(REFEREED RESEARCH)

A RESEARCH ON THERMAL INSULATION PROPERTIES OF NONWOVENS PRODUCED WITH RECYCLED JUTE AND WOOL FIBRES

GERİ DÖNÜŞTÜRÜLMÜŞ JÜT VE YÜN LİFLERİYLE ÜRETİLEN DOKUSUZ YÜZEYLERİN ISI YALITIM ÖZELLİKLERİ ÜZERİNE BİR ARAŞTIRMA

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ABSTRACT

Nonwovens materials are porous materials consisting of fibers and an interconnected void. Due to their unique fibre orientation and porous structure, nonwovens are ideal materials for insulation applications. In this paper some physical thermal insulation properties of single and double layered needle punched nonwovens produced with recycled jute and wool fibres were investigated. The use of recycled fibres is of high importance not only for cost reduction but also in means of environmental aspects. Polyester, wool and recycled jute (R-Jute) and recycled wool (R-Wool) fibres were used for the production of single and double layered needle punched nonwoven structures in this study. In the latter stage fibre fineness, basis weight, thickness, air permeability, thermal conductivity and thermal resistance properties were tested. The results were analysed statistically by using SPSS software in 95% confidence interval. Results have shown that wool and recycled wool inclusion in single and double layered nonwoven structures enhance the thermal insulation properties. And also it was found out that recycled fibres can be used in insulation applications without sacrificing from thermal properties. Nonwoven structures are good candidates to be used as low cost and environmental friendly insulation materials not only in buildings but also in automotive, furniture and clothing industries.

Keywords: Multilayer nonwoven, thermal insulation, recycled jute, wool, recycled wool.

ÖZET

Nonwoven malzemeler yapılarındaki lifler ve aralardaki boşluklardan oluşan gözenekli malzemelerdir. Bu benzersiz gözenekli ve lifli yapıları, onları yalıtım uygulamaları için ideal kılar. Bu çalışmada geri kazanılmış jüt ve yün lifleri kullanılarak iğneleme yöntemine göre üretilmiş tek ve çift katlı nonwoven malzemelerin bazı fiziksel ve ısı yalıtım özellikleri incelenmiştir. Geri kazanılmış liflerin kullanımı yalnızca maliyet azaltma açısından değil, aynı zamanda çevresel konular açısından da önem arz etmektedir. Bu çakışmadaki tek ve çift katlı nonwoven yapıların üretiminde polyester, yün, geri kazanılmış jüt ve geri kazanılmış yün lifleri kullanılmıştır. Sonraki aşamada numunelerin lif inceliği, gramaj, kalınlık, hava geçirgenliği, ısıl iletkenlik ve ısıl direnç özellikleri test edilmiştir. Test sonuçları SPSS yazılımı kullanılarak %95 güven aralığında analiz edilmiştir. Çalışma sonuçları, yapıdaki yün ve geri dönüşştürülmüş yün lifi içeriğinin ısı yalıtım özelliklerini iyileştirdiğini göstermiştir. Sonuçlarda ayrıca ısı yalıtım özelliklerinden feragat etmeksizin geri dönüştürülmüş liflerin de yapıda kullanılabileceğini göstermiştir. Çalışma kapsamında üretilen nonwoven yapılar düşük maliyetli ve çevre dostu yalıtım malzemeleri olarak sadece bina ve inşaat sektöründe değil otomotiv, mobilya ve giyim sektörlerinde de kullanılmaya uygundur.

Anahtar Kelimeler: Çok katlı nonwoven, ısı yalıtımı, geri dönüştürülmüş jüt, geri dönüştürülmüş yün.

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1. INTRODUCTION

The technical developments in polymers and fiber technology have led to improvements in physical, mechanical, thermal and sound properties of nonwoven fabrics. Nonwovens are used in different industrial applications ranging from baby diapers to packaging, furniture, household, automobile, and airplane accessories [1]. Nonwoven materials are very promising for thermal and acoustic insulation applications due to their unique porous structure.

Thermal insulation is one of the most important aspects for buildings in means of life comfort, energy saving, cost reduction and also to prevent the global warming. Thermal insulating materials are often used in the automotive and building industries.

To achieve an energy-efficient world, governments, businesses and individuals should transform the building sector via a multitude of actions, starting from the growing awareness of the global energy issue. Buildings today account for the 40% of the world's energy use. The resulting carbon emissions are substantially higher than those of the transportation sector. New buildings using more energy than necessary are being built every day, and millions of today's inefficient buildings will remain standing until at least 2050. It's therefore necessary to start reducing energy use in new and existing buildings in order to reduce the planet's energy-related carbon footprint. Growing interest, space, and attention in the architecture sector are directed to environmental issues according to the principles of green building. Mineral, vegetable, or animal materials such as perlite, vermiculite, rock wool, glass wool, cork, plant fibers (cotton, flax, hemp, coconut, etc.), wood fiber, cellulose, and sheep's wool can be used for the production of insulation panels [2]

Nonwoven textile materials, produced using needles, are complex three dimensional fiber structures and have the application in many industrial fields. Anisotropic structure of needled nonwoven materials contributes to various, sometimes hardly explicable behavior of nonwoven textiles. During the needling process, fibers in the felt are interconnected with their own fibers, using needles of special construction that transfer fibers from the surface into the felt depth. In this way a product of special structure is produced which is resistant to mechanical action and therefore finds broad and various applications [3].

Nonwovens are porous materials consisting of solid matrix (the fibers) with an interconnected void. The interconnectedness of the void (the pores) allows the flow of one or more fluids through the material. In our situation there is a single phase flow constituted by the air, which makes the nonwoven materials ideal media for insulation applications.[4]

Insulation materials are often composed of glass fibers, polymeric fibers, or mineral wools. However, in some applications involving high temperatures, steel fibers, alumina fibers, and/or other similar temperature-resistance materials have also been used for insulation. Heat transfer in a fibrous insulation material occurs through conduction, convection, and radiation. The contribution of each of these modes of heat transfer varies depending on the application. Convection heat transfer can often be neglected since the friction between the fibers and the interstitial fluid may suppress convective motions inside the media. While radiative heat transfer is generally important in high-temperature applications, conductive heat transfer is often the mechanism by which heat transfers through fibrous materials in temperatures near or below room temperature. Conductive heat transfer occurs through the fibers and the interstitial fluid. Therefore, an effective thermal conductivity, which includes the contributions of the solid and the interstitial fluid, is often defined and used in discussing the performance of an insulation material. The effective thermal conductivity of a fibrous material is greatly influenced by its microstructural parameters such as solid volume fraction , thermal conductivity of the solid fibers and the interstitial fluid, fiber diameter, and fiber orientation. Obviously, for media consisting of more than one type of fibers, i.e., composite insulation media, there are more parameters influencing the insulation performance [5, 6].

There are some studies in the literature investigating the thermal insulation properties of nonwovens. Abdel-Rehim et.al. studied the thermal insulation properties of 100% Polyester and 100%Polypropylene nonwovens. They found out that Polyester fabric had higher thermal resistance and specific heat resistance than polypropylene. Fabric thickness had a significant effect on the fabric temperature variations[7]. Debnath studied the thermal resistance and air permeability of needle punched nonwovens made from jute and polypropylene blends and observed that the thermal resistance and thickness increase but air permeability decrease significantly with the increase in fabric weight and also that all dependent variables were influenced significantly by fabric weight [8]. Sakthivel and Ramachandran studied the thermal conductivity of nonwoven materials using reclaimed fibres and observed that thermal insulation properties of the nonwoven materials vary significantly, depending on the type of Reclaimed fibre [9]. Ghane et.al. investigated the Effective Parameters on Thermal conductivity of Needle Punched Nonwovens and found out that porosity was the more significant parameter affecting thermal conductivity of nonwoven in comparison to the mean fiber orientation [10]. Kopitar et.al. studied the influence of calendaring process on thermal resistance of polypropylene nonwoven fabric structure and observed that a change in structure of the calendered samples caused a considerably lower thermal resistance i.e. better thermal conductivity. With increasing nonwoven fabric mass, the difference between thermal resistances of needled and needled as well as additionally bonded by calendering the nonwoven fabric was reduced [11]. Martin and Lamb studied the measurement of thermal conductivity of nonwovens using a dynamic method and indicated that in agreement with established theory, conductivity decreases if the nonwoven is compressed or is made with finer fabrics or has a reflective coating on the fiber surface, due to the reduction in the radiative component of heat transfer. Fiber shape has no effect on thermal conductivity [12].

The use of recycled fibres in the production of new materials is an important aspect for both environment and economy. Use of recycled fibres from textile wastes is gaining more importance day by day. It is known that recycled fibres exhibit weaker mechanical properties compared to virgin fibres, but if appropriate application areas are found, the use of recycled fibres in the formation of new products have huge impact on saving the raw materal resources and energy. Nonwovens used in heat insulation applications is one of the promising potential application areas for recycled jute and wool fibres [13, 14]

Even though there are some studies in the literature that investigated the thermal insulation properties of nonwoven materials, studies about the thermal insulation properties of double layered nonwovens produced with recycled fibres is very limited.

This study focuses on investigating the thermal insulation properties of single and double layered needle punched nonwovens produced with recycled jute and wool fibres. Biodegradable and environmental friendly jute fibres are used in many application areas including composites, packaging, shoes, clothing, agriculture, construction, marine, automotive and medicine sectors [14 ,15] Wool fibres are the most commonly used natural fibres for thermal insulation.

2. MATERIALS AND METHOD

Polyester, wool and recycled jute (R-Jute) and recycled wool (R-Wool) fibres were used for the production of single and double layered nonwoven structures in this study. Jute and wool wastes to be recycled were obtained from Turkish carpet industry. Recycling of the wastes were made in two stages namely cutting and openning stages. In the first stage, the wastes were cut into small pieces of 12 cm. In the second stage the pieces were openned into the fibres by using a 3 sectioned openning machine.

The fibres were processed in Dilo needling machine with automatic feeding system. During the production process of singlelayered structures, recycled jute (R-Jute) and recycled wool (R-Wool) fibres were blended with virgin polyester and wool fibres for better processability due to short fibre length. 100% wool and 100% PES single layered nonwovens were also produced for comparison. Then double layered structures were produced by combining the single layered nonwovens with each other in different ways by needling in the needle loom. The properties of produced samples are given in Table 1 and Table 2.

Basis weight, thickness and air permeability tests were applied to the nonwovens, according to the standards TS 251, TS 7128 EN ISO 5084, TS 391 EN ISO 9237 respectively. Thermal properties of the samples were measured by using Alambeta Device [16, 17] Results were evaluated statistically by using SPSS software in 95% confidence interval.

Table 1. Raw materials and processes involved in the production of single layered nonwoven samples

Single LayeredStructures
100 % Wool
100 % PES
%50 Wool/%50 R-Jute
%50 Wool/%50 R-Wool
%50 PES/%50 R-Jute
%50 PES/%50 R-Wool

3.RESULTS AND DISCUSSIONS

3.1 Fibre Fineness

Fineness of the fibres were tested by using a Leica DM EP light microscope with 400x zoom. 20 measurements were taken for each fibre type and average results are given in Table 3.

3.2 Thickness

Table 3 shows the thickness values of single and double layered nonwovens. Even though all the single layered nonwonvens were aimed to be produced in the same thickness, there are flunctuations in the thickness values of the samples produced with wool fibres, which were processed more difficulty in the needle loom compared to PES fibres, due to coarser fibre structure. This trend was more obvious while processing wool and recycled fibre blended nonwovens in needle loom, due to high difference of fibre fineness. The same difficulty was not faced with PES fibres, since the fibre fineness is more compatible with the recycled fibres (see Table 3).

Table 2. Raw materials and processes involved in the production of double layered nonwoven samples

Double Layered Structures	Layer 1	Layer 2
100 % Wool+100 % Wool	100 % Wool	100 % Wool
100 % PES+100 % PES	100 % PES	100 % PES
%50 Wool/%50 R-Jute+100 % Wool	%50 Wool/%50 R-Jute	100 % Wool
%50 Wool/%50 R-Wool+100 % Wool	%50 Wool/%50 R-Wool	100 % Wool
%50 PES/%50 R-Jute+100 % PES	%50 PES/%50 R-Jute	100 % PES
%50 PES/%50 R-Wool+100 % PES	%50 PES/%50 R-Wool	100 % PES

Table 3. Average fibre fineness for each fibre type

Fibre Type	Fibre Fineness (μm)
Wool	117,7
Polyester (PES)	47,7
Recycled wool (R-Wool)	17
Recycled Jute (R-Jute)	30,2

Table 4. Thickness values of single and double layered nonwovens

Single Layered Structures	Thickness (mm)
100 % Wool	3,252
100 % PES	3,453
50% Wool/50% R-Jute	2,761
50% Wool/50% R-Wool	4,176
50% PES/50% R-Jute	3,652
50% PES/50% R-Wool	3,629
Double Layered Structures	
100 % Wool+100 % Wool	3,811
100 % PES+100 % PES	3,820
50% Wool/50% R-Jute+100 % Wool	3,849
50% Wool/50% R-Wool+100 % Wool	5,110
50% PES/50% R-Jute+100 % PES	4,088
50% PES/50% R-Wool+100 % PES	4,070

3.3 Basis Weight

Results of the basis weight measurements of single and double layered samples are presented in Table 5.

Table 5 shows that among the samples of similar thickness 100% wool nonwovens weighed higher than 100% PES nonwovens for both single and double layered structures. This is due to the difference in the specific weights of wool and PES fibres.

Table 5. Basis weight values of single and double layered nonwovens

Single Layered Structures	Basis Weight (g/m^2)
100 % Wool	140,33
100 % PES	105
50% Wool/50% R-Jute	106,67
50% Wool/50% R-Wool	281,00
50% PES/50% R-Jute	154,33
50% PES/50% R-Wool	137,67
Double Layered Structures	
100 % Wool+100 % Wool	272
100 % PES+100 % PES	159,67
50% Wool/50% R-Jute+100 % Wool	254
50% Wool/50% R-Wool+100 % Wool	362,33
50% PES/50% R-Jute+100 % PES	160,33
50% PES/50% R-Wool+100 % PES	200,66

It can be seen in Table 5 that the highest weight results were obtained with 50% Wool/50% R-Wool in single layered nonwovens. This is due to higher thickness compared to other samples. Among the R-Jute blended structures, 50% PES/50% R-Jute single layered nonwoven weighed heavier than 50% PES/50% R-Wool of the same thickness, due to higher specific weight of R-Jute fibres compared to R-Wool fibres.

Results obtained from double layered nonwovens followed the same trend as single layered nonwovens. The highest results were obtained with 50% Wool/50% R-Wool+100 % Wool structures, due to the high thickness of wool and wool blended layers.

3.4 AirPermeability

Figure 1 and Figure 2 show the air permeability results of single and double layered nonwovens respectively.

In general, it can be commented that lower air permeability results were obtained with wool and wool blended nonwovens, compared to PES based nonwovens, for both single and double layered samples. This trend can most clearly be observed when 100% wool samples are compared with 100%PES samples. Wool samples form a more isotropic structure due to felting effect, caused by their surface structure. That makes them preferable for thermal insulation applications.

The lowest air permeability results were obtained with 50% Wool/50% R-Wool samples in single layered structures and 50% Wool/50% R-Wool+100 % Wool samples in double layered structures, mainly due to highest thickness and basis weight of that samples.

Table 6 shows the p values of factors affecting the air permeability for 95% confidence interval.

Table 6. P values of factors affecting the air permeability for 95% confidence interval.

	p value
Wool ratio of the upper layer	0,000
Wool ratio of the lower layer	0,000
PES ratio of the upper layer	0,000
PES ratio of the lower layer	0,403
R-wool ratio of the upper layer	0,001
R-jute ratio of the upper layer	0,072

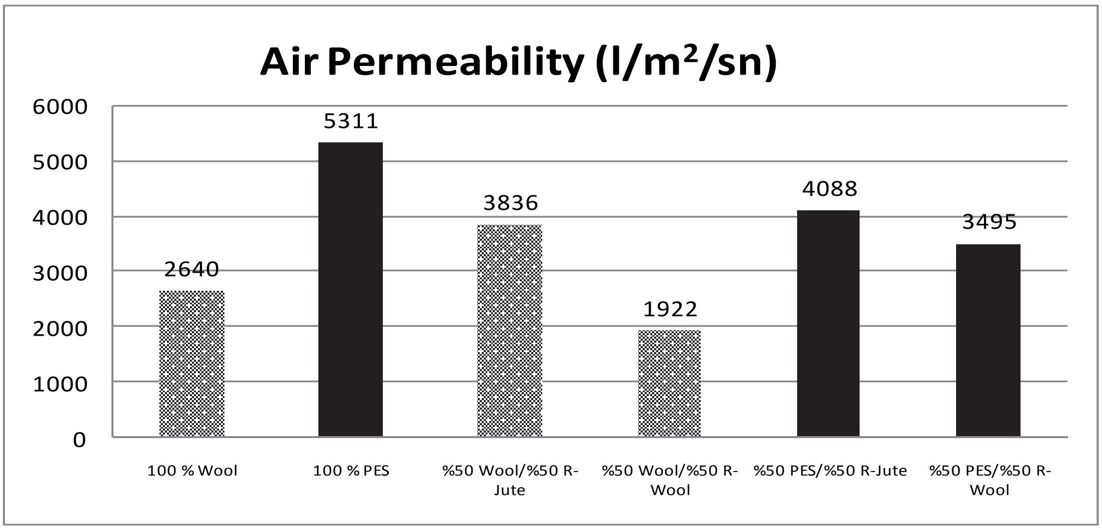

Figure 1. Air Permeability values of single layered nonwovens

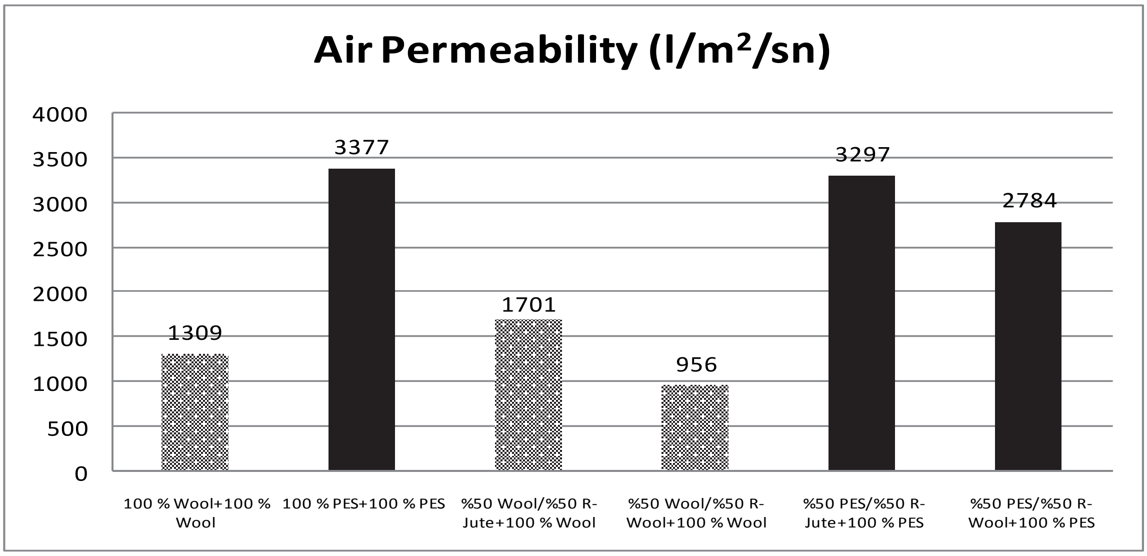

Figure 2. Air Permeability values of double layered nonwovens

As it can be seen in Table 6, effects of wool ratio of the upper layer, wool ratio of the lower layer, PES ratio of the upper layer, and R-wool ratio of the upper layer on air permeability and R-jute ratio of the upper layer are statistically significant. Results of the statistical evaluations have shown that air permeability decreased with decreasing PES ratio of the upper layer, increasing Wool ratio of the upper layer and increasing R-Wool ratio of the upper layer. It was also observed that, the difference between the air permeability results of samples including 100% and 50% wool at the upper layer were not statistically significant, while the difference of 0% wool from 100% and 50% wool were found to be statistically significant. The lowest sir permeability results were obtained with 0% Wool and 0% R-Wool including samples at the upper layer. This is due to the lower basis weight of the sampes with 0% wool inclusion in the upper layer. Air permeability increased with increasing PES ratio at the upper layer. Higher air permeability results were obtained with samples including 100% PES, compared to the samples including 50% PES for both single and double layered structures. This might be due to the lower thichness and basis weight values of the samplers including 100%PES at the upper layer, compared to the samples including 50% PES at their upper layer.

Results of the statistical analysis have shown that effect of PES ratio of the lower layer is not statistically significant. This might be caused by the heterogenity between the layers of the double layered structure; due to the existance of R-Wool and R-Jute fibres in the upper layer, when PES was used at the lower layer. This is not the case for the samples having 100% PES at the upper layer due to homogenity. Also, this situation is not valid for the samples having 100% Wool at the lower layer, since Wool fibres have a more curly structure compared to PES fibres, resulting in more homogenity between the layers.

3.5 Thermal Properties

Table 7 shows the p values of factors affecting the thermal conductivity and thermal resistance for 95% confidence interval.

3.5.1 Thermal Conductivity

Thermal conductivity can be thought of as a flux of heat (energy per unit area per unit time) divided by a temperature gradient (temperature difference per unit length). For textile materials, still air in the fabric structure is the most important factor for conductivity value, as still air has the lowest thermal conductivity value compared to all fibers (λair = 0.025) [18].

Thermal conductivity of a structure is a very important property for determining the thermal insulation properties of the structure. It is known that lower thermal conductivity leads to better thermal insulation function.

Results of the statistical analyses have shown that, Wool ratio of the upper and lower layers, PES ratio of the upper and lower layers, R-Wool and R-Jute ratios of the upper layers and basis weight of the samples have significant effect on the thermal conductivity. Thermal conductivity decreased with increasing PES ratio of the upper layer, increasing R-Wool ratio of the upper layer and decreasing Wool ratio of the upper layer. The lowest thermal conductivity results were obtained with the samples containing 0% Wool at the upper layer. The highest results were obtained with samples containing 100% Wool at the upper layer and 0% R-Wool at the upper layer.

It can be seen in Figure 3 and Figure 4 that, higher thermal conductivity results were obtained with wool and wool blended samples, compared to PES based samples for both single and double layered samples. As explained in air permeability results, since wool fibres form a tighter structure due to felting effect, compared to PES fibres, heat is conducted via the fibres more easily.

Lowest thermal conductivity results are obtained with 100%PES samples in single layered structures and with 100 % PES+100 % PES sampes in double layered structures; wich exhibited the highest air permeability results. High air permebaility of a sample can lead to a lower thermal conductivity because of the air gaps in the structure. When 50% Wool/50% R-Jute and 50% Wool/50% R-Wool Single layered structures are compared, it can be seen that the latter shows a lower thermal conductivity, due to higher wool fibre inclusion and also higher thickness. This difference appeared to be smaller in double layered structures namely 50% Wool/50% R-Jute+100 % Wool and 50% Wool/50% R-Wool+100 % Wool, since the difference between the amounts of wool decreased. The same effect was seen between 50% PES/50% R-Jute and 50% PES/50% R-Wool samples. The latter showed lower thermal conductivity results due to the R-Wool inclusion. The same effect was also observed in double layered structures, 50% PES/50% R-Jute+100 % PES and 50% PES/50% R-Wool+100 % PES, with a smaller difference in thermal conductivity values.

Table 7. P values of factors affecting the thermal conductivity and thermal resistance for 95% confidence interval.

	p value	
	Thermal Conductivity	Thermal Resistance
Wool ratio of the upper layer	0,000	0,044
Wool ratio of the lower layer	0,000	0,011
PES ratio of the upper layer	0,000	0,782
PES ratio of the lower layer	0,014	0,039
R-wool ratio of the upper layer	0,031	0,000
R-jute ratio of the upper layer	0,074	0,004

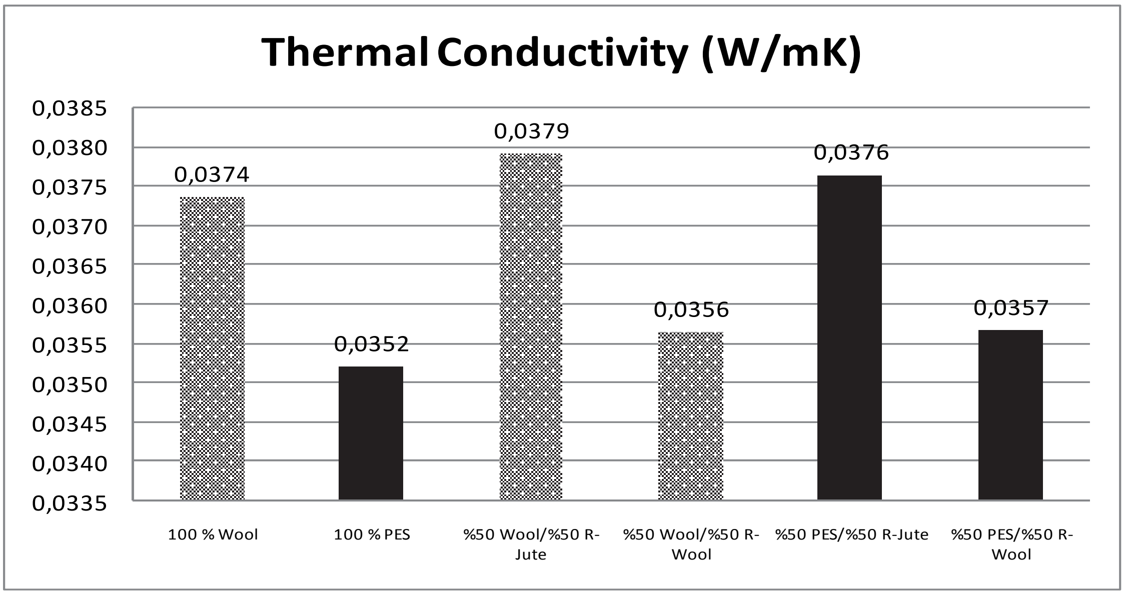

Figure 3. Thermal conductivity results of single layered nonwovens

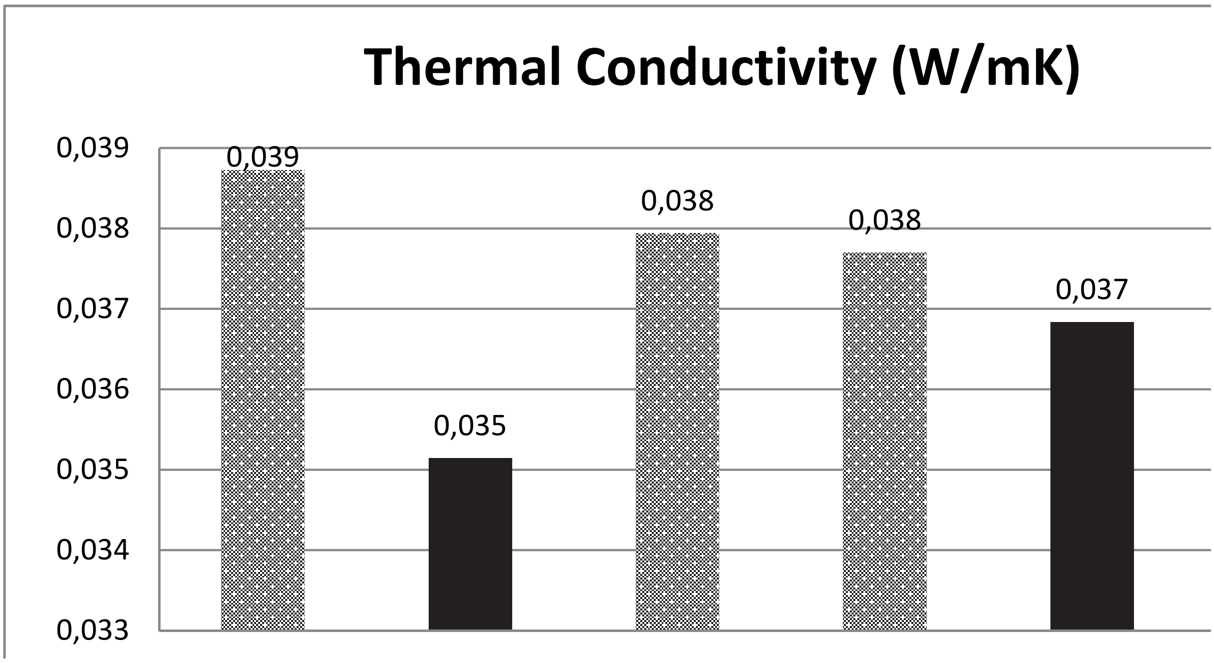

Figure 4. Thermal conductivity results of double layered nonwovens

3.5.2 Thermal Resistance

Thermal resistance is an indication of how well a material insulates. It is based on the equation: R = h/λ; where R is the thermal resistance, h is the thickness and λ is the thermal conductivity [18]

Results of the statistical analyses have shown that; thermal resistance was affected by Wool ratio of the upper and lower layers, PES ratio of the lower layer, R-Wool and R-Jute ratios of the upper layers significantly. It was seen that the thermal resistance was increased with decreasing Wool ratio of the upper layer. Even though there were no statistically significant difference between 0% and 50% Wool inclusing samples at the upper layer, samples with 100%Wool at their upper layer showed lower thermal resistance values. Thermal resistance increased with increasing R-Wool ratio at the upper layer, which means that samples produced with R-Wool fibres at their upper layer showed higher thermal resistance results compared to other samples. This can be caused by the fine structure of the R-Wool fibres, which leads to a better entanglement among the fibres and a tighter structure. It is also supported by Figure 1 and Figure 2 which show that, R-Wool blended samples showed considerably lower air permeability results compared to 100% Wool, %100 PES and R-Jute blended samples in both single and double layered structures.

Results of the statistical anayses have shown that PES ratio of the upper layer did not have a statistically significant effect on thermal resistance; even though it had a significant effect on thermal conductivity, as it was explained in thermal conductivity part. Thermal conductivity decreased with increasing PES ratio of the upper layer, whereas thermal resistance was not effected significantly. This is thought to be caused by existance of the thickness factor used in the calculation of thermal resistance, from thermal conductivity.

Figure 5 and Figure 6 show the thermal resistance results of single and double layered nonwovens. It is known that lower thermal conductivity leads to higher thermal resistance of a structure and thus better thermal insulation properties.

Among the 100% Wool and 100% PES samples, the latter showed higher thermal resistance results. This is mainly because of higher thickness and also higher thermal resistance and specific heat resistance of Polyester which Abdel-Rehim et.al. also mentioned in their study [7]. When 50% PES/50% R-Jute and 50% PES/50% R-Wool single layered samples with almost the same thickness are compared it can be said that 50% PES/50% R-Wool samples show higher thermal resistance. The same trend can be observed for 50% PES/50% R-Jute+100 % PES and 50% PES/50% R-Wool+100 % PES double layered samples, also matching with the thermal conductivity results. This is thought to be caused by the inclusion of R-Wool fibres in the structure.

It can be generally commented that for both single and double layered structures, the highest thermal resistance reults were obtained with 50% Wool/50% R-Wool structures in single layer and with 50% Wool/50% R-Wool+100 % Wool structures in double layer, both due to higher wool fibre inclusion and also higher thickness. Abdel-Rehim et.al. also mentioned in their paper that the effect of fabric thickness on the fabric temperature variations has the obvious significance that higher thickness means good thermal insulation [7].

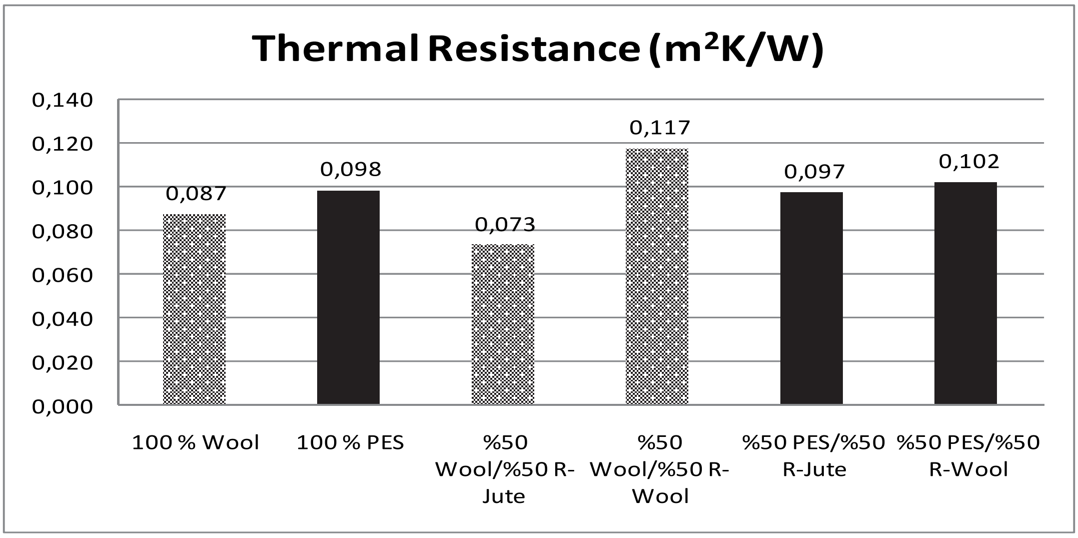

Figure 5. Thermal resistance results of single layered nonwovens

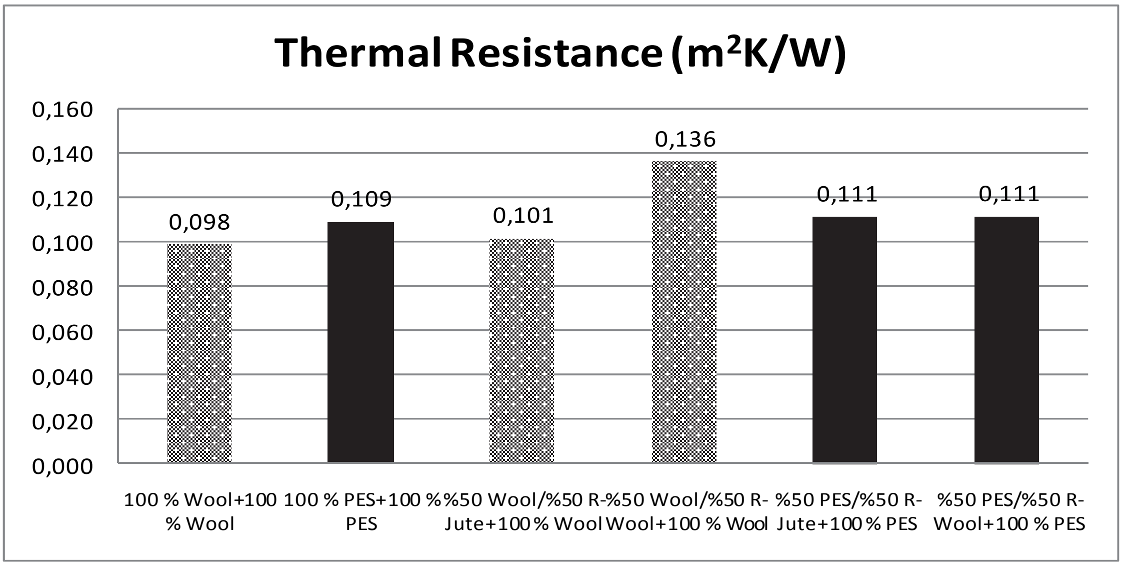

Figure 6. Thermal resistance results of double layered nonwovens

5. CONCLUSION

In this paper, some physical and thermal insulation properties of single and double layered nonwovens produced from recycled jute, recycled wool, polyester and wool fibres and their combinations as double layered structures were investigated.

The results have shown that single and double layered nonwoven structures containing wool and recycled wool are good candidates to be used in insulation applications, since they exhibit low thermal conductivity and high thermal resistance results. Samples including R-Jute and R-Wool fibres in their structures have also shown comparable thermal insulation properties to 100%Wool samples. It can be generally commented that for both single and double layered structures, the highest thermal resistance reults were obtained with 50% Wool/50% R-Wool structures in single layer and with 50% Wool/50% R-Wool+100 % Wool structures in double layer. The reason is high basis weight of these samples compared to other samples. It is known that basis weight has a significant imfact on thermal insulation properties of nonwoven materials. This result is also supported by the other studies in the literature. Debnath found out that the thermal resistance and thickness increase but air permeability decrease significantly with the increase in fabric weight and also that all dependent variables were influenced significantly by fabric weight [8].

The results of this study show that recycled fibres can be used in insulation applications without sacrificing from thermal properties. Such type of nonwoven structures can be used as insulation materials not only in buildings but also in automotive, furniture and clothing industries.

This result may lead to the development of new thermal insulation materials with low cost and good thermal insulation properties. This result is also very important for environmental aspects.

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