TEKSTİL VE KONFEKSİYON

VOL: 32, NO. 1

DOI: 10.32710/tekstilvekonfeksiyon.941068

Thermal and Sound Insulation Performances of Building Panels Produced by Recycling Waste Fibres of Yarn Factories

Erkan Türkmen Dönmez[1] 0000-0002-3002-5589
Erkan Türker[2] 0000-0003-3176-5164

[1]Amasya University / Vocational School of Technical Sciences / Department of Design, 05100, Amasya, Türkiye
[2]Uşak University / Engineering Faculty / Department of Textile Engineering, 64200, Uşak, Türkiye

Corresponding Author: Erkan Türkmen Dönmez, eturkmen.donmez@gmail.com

ABSTRACT

Recycling of materials such as textiles, plastics, glasses, papers and metals instead of storing, burying or burning results a reduction in raw material demands of industry. This means also that a reduction in amount of money, time and energy spent on to obtain raw materials. From this point of view, the main purpose of this study was determined as the production of textile surfaces with high waste fiber content by recycling textile fiber wastes in sizes that cannot be used in the textile manufacturing industry again. In this sense, various composite plates that can be used for sound and heat insulation on the exterior and interior surfaces of the buildings were produced by using unconventional methods from the waste fibers varying in lenghts of 1-25 mm. The effect of changed parameters such as density, fiber type, waste fiber ratio and aluminum foil layer addition were investigated. As a result of the tests, it was observed that the thermal conductivity coefficient values of the all produced composite panels varied between 0.033-0.038 W/mK, and the sound transmission loss values between 24.2-32.6 dB.

ARTICLE HISTORY

Received: 22.05.2021

Accepted: 04.10.2021

KEYWORDS

Recycling, waste fibres of yarn factories, waste cotton fibres, waste polyester fibres, waste acrylic fibres, thermal insulation, sound insulation, composite building panels, composite insulation material, aluminuim foil effect.

1. INTRODUCTION

The rapidly increasing population and changing living standards make it difficult to control and manage the waste due to its ever-increasing volume and diversifying composition. The amount of the pollution caused by solid wastes and the current and potential risks associated with it are increasing day by day [1]. In this sense, recycling of wastes is extremely important for both the economy and the environment. By recycling materials such as plastic, glass, paper, metal, textile, bone and wood instead of being stored or buried, a reduction in the need of raw materials in the industrial field is achieved. In this way, the amount of energy consumed for the raw materials are reduced and new spaces are not required due to extending usage life of storage areas [2].

The reasons for the occurrence of wastes that can be reused or never be used in production of the textile enterprises are a complex problem and depend on various factors as raw materials, production conditions, order size, insufficient quality control. For this reason, waste control should be handled step by step and types of wastes should be classified [3]. Textile wastes can be diveded into three main groups. These are spinning mill wastes, textile manufacturing wastes and consumer textile wastes [4]. According to the 2008 data, 4.37% of the total solid waste amount of Turkish industry are composed by textile and clothing manufacturing industry. Approximately one fourth of 4.37% is waste of textile manufacturing industry and waste of clothing (ready-wear) manufacturing industry consitutes the rest [5]. In 2017, 267.8 millions of tons Municipal solid waste was created in the U.S. and 6% of this amount belongs to textile waste. In addition, between 2000 and 2017, the percent changed in tons generated was 78%. U.S [6].

To cite this article: Dönmez ET, Türker E. 2022. Thermal and sound ınsulation performances of building panels produced by recycling waste fibres of yarn factories. *Tekstil ve Konfeksiyon*, 32(1), 9-23.

The necessity of the recycling rate of textile wastes rapidly is so clear according the numbers. However, another factor that is as important as this necessity is that energy, which is one of the important components of economic and social development, should be controlled and used efficiently [7]. In this sense; considering that 35-40% of the energy is consumed in buildings and 85% of this amount is used for heating purposes, the quality and performance of the thermal insulation materials used in buildings are becoming a vital issue [8].

In addition to thermal insulation in buildings, special insulation materials are also used to provide sound comfort. These materials protect the buildings we live in like residences, schools, workplaces and the places used for special purposes like recording studios, cinemas and concert halls from the harmful effects of noise by insulating them from unwanted sounds. Besides, although it varies according to people and societies, they also prevent the sound from creating various physiological and psychological disturbances on people by reducing the equivalent noise level [9].

In today's conditions, the increasing importance of heat, sound insulation and recycling issues has caused researchers to make studies in these areas. In this sense, some researchers have produced various surfaces by recycling waste textiles and examined their thermal and sound insulation performances.

Eken [10] produced panels at different pressures by mixing sunflower stalk, stubble (roots and stems remaining in the soil of crops harvested as a result of agricultural production), cotton waste obtained from textile factories, binders such as epoxy and gypsum in various proportions. The thermal conductivity coefficient of the most insulating panel is 0.0728 Wm/K and its sound permeability is 108.52 m/sec. Binici et al. [11] produced plates and blocks by mixing textile fiber wastes with cement, ash and water at 6.89-14.38% by weight in the mixture, and conducted various tests. As result of the tests, they reached a thermal insulation value of 0.235-0.268 kcal/m^{2}h^{0}C, that is approximately 0.273-0.311 W/mK. Binici et al. [12] mixed cotton waste, fly ash from thermal power plants, adhesive resin and barite in different proportions and placed them between chipboard plates. According to their results, one of sample which contains textile waste, behaves more resistant in terms of sound transmission values and shows a positive feature against sound insulation. The sound permeability values of the samples vary between 10.6-54.0 dB. Turak [13] prepared block samples by adding wool and cotton fiber wastes, cotton yarn, fabric and paper wastes into a cement-fine sand mixture. The thermal conductivity coefficient of the reference sample produced without using waste was 0.803 W/mK, and the lowest value was obtined as 0.687 W/mK for the samples having waste.

Tayyar and Çetin [14] changed the blend ratio of v-PET (pure PET fibers) and r-PET (PET fibers obtained by recycling from PET bottles) fibers and the number of web layer during the production of non-woven fabric, which they intend to use as an insulation material in the construction industry. The effects of blend ratios and web layer amount on some physical, mechanical and conductivity properties of fabrics were investigated. They found the thermal conductivity coefficient values of samples between 0.0312-0.0361 W/mK. Celep and Yüksekkaya [15] produced blankets using Nm 9 number open-end yarn spun from recycled fibers and original fibers as weft yarn in order to compare with the thermal comfort properties of classical blankets. At the end of their study, they stated that there was no statistically significant difference in thermal conductivity values of blankets obtained from recycled fibers and original fibers. They have reached approximately 0.046 W/mK as coefficient of thermal conductivity. Yachmenev et al. [16] have produced various nonwoven samples in different production techniques from kenaf, PE, PP, recycled PE, recycled PP, cotton and sugar cane fibers. It was used recycled PE and PP fibers to blend 30% by weight with individual cotton, kenaf and jute plant fibers to thermoplastically bond with loosely woven PET fabric. Thermal conductivity coefficient were measured as 0.0385 W/mK for cotton produced, 0.0366 W/mK for hemp and 0.0363 W/mK for jute fiber. Huang et al. [17] produced the nonwoven composite boards made from recycled polypropylene nonwoven selvages, two types of polyester fiber, and thermoplastic polyurethane. They were baked by placing PP nonwoven surfaces between the layers formed by different fibers and they provided the bonding. They mentioned that PET/PP and PET/PP/TPU composite samples have good thermal conductivity values ranging from 0.0373-0.0751 W/mK. They underlined that the sound absorption coefficient of 10 layer PET/PP composite samples reached 0.682. They stated that the average sound absorption coefficient of the TPU surface increased enormously to 0.491 in the middle and low frequency bands.

Horga et al. [18] turned textile wastes from various knitting and garment factories usable form and produced samples in different densities with 56% Polyamide and acrylic fiber, 36% yarn ends and 8% unopened parts. In addition, they also produced samples in different densities from waste cotton fibers and compared them with a commercially available rock wool in terms of thermal conductivity. The lowest coefficient of thermal conductivity for samples obtained from waste textiles is approximately 0.059 W/mK. The lowest coefficient of thermal conductivity for samples obtained from waste cotton is about 0.069 W/mK. Lin et al. [19] produced nonwoven surfaces by blending recycled kevlar, Nylon 6, low-melting polyester and polypropylene fibers in different proportions. They investigated the effects of fiber ratios, bonding angles of surfaces and pressing temperatures on sound and heat insulation. They obtained the value of 0.041 W/mK as the best thermal conductivity coefficient. Ricciardi et al. [20] produced various surfaces using glue from waste polypropylene fibers and pieces of paper. Sound and heat insulation tests were made on the surfaces. It was observed that the thermal conductivity coefficients of the samples were 0.034-0.039 W/mK and the sound transmission loss values were approximately 15-20 dB for 500Hz. Moretti et al. [21] produced panels with high fiber content, which can be used for coating the exterior of buildings, with a thickness of 9 - 18 - 27 mm and densities ranging from 115 - 200 kg/m^3, by mixing 6 cm long basalt fibers with about 7% resin. Coefficient of thermal conductivity values of the basalt fibers used are 0.031 - 0.032 W/mK. Thermal conductivity coefficient values of the samples produced in 9 mm thickness varied between 0.0305 - 0.0345 W/mK. Approximately normal incidence sound transmission loss value at 500 Hz of the sample with 9 mm thickness of 145 kg/m^3 was 4 dB, the sample with 18 mm 175 kg/m^3 was approximately 8 dB, and the sample with 27 mm 200 kg/m^3 was 13 dB. Rubino et al. [22] produced composite panels with a thickness of 5 cm and densities in the range of 80 - 197 kg/m^3 by bonding waste wool fibers with chitosan and arabic gum for use in buildings. They measured the acoustic and thermal properties of the samples and reached coefficients of thermal conductivity ranging from 0.049-0.060 W/mK.

In the studies conducted by the researchers, it was seen that they provided recycling of textile wastes and produced surfaces that can be used for different purposes. However, the remarkable point in terms of recycling and production here is that in most of these studies, textile wastes were used as auxiliary materials much more than being the main material. In other words, waste textiles were used in low amounts in the surfaces produced from the mixture of many materials. This situation raises questions regarding the reduction of rapidly increasing textile wastes by recycling. From this point of view, the main purpose of this study was determined as the production of textile surfaces with high waste fiber content by recycling textile fiber wastes in sizes that cannot be used in the textile manufacturing industry again. In this sense, various composite panels that can be used for sound and heat insulation on the exterior and interior surfaces of the buildings were produced by using unconventional methods from the waste fibers collected from the spinning factories in the Uşak Organized Industrial Zone. Another aim of the study was to produce widely used panels at low costs in order to compete with commercial products.

2. MATERIAL AND METHOD

2.1 Material

Textile fibre wastes collected from the yarn factories in Uşak Organized Industrial Zone, were used as raw material in the production of composite panels. In the raw material analysis of the waste fibers collected in two batches from factories, it was found that one batch of fibers contained 100% Acrylic (PAC), the other have 80% Cotton (CO) and 20% Polyester (PES). Textile wastes consist of fiber wastes from various machines in the yarn production line. Waste CO/PES fibers were collected from factories that supply yarn to mills producing home textiles. In this sense, waste fibers include the wastes of blowroom, card, draw frame, combing and roving machines in the open-end and ring yarn production lines. On the other hand, waste PAC fibres were collected from factories that supply yarn to mills that produce blanket. Waste fibers consist of the wastes of the blowroom, card, vargel, tops and draw frame machines in the straygarn yarn production line. For this reason, fiber lengths show heterogeneous distribution by varying between 1 and 25 mm. Table 1 shows the physical properties of various textile fibers.

In the production of composite textile panels, phenol formaldehyde was used as a binder (resin) so that the wastes can hold together and form a composite structure. Phenol formaldehyde was preferred due to having low coeffiecient of thermal conductivity, high electrical non-conductivity, very difficult to ignite and burn, easy to process (limitless water tolerance) and high dimensional stability, high chemical resistance to alcohol, oils, many solvents, weak acids and alkalis and low cost features.

Table 1. General physical properties of various textile fibers

Fibres	Length (cm)	Fineness (µm)	Density (g/cm^3)	Strenght (cN/tex)	Coefficient of thermal conductivity (W/mK)	Ability of dehumidification (%)
Cottton	1-6	12-45	1.55	19-45	0.071	8.5
Wool	3-30	10-200	1.30	12-14	0.054	16
Polyester	Desired Lenght	Desired Fineness	1.39	47-56	0.14	0.4
Acrylic	Desired Lenght	Desired Fineness	1.19-1.29	27-34	0.07	1-2.5
Polyamide 6.6	Desired Lenght	Desired Fineness	1.14	37-66	0.25	3.5-5
Viscose	Desired Lenght	Desired Fineness	1.52	18	0.054-0.07	10-16

2.2 Preparing of the Composite Panels

Production of the composite panels having sound and heat insulation properties started with the application of opening process to floc waste fibers. Then, a solution was prepared by mixing phenol formaldehyde having infinite water tolerance with water in a ratio of one to one by weight. The prepared solution was sprayed evenly on the opened fibers and generated mixture. Figure 1 shows the pressing of Acrylic and Cotton/Polyester mixture.

The prepared mixture with waste fibers and binder phenol formaldehyde was placed in the mold covered with non-adhesive PET film by distributing it homogeneously by hand lay method. The temperature of the mold was adjusted to 130 ^{0}C in order to activate the phenol formaldehyde in the mixture and to establish a chemical bond with the waste fibers. Then, by pressing for 45 minutes, samples in sizes of 50x50x5 cm were obtained. Various parameters of produced composite samples by following the mentioned processes were changed and it was observed how these parameters affect sound and heat insulation performance. In this sense, two different waste fiber groups, PAC and CO/PES, were created to investigate the effect of the fiber differance. The samples were primarily produced in different densities within their own groups by changing the raw material and binder ratios. The properties and codes of these samples are shown in Table 2.

a b c

Figure 1. a) Acrylic mixture b) Cotton/Polyester mixture and c) Pressing [40]

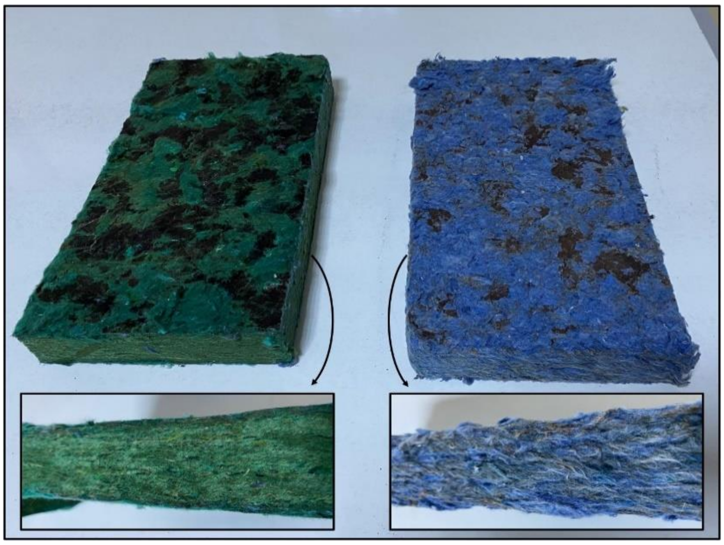

Figure 2. View of two samples of produced acrylic and cotton/polyester panels

In addition, three different P14 samples were produced by using 14 µm thick aluminum foil. For the production of these samples, 40x40 cm aluminum foils were cut. Since the composite panels were considered to be evaluated in the construction area, it was aimed to produce as much performance and light weight samples as possible in our study. In direction of this aim, the weight of the added aluminum foils and the binder that will bond the foils together were determined as approximately 1% of the P14 sample weight. This was equal to the weight of 15 layers of aluminum foil and the binder. In this sense, the cut foils were bonded to each other with phenol formaldehyde and aliminum surfaces having 15, 8, 7 and 5 layers were formed. The "O" code sample was produced by placing aluminum surface having 15 layers in the middle of the sample. Then, two aluminum surfaces having 8 and 7 layers were adhered to the lower and upper surfaces of the sample, and the "UA" code sample was obtained. The "UOA" sample was produced by placing three aluminum surfaces having 5 layers in the middle, upper and lower surfaces of the sample. Aluminum surfaces were placed parallel to the cross section of the composite panels as shown in Figure 3. Because it is known that if aluminum surfaces were placed vertical to the cross-section of the composite material (along its thickness), the heat transfer between the surfaces of the composite samples would increase and hence the coefficient of thermal conductivity would increase and the thermal insulation would decrease.

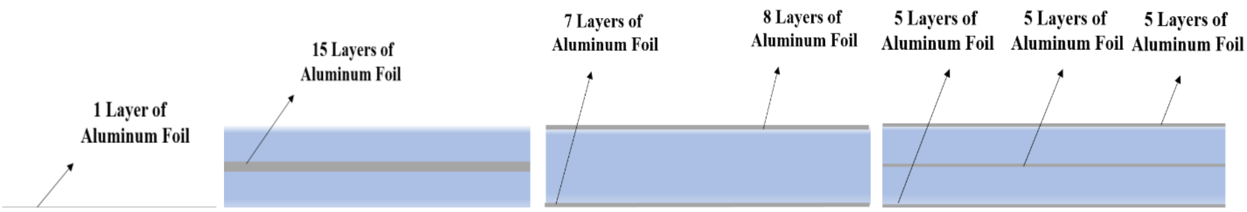

Figure 3. The Layout of Aluminum Surface/s In samples

Table 2. Properties and sample codes of produced composite panels

Cotton/Polyester				**Acrylic**			
Group of density (kg/m^3)	Amount of waste fiber (weight %)	Binder amount (weight %)	Sample codes	Group of density (kg/m^3)	Amount of waste fiber (weight %)	Binder amount (weight %)	Sample codes
100	90	10	P11	100	90	10	A11
100	85	15	P12	100	85	15	A12
100	80	20	P13	100	80	20	A13
100	75	25	P14	100	75	25	A14
200	90	10	P21	200	90	10	A21
200	85	15	P22	200	85	15	A22
200	80	20	P23	200	80	20	A23
200	75	25	P24	200	75	25	A24
300	75	25	P31				
100	75	25	U				
100	75	25	UA				
100	75	25	UOA				

2.3 Testing of Composite Materials

2.3.1 Testing of the Thermal Insulation

Testing of the thermal insulation was done according to hot box experiment. This experiment was conducted according to TS EN ISO 8990 "Determination of steady-state thermal transmission properties-calibrated and guarded hot box" standard. Hot box test set up is isolated very well and consists of two rooms. Left room is hot and right room is cold. Samples being 40x20 cm were placed in the middle of test set up and divide it as cold and hot rooms. A heater (20-400Watt) and a ventilator were installed in hot room in order to maintain air temperature. During tests, thermocouples having 0.1 ^{0}C sensitivity used to measure the temparature in degrees centigrade of hot room and cold room. In addition, thermocouples measured the temperature of the hot surface and cold surface of the sample. For calculating the coefficient of thermal conductivity, "the amount of heat transmitted by conduction per unit area is proportional to the temperature gradient in the direction of heat transfer (1)" principle was used and

$$\frac{Qx}{A} \approx \frac{dT}{dx} \tag{1}$$

$$Qx \cong -kA.\left(\frac{dT}{dx}\right) \tag{2}$$

the relation is obtained (2). This equation is called the Fourier heat conduction law (2).

If integral is taken;

$$Q_x \int_{x_1}^{x_2} dx = kA \int_{T_1}^{T_2} dt \quad (3)$$

$$Q_x(x_2 - x_1) = -kA(T_2 - T_1) \quad (4)$$

$$Q_x = kA\left(\frac{T_2 - T_1}{x_2 - x_1}\right) \quad (5)$$

$$k = \frac{Q_x}{A\left(\frac{T_2 - T_1}{x_2 - x_1}\right)} \quad (6)$$

equality is revealed to calculate the coefficient of thermal conductivity (3-6) where Qx is heat amount trasnfered per unit time (W), A is surface area vertical to the heat transfer direction (m^2), k is coefficient of thermal conductivity $\left(\frac{W}{mK}\right)$, temperature gradient in the direction of heat transfer is $\left(\frac{dT}{dx}\right)$.

2.4 Sound Insulation Test

Sound insulation tests were conducted according to TS 2381-1 EN ISO 717-1 standards. Measurements were done in 1/3 octave 63 - 125 - 250 - 500 - 1000 - 2000 - 4000 Hz band frequencies which were taken as referance points in studies because of finding out logarithmic behaviour of sound insulation. A laboratory-sized test setup in which "One Chamber and One Face Open Sound Measurement Method" is applied under laboratory conditions was used for measurements. The frequency-dependent sound transmission loss values of the test samples were calculated as the difference between the sound pressure level measured at each frequency value without a sample in the measurement setup and the sound pressure level measured with the sample. The equipments and components specified in the experimental measurements were used; GAG 809/810 model Audio Signal Generator capable of generating signals from 10 Hz to 1 MHz (The output impedance of the device is 600 Ω), SONORA Brand mono amplifier (amp) that enables the input signal amplitudes to be amplified to larger amplitude signals and the amplifier can deliver maximum 60W of sound power to a 4 Ω impedance speaker by driving 600 Ω microphone input with 5V rms sine, versatile speaker that converts the energy from the amplifier into sound energy, sound level meter (decibel meter) with the sensitivity of measuring with 0.1 dB resolution in the range of 30–130 dB sound intensity, calibrator and tripod.

3. RESULTS AND DISCUSSION

The results of the tested samples were evaluated under the headings of heat insulation and sound insulation.

3.1 Thermal Insulation Test Results

The results of the composite samples were evaluated separately in terms of the effect of sample density, difference of fibres, sample composition and aluminum surface addition to the samples on the coefficient of thermal conductivity. Although samples were intended to be produced at certain density values, it is not possible to distribute the mixture evenly over the entire surface during production process. In this sense, although there were minor differences, density values were calculated for each sample. The thermal conductivity coefficient values of the composite samples are given in Table 3.

When the results given in Table 3 were evaluated, it was seen at first glance that all samples provide the required heat conduction coefficient values to be classified as "**thermal insulation material**" according to ISO, CEN, DIN and TS standards. Because, according to Turkish Standards TS 825 and German DIN norm 4108; materials having a thermal conductivity coefficient value (λ) below 0.060 kcal/mhºC (~ 0.069 W/mK) are defined “thermal insulation materials” and all materials above this value named as “construction materials”. According to IS0 and CEN Standards, materials having a coefficient of thermal conductivity value less than 0.065 W/mK are defined “thermal insulation material” and others named as “building materials”.

Table 3. Thermal conductivity coefficient and density values of composite samples

Sample codes	Coefficient of thermal conductivity (W/mK)	Density (kg/m^3)	Sample codes	Coefficient of thermal conductivity (W/mK)	Density (kg/m^3)
P11	0.033	113.8	A11	0.034	135
P12	0.033	112.1	A12	0.034	135.9
P13	0.033	101.7	A13	0.034	134.4
P14	0.034	129.9	A14	0.034	133
P21	0.036	211.8	A21	0.036	206.8
P22	0.036	219.8	A22	0.036	204.3
P23	0.036	202	A23	0.035	179.5
P24	0.035	187.4	A24	0.036	198.7
P31	0.038	265.1			
U	0.034	156.2			
UA	0.033	122			
UOA	0.034	148			

3.1.1 The Effect of Density on Thermal Conductivity Coefficient

Figure 4 shows graphically the change in the thermal conductivity coefficients caused by the density change of samples produced from CO/PES and PAC fibers.

In the light of the results from the thermal insulation test, it was seen that the thermal conductivity coefficient values of the samples change with the change of density. In the samples produced from both fiber groups, the density increase of 100 kg/m^3 caused an increase of approximately 6% in the thermal conductivity coefficient values. This means that the increase in density decreases the thermal insulation of the samples. As the density of the samples having constant thickness increases, a decrease occurs in the number and volume of closed pores having still air. This situation causes the heat insulation to be adversely affected by increasing the heat flow. On the other hand, as can be seen in Figure 5, it was revealed that there is a positive linear relationship between the thermal conductivity coefficients of the samples and their density. In other words, the increase in thermal insulation as the density decreases creates an advantage in terms of the low weight loaded by these panels to be used for insulation in buildings.

3.1.2 The Effect of Fiber Difference and Binder Amount on Thermal Conductivity Coefficient

In Figure 6, the change in the thermal conductivity coefficients caused by the density change of the samples produced from Cotton/Polyester and Acrylic fibers is shown graphically.

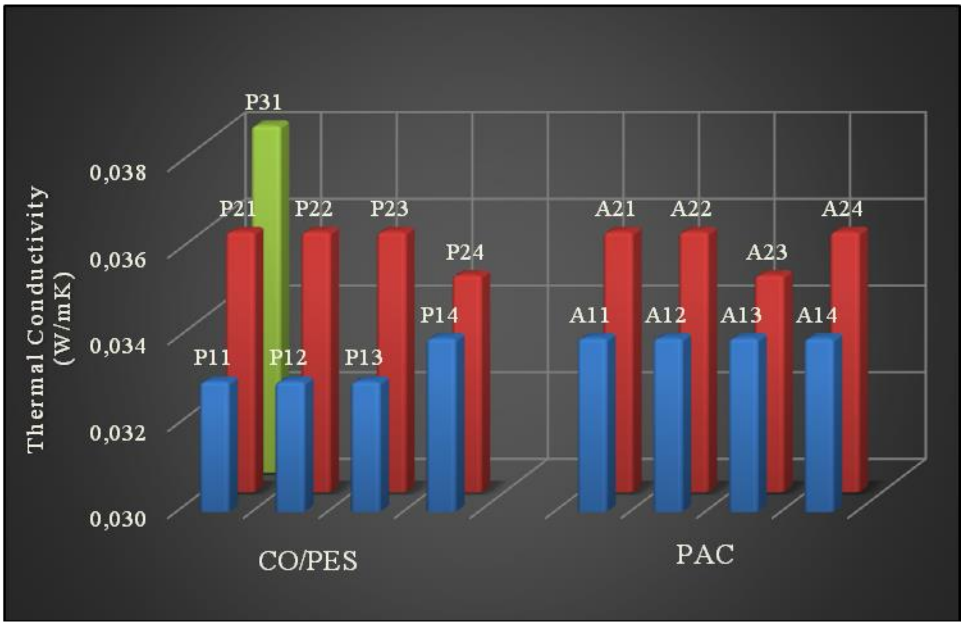

Figure 4. The Effect of density change on thermal conductivity coefficient

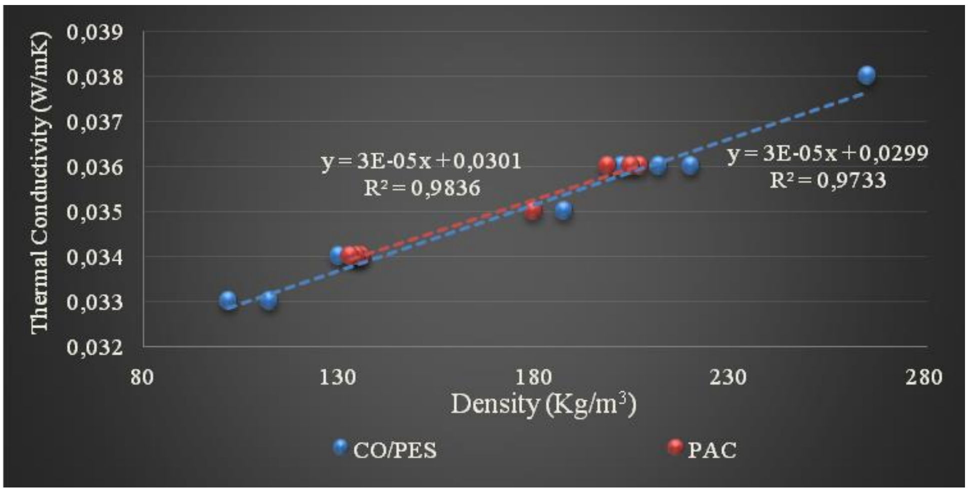

Figure 5. The correlation between density and thermal conductivity coefficient

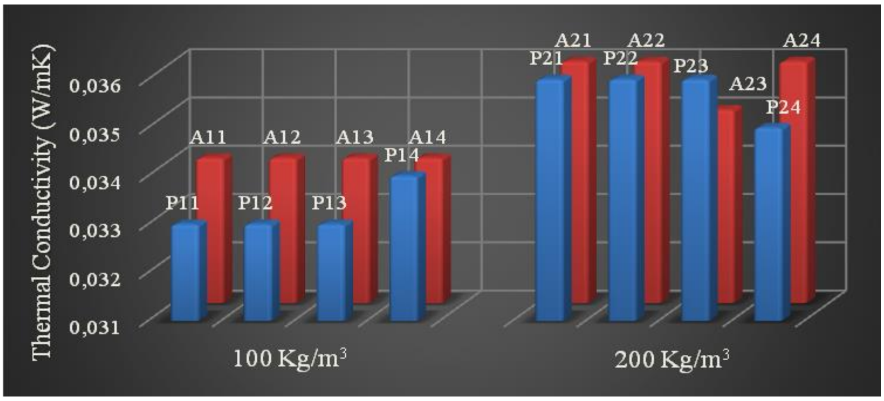

Figure 6. The effect of fiber difference on thermal conductivity coefficient

According the graphic in Figure 6, it was seen that the thermal conductivity coefficients of the samples produced from different fibers having the same density are the same or there is a maximum change of 2.9%. Although the thermal conductivity coeffecient value of the waste cotton fiber is 0.071 W/mK, the polyester fiber is 0.14 W/mK, the acrylic fiber is 0.07 W/mK, and the binder is 0.25 W/mK, the thermal conductivity coeffecient values of all composite panels are the same or very close. This is one of the most striking results of this study. This means that not only samples produced from CO/PES and PAC fibers with the same production method and same density, but also the panels to be produced with different types of fibers will show similar insulation performances due to the pore structure and number of them. The studies were conducted by Yachmenev et al. [16, 23], Moretti et al. [21], Bourguiba et al. [24], Drochytka et al. [25], El Wazna et al. [26] and Patnaik et al. [27] are very important indicators for proving this opinion because they all reached same or very close thermal conductivity coeffecient values by producing similar composite materials with different types of waste fibers from this study. In this sense, the fact that the thermal conductivity coefficients of the produced composite materials are the same or close gives an important advantage in the recycling of all waste textile fibers. Because, this situation provides the elimination of problems such as wasting time and energy for classifying of waste textile fibers before and after being collected. Thus, the possibility of sending the waste fibers directly to production in mixed form without classifiying will be gained. Therefore, the amount of recycled waste textile fibers will increase with high production speed.

The effects of the change of fiber composition or binder ratio on the thermal conductivity coefficients of the produced samples are also shown graphically in Figure 10. When the results obtained were evaluated, it was observed that the coefficient of thermal conductivity does not change with the change of the binder amount of the produced samples with both CO/PES and PAC waste fibers. This situation creates the advantage that composite materials can be produced with the desired hardness and rigidity according to the areas where they will be used, without making concessions to the thermal insulation values. For example, the flexibility and softness of an insulation material to be used under the roof and/or the outer surface of the building will not be the same. But, this will not create a difficulty in terms of time and cost for the manufacturers and they will be able to produce insulation materials by only changing the binder amount without regulating the production process.

3.1.3 The Effect of Foil Layers on Thermal Conductivity Coefficient

The comparison of the thermal conductivity coefficients of P14 and P14 samples with aluminum foil is graphically shown in figure 7.

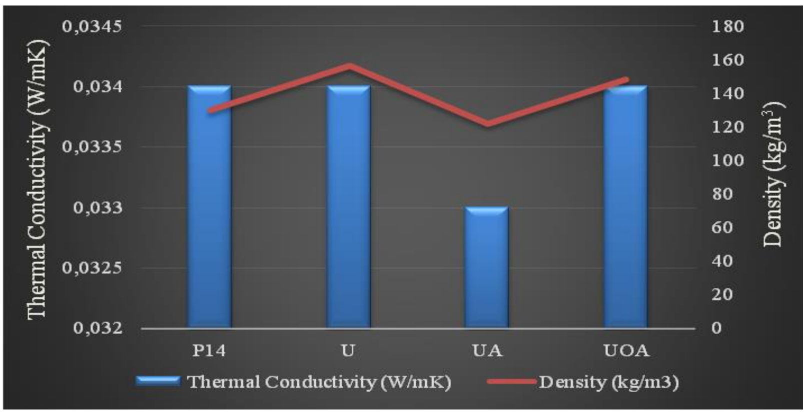

Figure 7. The effect of foil on thermal conductivity coefficient

When the thermal conductivity coefficient values were evaluated according the Figure 7, it was seen easily that aluminum foil addition has no any effect on the thermal conductivity. Foils placed in different positions did not change the thermal conductivity coefficient either. This is thought to be due to the fact that the foils were placed parallel to the cross section of the material. Such a result is caused by the prevention of the formation of thermal bridges across the thickness of the material due to the way the foil is placed. This situation shows that metal surfaces to be placed parallel to the cross section of the composite material will not create a change in terms of thermal conductivity coefficient. Thus, for further innovative studies to be carried out to develop the composite material, metal surfaces might be used to give different properties such as electromagnetic shielding without making any concession to thermal conductivity.

In addition to these evaluations, the results were also evaluated by performing ANOVA analysis. In this sense, it was investigated whether there is a difference between the thermal conductivity coefficient measurement groups of CO/PES and PAC fibers. The results of the ANOVA test are given in Table 4. As seen in Table 4, the P value is above 0.05. Therefore, no significant difference was found between the groups and it was statistically understood that the fiber difference has no any effect on the thermal conductivity coefficient values.

Table 4. ANOVA Analysis Results

ANOVA analysis						
Source of variance	**SS**	**df**	**MS**	**F**	**P-value**	**F criterion**
Between Groups	5.63E-07	1	5.63E-07	0.37725	0.54893	4.60011
In Groups	2.09E-05	14	1.49E-06			

Table 5. Comparison with studies in the literature

Materials	**Density (Kg/m^3) (~)**	**Thermal conductivity (W/mK) (~)**	**Components weight ratio (%)**	**Thickness (mm)**	**Ref.**
P11 P21 P31	113.8 211.8 265.1	0.033 0.036 0.038	-	50	In This Study
Jute or kenaf or cotton fines + recycled PE + PP	92.7 93.9 94.7	0.036 0.037 0.039	35:35:30	-	[16]
Recycled PE + PP	78.7	0.036	70:30	-	[16]
Kenaf (T-2) or cotton fines or jute + recycled PE + PP	70.4 75.3 57.7	0.035 0.037 0.035	35:35:30	-	[23]
Recycled PE + PP	57.0	0.035	70:30	-	[23]
Acrylic/polyamide + yarn ends + pieces non opening	47.2 67.3 94.3 130.5	0.061 0.059 0.064 0.075	56:36:8	-	[18]
Cotton waste	47.2 67.3 94.3 130.6	0.077 0.070 0.069 0.075	100	-	[18]
Recycled kevlar + nylon +low-melt PET + recycled PP	-	0.046	%30 Low melt PET	10	[19]
Wool waste + Tetra pak waste	-	0.063 0.062 0.062 0.061 0.062	0:100 5:95 10:90 15:85 20:80	4.94 4.77 4.82 5.06 5.20	[28]
Nylon-Spandex Waste + PU Foam	1060.0	0.095	60:40	10	[29]
Recycled Polyester	62.5	0.035	100	16	[27]
Waste polyester + BiCO	80.0	0.047 0.049	85:15	-	[25]

Table 5. Continue

Materials	**Density (Kg/m^3) (~)**	**Thermal conductivity (W/mK) (~)**	**Components weight ratio (%)**	**Thickness (mm)**	**Ref.**
Wool waste	45.0	0.031 0.034	100	30	[26]
Coring wool + Recycled polyester	62.5	0.032	50:50	16	[27]
Recycled Cotton	25.0 45.0	0.039 0.044	100	-	[30]
Sunflower stem sponge + cotton waste + epoxy	-	0.087	-	-	[31]
Acrylic waste	14.6	0.043 0.486	100	-	[32]
Polyurethane foam	30.0 80.0	0.020 0.027	-	-	[33]
Commercial glass wool	92.5	0.040	-	10	[34]
Commercial mineral wool	36.0	0.040 0.045	-	-	[26]
Commercial rock wool	80.0 200.0	0.025 0.035	-	-	[35]
Commercial fiber glass	24.0 112.0	0.035 0.032	-	-	[33]
Waste of Feather + Polyester fibre and fabric + OSB Timber board	-	0.051 0.063	-	10	[24]
Waste paper + textile fibres	433.0 483.0	0.340 0.039	-	12 20	[20]
Basalt Fibre + Resin	115.0 200.0	0.031 0.035	-	9 18 27	[21]
Recycled Wool + Chitosane or Arabic Gum Binder	80.0 197.0	0.049 0.060	-	50	[22]

In the literature review as shown in table 5, it was seen that the produced samples generally have density values varying between 100-200 kg/m^3. When an evaluation was made considering the increase in thermal insulation with the decrease of density, it was seen also that the thermal insulation values of the produced samples in this study have best values with panels of Moretti et al. [21] and conventional insulation materials. In study of Rubino et al. [22], although it was produced composite materials by recycling wool fibers, they reached approximately 26% lower thermal insulation values according to this study. In addition, it was also observed that the thermal insulation values obtained from studies in which similar composite materials were produced varied between 0.03 and 0.06 W/mK although it was used waste fibers having the different dimensions and the coefficient of thermal conductivity chancing between 0.054 - 1.5 W/mK. This is another result compatible with this study.

3.2 Results of Sound Insulation Tests

The results of the composite samples were evaluated separately in terms of the sample density effect, difference of fibres, sample composition and aluminum surface addition to the samples on sound transmission loss. Values of ound transmission loss and average sound transmission loss are given according to the frequencies of composite samples produced from CO/PES in Table 6 and PAC fibers in Table 7.

Tablo 6. Sound transmission loss values of samples produced from CO/PES fibers

	Sound transmission loss values (dB)											
Freq. (Hz)	**P11**	**P12**	**P13**	**P14**	**P21**	**P22**	**P23**	**P24**	**P31**	**U**	**UA**	**UOA**
63	9.3	9.2	8.3	8.4	14.7	15	14.3	13.7	16.7	10.3	9.2	10.9
125	9.9	9.8	9	9	15.3	15.7	14.9	14.3	17.3	10.9	9.8	11.5
250	23.2	23.1	22.2	22.3	28.6	28.9	28.2	27.5	30.5	24.2	23.1	24.7
500	25.2	25.1	24.2	24.3	30.6	30.9	30.2	29.5	32.6	26.2	25.1	26.8
1000	28.6	28.5	27.7	27.7	34	34.3	33.6	33	36	29.6	28.5	30.2
2000	33.4	33.3	32.4	32.4	38.8	39.1	38.4	37.7	40.7	34.4	33.3	34.9
4000	44.2	44	43.2	43.2	49.6	49.9	49.1	48.5	51.5	45.2	44	45.7
Avg. (R)	**25.2**	**25.1**	**24.2**	**24.3**	**30.6**	**30.9**	**30.2**	**29.5**	**32.6**	**26.2**	**25.1**	**26.8**

Table 7. Sound transmission loss values of samples produced from PAC fibers

	Sound transmission loss values (dB)							
Freq. (Hz)	**A11**	**A12**	**A13**	**A14**	**A21**	**A22**	**A23**	**A24**
63	8.7	8.8	8.7	8.6	14.5	14.4	13.3	14.2
125	9.3	9.4	9.3	9.2	15.1	15	13.9	14.8
250	22.6	22.6	22.6	22.5	28.4	28.3	27.2	28
500	24.6	24.7	24.6	24.5	30.4	30.3	29.2	30.1
1000	28	28.1	28	27.9	33.8	33.7	32.6	33.5
2000	32.8	32.8	32.7	32.7	38.6	38.5	37.3	38.2
4000	43.5	43.6	43.5	43.4	49.3	49.2	48.1	49
Avg. (R)	**24.6**	**24.7**	**24.6**	**24.5**	**30.4**	**30.3**	**29.2**	**30.1**

3.2.1 The Effect of Sample Density on Sound Transmission Loss

The effect of density, which is one of the parameters changed during the production of samples, on sound transmission loss values was evaluated in this section. The graphic consisting of the results is given in Figure 8 and Figure 9.

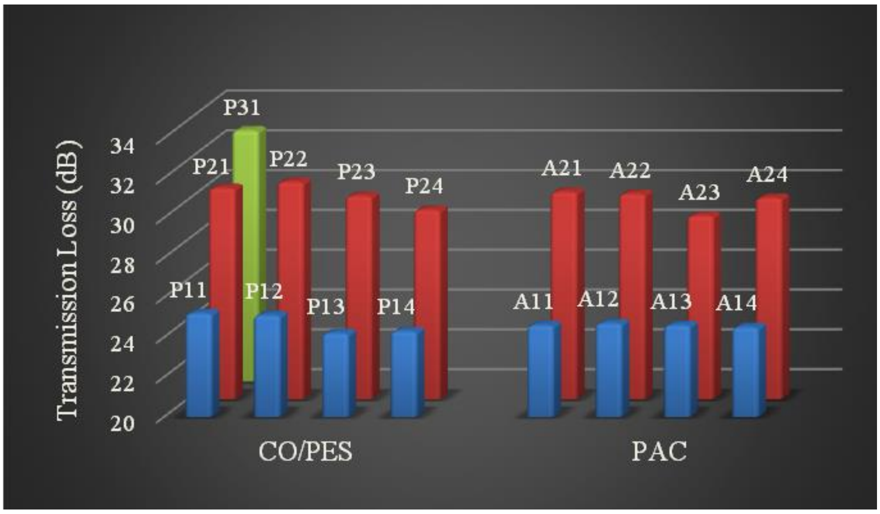

Figure 8. Effect of density change on sound transmission loss

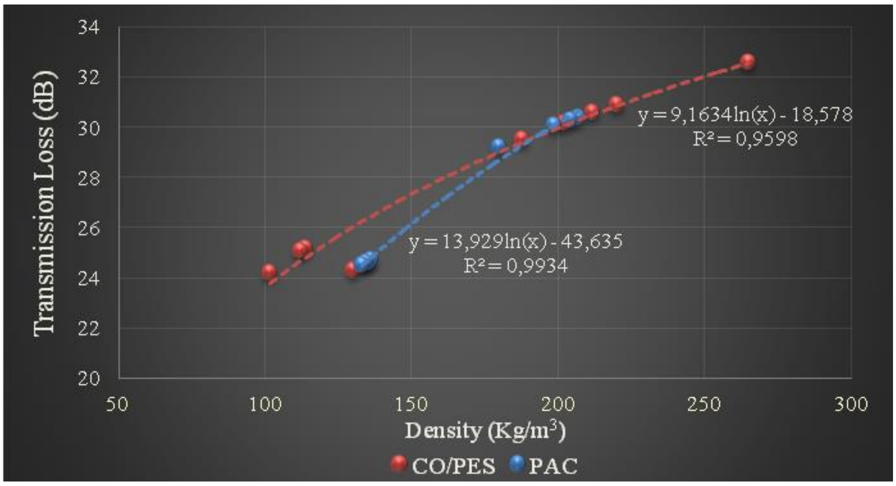

Figure 9. The correlation between density change and sound transmission loss

It was observed that the loss of sound transmission increased with the increase of density in all samples according to Figure 8 and 100 kg/m^3 increase of densities in all samples produced from both CO/PES and PAC fibers creates approximately 6 dB sound transmission loss effect. It was thought that the reason for this situation is the increase of mass. Because as the mass that creates resistance against sound vibrations increases, it causes an increase in sound transmission loss. Figure 9 shows a high correlation between density and loss of sound transmission. In addition, since there is a logarithmic relationship between sound transmission loss and density, as the frequency increases, the increase in the sound transmission loss value of composite materials slows down.

3.2.2 The Effect of Fibre Differences and Binder Amount on Sound Transmission Loss

The effect of fibre change of produced samples with 100 and 200 kg/m^3 densities are showed in Figure 10.

As it can be seen clearly in Figure 10, the difference between the sound transmission loss values varies between 0.1-1 dB. In this sense, it can be evaluated that the difference of fibres in both density values does not cause a change in the sound transmission loss values. The reason for this situation is that the density difference, which is the most effective parameter in sound transmission loss, is very low between samples. In addition, as it is clear in Figure 10, the change of binder ratio has not any effect on the sound transmission loss values of the samples. This is because of fiber/binder ratio that is changed according to mass, not to volume during sample production. Therefore, there was no change occured on sound transmission loss values of samples with the same density, since there was no change in the total mass.

3.2.3 The Effect of Foil Layers on Sound Transmission Loss

In Figure 11, the comparative sound transmission loss values of foiled samples and P14 samples are graphically shown. Foiled Samples and P14 Samples are compared in terms of sound transmission loss values according to frequencies in Figure 12.

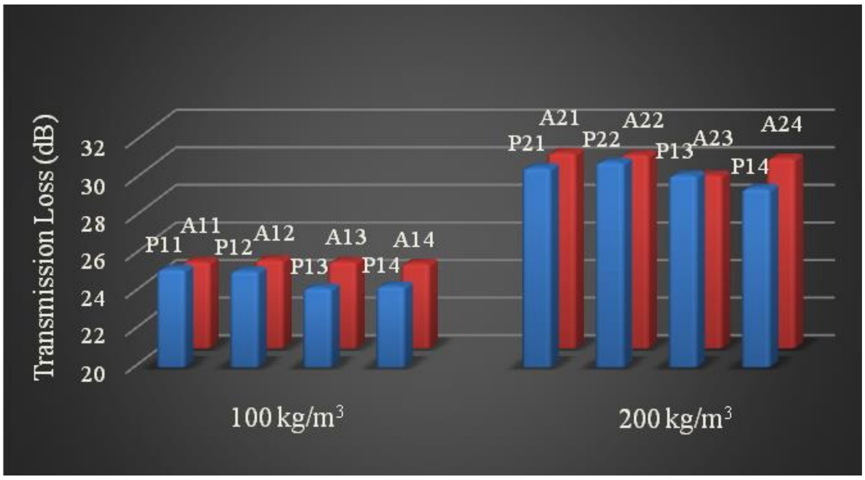

Figure 10. The effect of fibre differences sound transmission loss

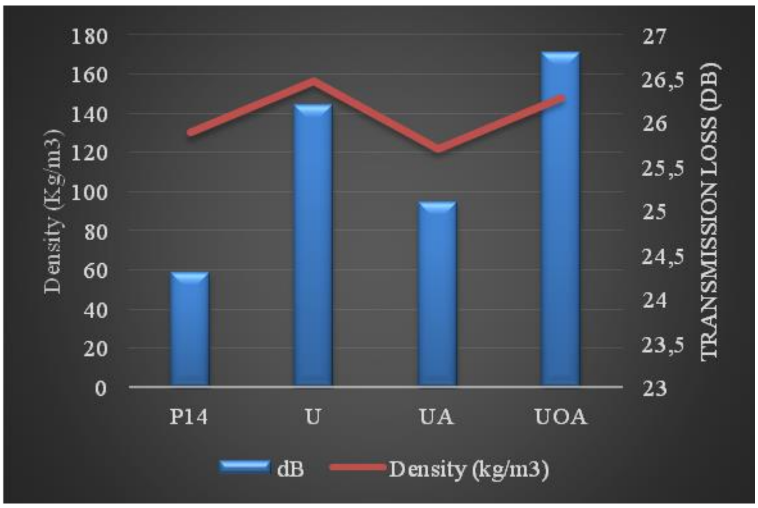

Figure 11. Comparative sound transmission loss values

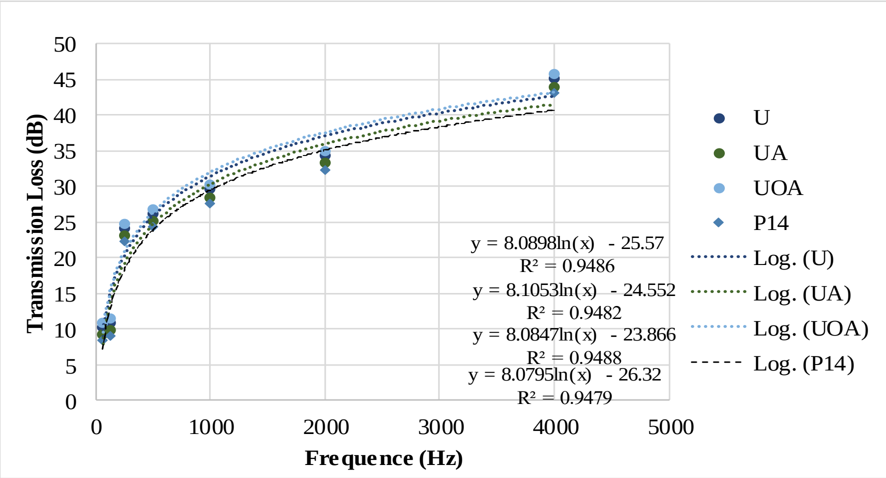

Figure 12. Comparative sound transmission loss values

As can be seen from the graphs in Figures 11 and 12, the sound transmission loss values of the samples using foil are higher compared to the P14 sample. When the variation according to the frequencies was evaluated, it was revealed that the use of foil makes a difference in sound insulation. It is also seen that foil placement has an effect on the sound transmission loss values.

In addition to these evaluations for sound insulation, the results were also evaluated by performing ANOVA analysis. In this sense, it was investigated whether there is a difference between the sound transmission loss measurement groups of CO/PES and PAC fibers. The results of the ANOVA test are given in Table 8. As seen in Table 8, the P value is above 0.05. Therefore, no significant difference was found between the groups and it was statistically understood that the fiber difference has no any effect on the sound transmission loss values.

Table 8. ANOVA analysis results

ANOVA analysis						
Source of Variance	***SS***	***df***	***MS***	***F***	***P-value***	***F criterion***
Between Groups	0.16	1	0.16	0.018082	0.89495	4.60011
In Groups	123.88	14	8.848571			

Table 9. Comparison with studies in the literature

Materials	**Density (kg/m^3)**	**Sound transmission loss (dB) (500 Hz)**	**Thermal conductivity (W/mK) (~)**	**Thickness (mm)**	**Ref.**
P11 P21 P31	113.8 211.8 265.1	25.2 30.6 32.6	0.033 0.036 0.038	50	In this study
Waste paper + textile fibres	433.0 483.0	16.0 19.0	0.034 0.039	12 20	[20]
Sandwich panels with polyurethane	-	30.0 32.0 32.0 32.0	0.600 0.500 0.410 0.310	50 60 75 100	[36]
Sand + wood mixed plank (Phonestar)	850.0 1200.0	19.0 22.0	0.170	15	[37]
Panetti	100.0	18.0 22.0	0.032 0.042	5	[38]
Fibre reinforced polimer and aluminium honey comb	1578.0 2700.0	15.0	-	10	[39]
Basalt Fibre + Resin	115.0 200.0	14.0 13.0	0.0305 0.0345	9 18 27	[21]

In the literature review as shown in Table 9, it was revealed that very few studies designed and produced similar composite panels in terms of properties, usage place and purpose like in this study. When compared with the sound insulation materials produced in the literature and sold commercially, it was observed that the composite panels produced in this study showed the best performance. Composite panels produced by Moretti et al. [21] were the most similar among studies and exhibited approximately 80% lower sound transmission loss performance. In addition, Panetti, which is sold as a sound insulation material in the market, gave 40% lower sound insulation results.

4. CONCLUSION

In the study, composite panels were produced from waste Acrylic and Cotton/Polyester fibers. Effects of changed parameters such as fiber type, binder amount, density and aluminum foil addition during production prosess on the heat and sound insulation were examined. Results are interpreted as follows;

- It was observed that sample density, which is one of the changed parameters, affects the thermal insulation in the light of the results. It was observed that the thermal conductivity coefficient of the samples produced from Acrylic and Cotton/Polyester fibers increases with the increase of density. This situation can be explained by the decrease of air gaps (porous structure) that provide insulation of the sample as the density increases. Considering that the most effective parameter is mass for sound transmission loss, it was seen that sound insulation values increase with the increase of density.

- Another changed parameter is the type of fiber used in the production of samples. The difference between the heat and sound insulation values of the samples produced from Acrylic and Cotton/Polyester fibers is insignificant. This situation gives an important advantage in the recycling of all waste textile fibers. Because, this situation provides the elimination of problems such as wasting time and energy for classifying waste textile fibers before and after being collected. Thus, it is gained the possibility of sending the waste fibers directly to production in mixed form without classifying. Therefore, the amount of recycled waste textile fibers will increase with high production speed.

- Another parameter that is changed during production is the amount of binding material. The increase in the amount of binder material in the samples produced from both fiber types did not cause a significant change in sound and heat insulation. This situation creates also the advantage that composite materials can be produced with the desired hardness and rigidity according to the areas where they will be used, without making any concession to the thermal insulation values. For example, the flexibility and softness of an insulation material to be used under the roof and/or the outer surface of the building will not be the same. But, this will not create a difficulty in terms of time and cost for the manufacturers and they will be able to produce insulation materials by only changing the binder amount without regulating the production process. In other words, if more rigid, strength, durable and harder composite panels are desired according to area, it will be sufficient to increase only the amount of binder.

- Addition of aluminum foil layers to the samples did not cause any change in terms of thermal insulation performance. In innovative works to be carried out for the development of composite material, electromagnetic shielding property can be provided to the material without making any concession to heat insulation by placing metal surfaces. It is also observed that the use of foil layers causes an increase in the sound transmission loss values, and the foil placement affects the sound insulation.

In the study, all of the composite panels produced by using a high rate of waste textile fiber were obtained the thermal conductivity coefficients required to be "thermal insulation material" with 0.033-0.038 W/mK values. On the other hand, samples showed a good performance by reaching sound transmission loss values ranging from 21.4-32.6 dB for sound insulation. With these values, it was revealed that it is one of the most insulating materials among the composites developed by both commercial and researchers. The composite panels, which passed successfully the heat and sound insulation tests planned as the first step of the product development phase, give hope for future studies. The fact that the necessary values for the insulation material basic criterion have been achieved in the findings will enable to focus on gaining other ancillary properties in future studies. In addition, the fact that the composite panels have also odorless, absorbing moisture, being avaible for transporting and maintining first form features will help the product to become commercial by completing its certification features in the future. So further studies will be based on providing composite panels with features such as being non-flammable, durable, resistant to decay and not being home to bacteria and pests.

5. REFERENCES

1. İSTAÇ A.Ş., 2016. Integrated solid waste management, http://istac.com.tr/contents/44/cevremakaleleri_130838592910380265.pdf (2016) (Accessed 25 may 2016)
2. Kavadar, F. 2014. Recycle of wastes. graduation project. Yeni Yüzyıl University Graduate School of National and Applied Sciences, İstanbul.
3. Bozkurt, Y. 1983, The problem and evaluation opportunities of wastes in the textile sector, Nature'83. *II. National Environmental Engineering Symposium*, İzmir, 1-5 June.
4. Bridgewater, A., Mumford, C. 1980. Waste recycling and pollution control handbook, *Van Nostr and Reinhol Company*, U.S.A.
5. Waste Statistics, 2011. http://www.tuik.gov.tr/VeriBilgi.do?tb_id=10&ust_id=3

6. Textile Recovery, 2021, https://recycle.com/whats-new/textile-recovery/ (Accessed 01 March 2021)

7. İlker, F. 2013. Economic analysis of effect on energy saving of thermal insulation and thermal insulation applications at buildings in Erzincan province. Master Thesis. Atatürk University Graduate School of National and Applied Sciences, Erzurum.

8. Özel, M. 2008. Dynamic approach and cost analysis for optimum insulation thicknesses of the building external walls. *J. Fac. Eng. Arch. Gazi Univ.* 23 (4), 879-884.

9. Sound Insulation, 2016. http://www.ode.com.tr/ses-yalitimi/ (Accessed 23 February 2016)

10. Eken, M., 2012. The use of waste materials in the production of insulation material. Master Thesis. Kahramanmaraş Sütçü İmam University Graduate School of National and Applied Sciences, Kahramanmaraş.

11. Binici, H., Aksoğan, O., Gemci, R., 2008. Insulation properties of light construction materials made with cotton and textile ash wastes as admixtures. *Çukurova University Journal of The Faculty of Engineerıng and Architecture*, 23(2), 15-23.

12. Binici, H., Gemci, R., Küçükönder, A., Solak, H.H. 2012. Thermal conductivity, sound insulation and radiation transmission of cotton waste, fly ash and barite reinforced chipboards. *Electronic Journal of Construction Technologies,* 8(1), 16-25.

13. Turak, B. 2013. Investigation of thermal insulation composite materials obtained from textile waste. Master Thesis. Süleyman Demirel University Graduate School of National and Applied Sciences, Isparta.

14. Tayyar, A.E., Üstün Çetin, S. 2012. Thermal properties of nonwoven fabrics produced from r-pet fibers. *I. National Recycling Congress and Exhibition Proceedings Book,* 23-30.

15. Celep, G., Yüksekkaya, M.A. 2012. An ınvestigation on thermal comfort properties of the blankets produced from recycled fibers and original fibers. *I. National Recycling Congress and Exhibition Proceedings Book*. 157-162.

16. Yachmenev, V., Negulescu, I., Yan, C. 2006. Thermal insulation properties of cellulosic-based nonwoven composites. *Journal of Industrial Textiles*, 36(1), 73-86.

17. Huang, C.H., Lin, J.H., Chuang, Y.C., 2014. Manufacturing process and property evaluation of sound-absorbing and thermal-insulating polyesterfiber/polypropylene/thermoplastic polyurethane composite board, *Journal of Industrial Textiles*, 43(4), 627-640.

18. Horga, G., Horga, M., Hossu, I., Avram, I. 2013. Investigation on determining the coefficient of thermal conductivity to textile materials recoverable, used for thermal protection of hot pipelines, *Journal of Textile and Apparel*, 23(2), 94-100.

19. Lin, J.-H., Li, T.-T., Lou, C.-W. 2014. Puncture-resisting, sound-absorbing and thermal-insulating properties of polypropylene-selvages reinforced composite nonwovens. *Journal of Industrial Textiles*, 45(6), 1477–1489.

20. Ricciardi, P., Belloni, E., Cotana, F. 2014. Innovative panels with recycled materials: thermal and acoustic performance and life cycle assessment. *Applied Energy.* 134, 150-162.

21. Moretti, E., Belloni, E., Agosti, F. 2016. Innovative mineral fiber insulation panels for buildings. *Thermal and acoustic characterization. Applied Energy*, 169, 421-432.

22. Rubino, C., Aracil, M.B., Paya, J.G., Luizzi, S., Stefanizzi, P., Canto, M.Z. and Martelotta, F. 2019. Composite eco-friendly sound absorbing materials made of recycled textile waste and biopolymers. *Materials.* 12, 4020.

23. Yachmenev, V. G., Parikh, D. V., & Calamari, T. A. 2002. Thermal insulation properties of biodegradable, cellulosic-based nonwoven composites for automotive application. *Journal of Industrial Textiles*, 31(4), 283–296.

24. Bourguiba, A., Touati, K., Sebaibi, N., Boutouil, M., & Khadraoui, F. (2020). Recycled duvets for building thermal insulation. *Journal of Building Engineering*, 31, 101378.

25. Drochytka, R., Dvorakova, M., Hodna, J. 2017. Performance evaluation and research of alternative thermal insulation based on waste polyester fibers. *Procedia Eng*. 195, 236–243.

26. El Wazna, M., El Fatihi, M., El Bouari, A., Cherkaoui, O. 2017. Thermo physical characterization of sustainable insulation materials made from textile waste. *J. Build. Eng.* 12, 196–201.

27. Patnaik, A., Mvubu, M., Muniyasamy, S., Botha, A., Anandjiwala, R.D. 2015. Thermal and sound insulation materials from waste wool and recycled polyester fibers and their biodegradation studies. *Energy Build*. 92, 161–169.

28. Hassanin, A. H., Candan, Z., Demirkir, C., & Hamouda, T. 2016. Thermal insulation properties of hybrid textile reinforced biocomposites from food packaging waste. *Journal of Industrial Textiles*, 47(6), 1024–1037.

29. Dissanayake, D. G. K., Weerasinghe, D. U., Wijesinghe, K. A. P., & Kalpage, K. M. D. M. P. 2018. Developing a compression moulded thermal insulation panel using postindustrial textile waste. *Waste Management*, 79, 356–361.

30. Innotherm, 2019. Product information. http://www.inno-therm.com/product-information/ (Accessed 22 March 2019)

31. Binici, H., Eken, M., Dolaz, M., Aksogan, O., Kara, M. 2014. An environmentally friendly thermal insulation material from sunflower stalk, textile waste and stubble fibres. *Constr. Build. Mater*, 51, 24–33.

32. Wazna, M.E., Gounni, A., Bouari, A.E., Alami, M.E., Cherkaoui, O. 2018. Development, characterization and thermal performance of insulating nonwoven fabrics made from textile waste. *J. Ind. Text.* 48, 1167–1183.

33. Al-Homoud, M.S. 2005. Performance characteristics and practical applications of common building thermal insulation materials. *Build. Environ,* 40, 353–366.

34. Pennacchio, R., Savio, L., Bosia, D., Thiebat, F., Piccablotto, G., Patrucco, A., Fantucci, S. 2017. Fitness: sheep-wool and hemp sustainable insulation panels. *Energy Procedia* 111, 287–297.

35. Zou, N.Y. 2008. Thermal insulation materials for Wall and Roof. Chemical Industry Publish House, Beijing.

36. Akıncı, H. 2007. Today's thermal insulation materials applied, their properties, application techiques and cost analysts. Master Thesis. Sakarya University Graduate School of National and Applied Sciences, Sakarya.

37. Phone Star Catalouge. 2021. https://doczz.biz.tr/doc/295399/phonestar---proaktif (Accessed 10.05.2021)

38. Panetti Catalogue. 2021. https://www.panetti.com.tr/wp-content/uploads/2020/08/E-KATALOG_2020.pdf (Accessed 10.05.2021)

39. Arunkumar M.P. et al. 2016. Sound radiation and transmission loss characteristics of a honeycomb sandwich panel with composite facings: Effect of inherent material damping. *Journal of Sound and Vibration*, http: //dx.doi.org/10.1016/j.jsv.2016.07.028

40. Dönmez, E. T., 2017. Obtaining surfaces providing electromagnetic shielding, thermal and sound insulation by using textile wastes which are not recycled. Uşak University Graduate School of National and Applied Sciences, Uşak.