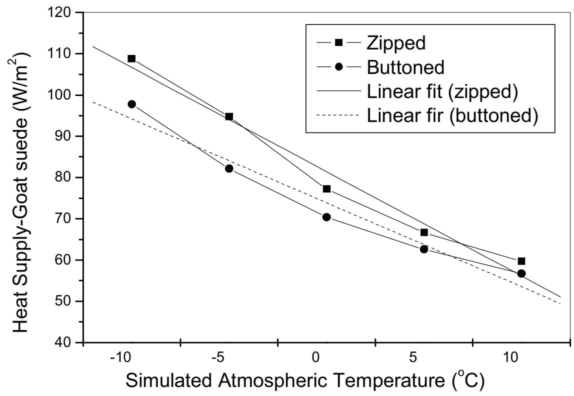
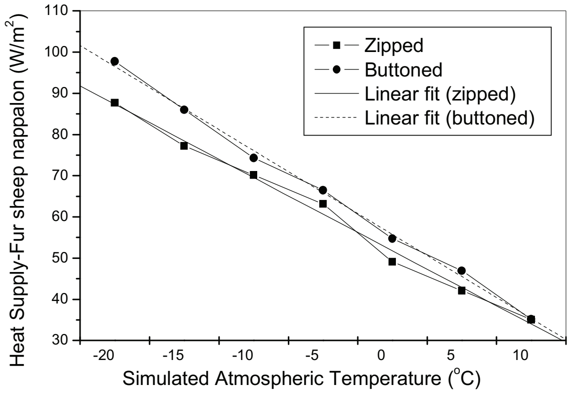


Fig. 2e



Thermal insulation values of different test samples for different simulated atmospheric temperatures are given in Table 1. Considering all the samples tested, the goat suede zipped garment possesses minimum thermal insulation, 0.402 m²˚C/W at 10˚C while the fur-sheep nappalon garment exhibits maximum thermal insulation, 0.692 m²˚C/W at 0˚C. At very low temperature (-20˚C), fur leather has thermal insulation in the range of 0.55 to 0.62 m²˚C/W but at high temperature (10˚C), both garment constructions have almost similar thermal insulation value of 0.68 m²˚C/W. Among the nappa leathers, cow nappa has a better thermal insulation compared to sheep and goat nappa leathers in most of the cases. It is possible to arrange nappa leathers in terms of increasing order of thermal insulation as follows: sheep nappa < goat nappa < cow nappa. The thermal insulation values were plotted against the simulated atmospheric temperatures for the different test samples as shown in the Fig. 3a - e. For sheep nappa leather, thermal insulation values of buttoned garment are more at low temperature (-10, -5˚C) compared to zipped garments, however, when the temperature is increased (5, 10˚C) the zipped garment shows better thermal insulation compared to buttoned garment. For goat nappa leathers, the opposite trend is observed. The cow nappa and fur sheep nappalon based zipped garments exhibit better thermal insulation compared to buttoned type throughout the temperature range. On the other hand, goat suede buttoned garment shows better thermal insulation compared to the zipped one. It is important to mention that all the garment samples have higher thermal insulation than the required minimum specification as per international standard. The minimum thermal insulation for protective clothing against cold based on EN standard is 0.15 m²˚C/W[11,12]. Comparing thermal insulation values of all the leather types over the simulated atmospheric temperature for zipped and buttoned garment constructions from Table 1 and Fig. 4 it is possible to arrange the various types of leathers in the increasing order of thermal insulation as follows: goat suede < sheep nappa < goat nappa < cow nappa < fur (sheep-nappalon). It is interesting to note that the thermal insulation values are fairly higher when measured near 0˚C. Changes in densities of air and moisture content nearer to 0°C are expected to play a major role on the overall thermal insulation values of all the types of leather

SEM Analysis: Variations in the thermal insulation of garments from different types of leathers may be attributed to the orientation as well as compactness of the fiber structure. Scanning electron micrographs of various leather samples chosen in this study showing the cross section at a magnification of x1000 are shown in Fig. 4a – e. Sheep nappa leather shows fine fiber structure with loose arrangement as evidenced by the large amount of micro pores present. Goat nappa exhibits compactly woven fiber structure with thick fibers and fiber bundles (Fig. 4b). Cow nappa leather possesses thin fibers forming thick fibre bundles which are compactly woven (Fig. 4c) compared to goat and sheep nappa leathers. This provides large number of macro as well as micro pores in the matrix. This would, in principle, provide more air space and hence more thermal insulation for cow nappa leathers compared to all nappa leathers. It is important to mention that the total surface area of the leather per gm is very high13 and is comparable with most of the successful commercial insulators. The air present inside this fibrous network acts as a very good insulator14,15. Studies have been made to find the thermal conductivity coefficient values of various types of leathers to compare with various commercial insulators and various shoe materials14,16,17. These studies reveal that the leather has better thermal insulation than that of the commercial insulators. Hence, it is evident that leather, in general, possesses good thermal insulation characteristics due to the spatial form (3D) features of collagen fibers, which holds large amounts of air inside the fiber network. Comparing the thermal insulation values of all nappa garments and their microscopic structure, it is evident that the more organized and dense fiber packing in cow nappa leather provides better thermal insulation. Since goat nappa leather has comparable compactness with that of cow nappa leather it has better thermal insulation value than sheep nappa leather. Among all nappa leathers, sheep nappa leather has scattered and loose fiber structure leading to less thermal insulation.

Fig. 3 Thermal insulation at different simulated atmospheric temperatures for (a) sheep nappa (b) goat nappa (c) cow nappa (d) goat suede and (e) fur sheep nappalon garments.

Fig. 3a

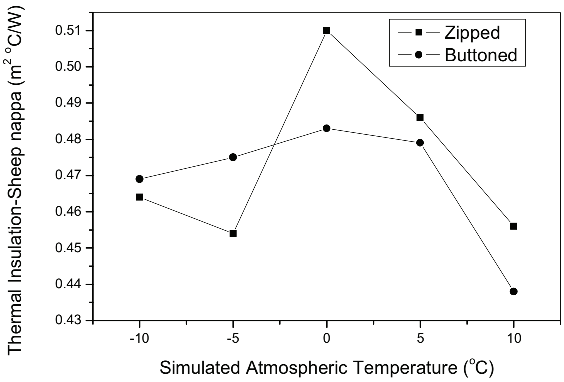


Fig. 3b

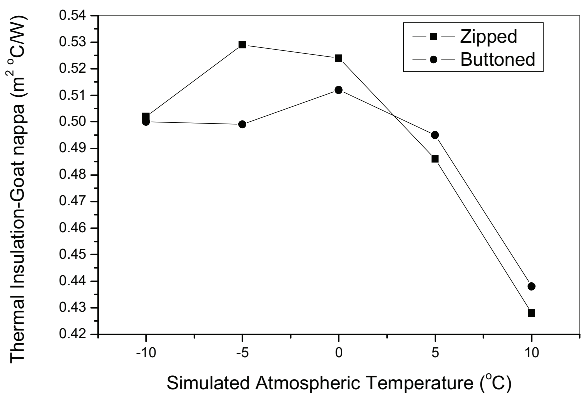


Fig. 3c

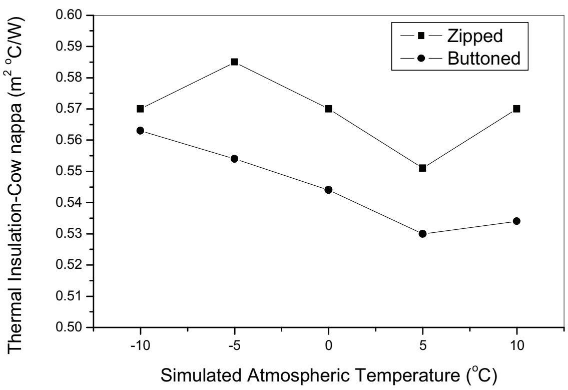


Fig. 3d

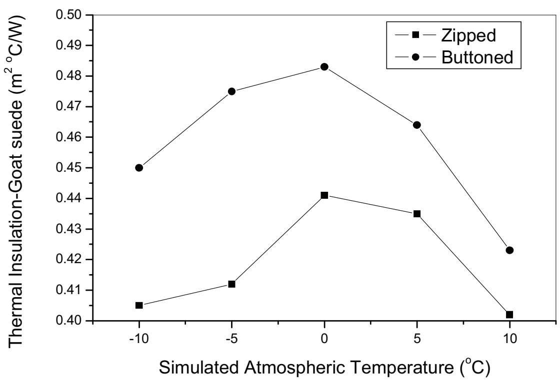


Fig. 3e

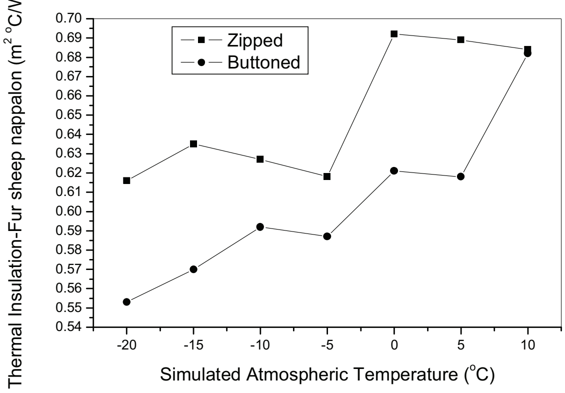


Fig. 4 Scanning electron micrographs of leather samples showing the cross section at x1000 magnification (a) sheep nappa (b) goat nappa (c) cow nappa (d) goat suede and (e) fur sheep nappalon

Fig. 4a

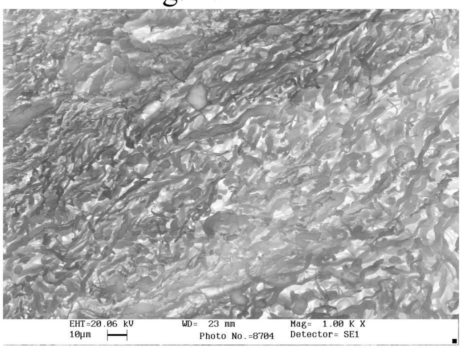


Fig. 4b

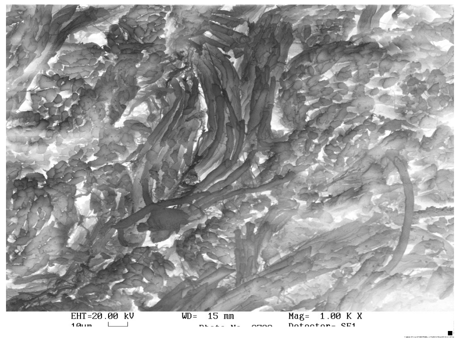


Fig. 4c

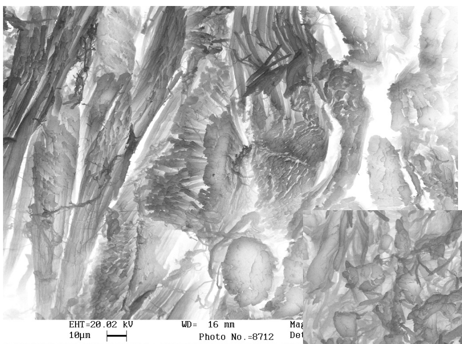


Fig. 4d

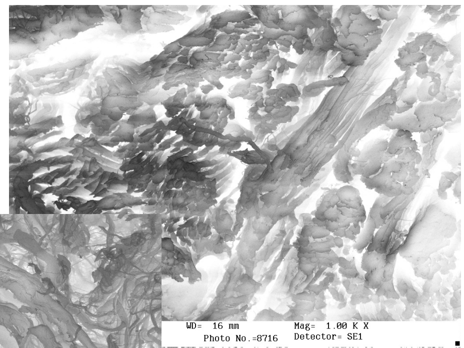
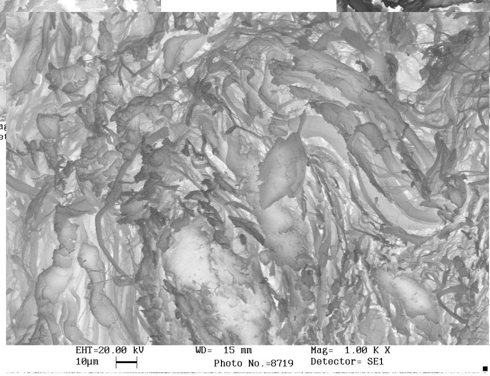


Fig. 4e



Conclusion

In this study, thermal insulation values were quantified for all the leather types with two different garment constructions and shown that the selected leathers and garment constructions meet the minimum thermal insulation value required for protection against cold as prescribed by International standards. Also it is concluded that there is a significant change in thermal insulation values when the wear temperature conditions are changed. Type of construction of the garment also has an influence on the thermal insulation values. Among all leather types (except suede), the zipped garment construction has more thermal insulation than the buttoned type. Goat suede leather has comparatively less thermal insulation value and fur (sheep nappalon) leather has better thermal insulation value compared to all the leathers selected. Microscopic analysis on cross section of the leathers reveals that there is a significant correlation between the fiber structure and the thermal insulation values.

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