(REFEREED RESEARCH)

INVESTIGATION OF THE EFFECTS OF PUMICE STONE POWDER AND POLYACRYLIC ESTER BASED MATERIAL ON THERMAL INSULATION OF POLYPROPYLENE FABRICS

POLİPROPİLEN KUMAŞLARIN ISI İZOLASYONU ÜZERİNE PONZA TAŞI TOZU VE POLİAKRİLİK ESTER ETKİSİNİN İNCELENMESİ

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ABSTRACT

This study has aimed at the development of thermal insulation and adhesion properties of polypropylene (PP) fabric. The texture PP weft yarn, the texture weft yarn produced from hollow PP fiber and the nonwoven produced from PP fiber were used as three different raw materials, each of which was one-side coated with the mixture containing polyurethane and pumice stone powder with different concentrations in order to improve thermal insulation properties. Then the other sides of these fabrics were coated with polyacrylic ester based material so as to improve adhesion behavior of the fabrics. Finally, heat transfer coefficients of each fabric were analyzed in accordance with fabric type, concentration of pumice stone powder and polyacrylic ester based material along with adhesion properties. The results demonstrated that the increase in the concentration of pumice stone powder and the use of polyacrylic ester based material caused the decrease in the thermal conductivity coefficients. In addition, the use of polyacrylic ester based material brought in adhesion properties to fabrics in order for the ability to adhere these fabrics onto any surface.

Key Words: Adhesion, Coating, Thermal insulation, Pumice stone, Polypropylene.

ÖZET

Bu çalışmada polipropilen(PP) kumaşların ısı izolasyonu ve adhezyon özelliklerinin geliştirilmesi amaçlanmıştır. Çalışmada, tekstüre PP atkı iplikten, içi boş PP elyaftan elde edilmiş tekstüre atkı iplikten ve PP elyaftan elde edilmiş dokusuz yüzey kumaş olmak üzere üç farklı PP kumaş kullanılmış, her kumaşın ısı izolasyonu özelliklerini geliştirmek için kumaşların bir yüzü farklı konsantrasyonlarda ponza taşı tozu içeren poliüretan bazlı materyal ile kaplanmıştır. Ardından kumaşların diğer yüzeyleri kumaşlara adhezyon özellik kazandırmak amacı ile poliakrilik ester bazlı madde ile kaplanmıştır. Kumaşların ısı iletim katsayılarına kumaş türünün, ponza taşı konsantrasyonun ve poliakrilik ester bazlı yapının etkisi ayrıca poliakrilik ester bazlı yapının kumaşların adhezyon özelliklerine etkisi incelenmiştir. Sonuçlar ponza taşı konsantrasyonu artışının ve poliakrilik esterin kullanımının numunelerin ısı iletim katsayılarının azalmasına neden olduğunu göstermektedir. Ayrıca poliakrilik ester bazlı yapının kullanımı, kumaşlara her yüzeye karşı adhezyon özellik kazandırmıştır.

Anahtar Kelimeler: Adhezyon, **K**aplama, Termal izolasyon, Ponza taşı, Polipropilen.

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1. INTRODUCTION

The use of thermal insulation materials is considered as one of the most effective means of minimizing the loss of heat energy (1). The major thermal insulation material is deemed as glass fiber as its heat transfer coefficient is considerably low compared to the other insulation materials. However, the use of this material significantly has diminished inasmuch as causing cancer and emphysema (2). Given their impacts on human health and environment, the use of the insulation materials with low thermal conductivity coefficients such as coconut, durian, particleboards, tissue paper manufacturing, corn peel, cotton stalk fibers, narrow-leaved cattail, corn cob, banana fibers, molded results in the preference of extruded polystyrene, polyurethane board, perlite, rock wool, eutectic organics, expanded graphite decanol and tetrahydroxy components are investigated (3-16). The porous materials with low thermal conductivity with quite a few numbers of air gaps such as pozzolana, suspend silicone, mezzo-porous silicone and silicone nano crystalline (17-20) are one of the most significant groups to provide thermal insulation.

In this study, the thermal conductivity coefficients of PP fabrics with dissimilar properties were investigated. In order to decrease thermal conductivity of different constructions, one side of fabrics were coated with polyurethane along with pumice stone powder. However, one should note that polyurethane was included in all of the samples, some of which also included pumice stone so as to investigate how pumice stone affected thermal conductivity coefficient. Pumice stone, as being a porous igneous volcanic rock, has micro porous structure and low thermal conductivity coefficient (0.08-0.12 W/m K) (22). In order to improve the adhesion of these materials prepared, the other side of each fabric was coated with polyacrylic ester based material which was inspired from gecko lizard so as to bring in adhesion properties to any surface. Finally the effect of the fabric type, concentration of pumice stone and polyacrylic ester based coating on thermal conductivity coefficient was investigated. Besides, the adhesion properties of samples were investigated. The aim of this study is the production of the fabric with thermal insulation and adhesion properties in order for widespread use in buildings. Although pumice stone powder and polyacrylic ester based material were used for different purposes, using them in a coordinative manner made significant contribution to thermal insulation properties of samples, serving the above-mentioned aim of this study.

2. MATERIALS AND METHODS

2.1. Fabrics

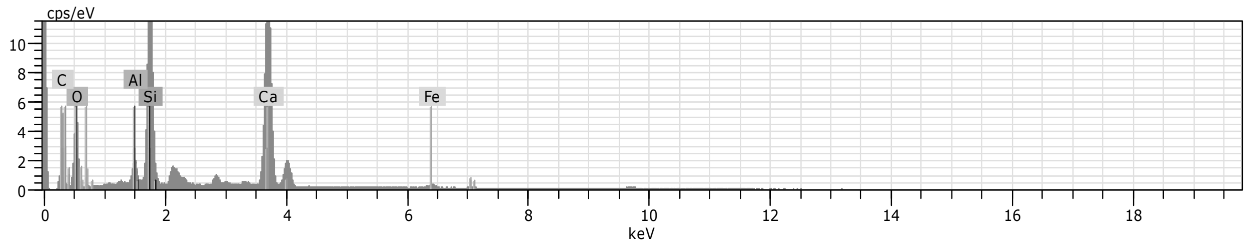
Thermal conductivity coefficients of the texture PP weft yarn, the texture weft yarn produced from hollow PP fiber and the nonwoven produced from PP fiber were investigated. The reason of using textured yarn, hollow fiber and nonwoven was that these materials had more air gaps within their structure, which, in turn, reduced heat transfer coefficients inasmuch as having low thermal conductivity coefficients (0.026 W/m K) (21). The properties of raw materials are given in Table 1.

2.2. Pumice stone

First, pumice stone was grinded by using a bead mill (Liya Lab. Machine C0042) and pulverized pumice stone was passed through the sieve with the pore size of 250 µm. Second, the chemical and physical structure of this material was analyzed with scanning electron microscope (SEM) and energy disperse X-ray spectroscopy (EDX) by using ZEISS/EVO 40 electron microscope. The chemical composition of pumice stone used in this investigation was evaluated by EDX. Figure 1 shows the chemical structure of pumice stone.

Table 1. The properties of raw materials

Sample code	Construction	Linear density weft (denier)	Linear density warp (denier)	Warp yarn density (threads/cm)	Weft yarn density (threads/cm)	Weight of fabrics (g/m^2)	Thickness (mm)
NW PP	Nonwoven	-	-	-	-	438	2.5
TPP	Plain weave	1100	2200	6	8	288	0.7
HTPP	Plain weave	1100	2000	6	10	358	0.9



HV:20.0kV Puls th.:7.37kcps

El	AN	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error [%]
O	8	K-series	43.58	54.20	68.52	5.4
Ca	20	K-series	21.31	26.50	13.38	0.6
Si	14	K-series	9.58	11.91	8.58	0.4
C	6	K-series	3.85	4.79	8.07	0.7
Al	13	K-series	1.07	1.33	0.99	0.1
Fe	26	K-series	1.02	1.27	0.46	0.1
		Total:	80.40	100.00	100.00	

Figure 1. Chemical structure of pumice stone The pumice stone contains 54.29% oxygen, 26.50% calcium, 11.91% silicium, 4.79% carbon, 1.33% aluminum and 1.27% iron.

2.3. Coating paste

In order to apply pumice stone powder to PP fabrics, polyurethane based coating material was used as linking agent and in order to prepare coating paste, RUCO-COAT PU 1110 (Rudolf Duraner), RUCO-COAT FX 8011 (Rudolf Duraner) and RUCO-COAT TH 821 (Rudolf Duraner) were mixed. RUCO-COAT PU 1110 is water based and aliphatic polyether polyurethane dispersion in anionic form. RUCO-COAT FX 8011 is blocked isocyanate cross-linking agent in anionic form. RUCO-COAT TH 821 is synthetic thickener and acrylate based in anionic structure. The coating chemicals were purchased from Rudolf Duraner Incorporated Company, headquartered in Bursa, Turkey, (hereinafter referred to as “Rudolf Duraner Inc.”). The chemical structure of polyurethane is given in Figure 2.

Polyurethane dispersion and cross linking agent were used in the ratio of 19:1. Then pumice stone powder was added to the paste prepared at the rate of 0%, 5% and 15%, respectively, which was based on the weight of the paste.

2.4. Coating paste to obtain gecko effect

Adhesion characteristic was gained to fabrics by using RUCO COAT AC 2510 water based, polyacrylic ester dispersion based in anionic-nonionic form purchased from Rudolf Duraner Inc. The chemical structure of polyacrylic ester was denoted Figure 3.

2.5. Coating

The properties of the fabrics following coating process were shown in Table 2. One side of the fabrics was coated with the mixture of polyurethane based material and pumice stone powder by using knife over roller laboratory machine (ATAC Lab. Machines RKL40). Then drying process was conducted by laboratory type stenter drier (ATAC Lab. Machines GK40E) at 110 ^{o}C for 10 minutes. The amount of the coated part per square meter was approximately measured as 275 g. The other side of the fabrics was coated with the polyacrylic ester based material in order to provide adhesion characteristic by laboratory type coating machine (ATAC Lab. Machines RKL40). The amount of the gecko coated part per square meter was measured about 245 g. After coating process, the surface was cured in the laboratory type stenter drier (ATAC Lab. Machines GK40E) at 110^{o}C for 7 minutes. As mentioned above, compared to the set of samples in which polyacrylic ester was not used, the set in which polyacrylic ester was used was not necessarily illustrated in table. Instead, the letter “G” was added to the end of sample codes above.

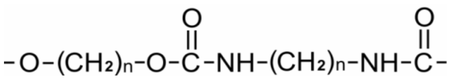


Figure 2. Chemical structure of polyurethane

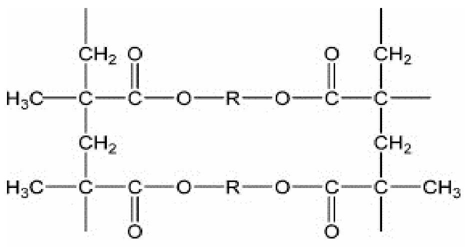


Figure 3. The chemical structure of polyacrylic ester (30)

Table 2. The property of the coated fabric

Sample code	**Properties of fabrics**	**Concentration of pumice stone (%)**
NW PP	Nonwoven polypropylene + coating paste	0
NW PP + 5% PS	Nonwoven polypropylene + coating paste + 5% pumice stone of the weight of paste	5
NW PP + 15% PS	Nonwoven polypropylene + coating paste + 15% pumice stone of the weight of paste	15
TPP	Woven from texture polypropylene weft yarn + coating paste	0
TPP + 5% PS	Woven from texture polypropylene weft yarn + coating paste + 5% pumice stone of the weight of paste	5
TPP + 15% PS	Woven from texture polypropylene weft yarn + coating paste + 15% pumice stone of the weight of paste	15
HTPP	Woven from texture yarn produced from hollow polypropylene fiber + coating paste	0
HTPP + 5% PS	Woven from texture yarn produced from hollow polypropylene fiber + coating paste + 5% pumice stone of the weight of paste	5
HTPP + 15% PS	Woven from texture yarn produced from hollow polypropylene fiber + coating paste + 15% pumice stone of the weight of paste	15

2.6. Measurement of thermal conductivity coefficient

Thermal conductivity coefficients of the samples were evaluated in accordance with TS 4512 Standard (TS 4512: Determination of Thermal Transmittance of Textiles, (1985))(31) via using P.A.HILTON LTD.H940 instrument. In order to measure thermal conductivity coefficients of the samples prepared, the samples with the diameter of 25 mm was primarily experimented. The heat value (Q) in watt was determined from the digital screen of the instrument. The measurements of the thickness and area of the tested fabrics as well as heat difference between them were replaced in the following equation (21).

$$Q = -k.A.\frac{dT}{dx} \qquad (1)$$

where Q is the heat flow (W), A is the surface field (m^2), x is the thickness of sample (m), ΔT is the temperature difference (K) and k is thermal conductivity coefficient (W/m K). The measurements of thermal conductivity coefficient were iterated three times.

3. RESULTS AND DISCUSSION

3.1. Calculation of thermal conductivity coefficients of samples

Thermal conductivity coefficients of samples were calculated in accordance with the Fourier Law. In the testing instrument, the heat flow (W) was 10 W, the surface field was $4.91.10^{-4}$ m^2 and after coating of the mixture comprising of polyurethane dispersion and pumice stone powder, the thickness of nonwoven, PP woven fabric as plain weave from texture PP weft yarn and PP woven fabrics as plain weave from texture yarn produced from hollow PP fiber were measured as 3.05±0.05 mm, 1.20±0.05 mm and 1.41±0.05 mm, respectively, by James Heal Thickness Gauge measures. After polyacrylic ester coating, thicknesses of nonwoven, PP woven fabric as plain weave from texture PP weft yarn and PP woven fabrics as plain weave from texture yarn produced from hollow PP fiber were 3.55±0.05 mm, 1.70±0.05 mm and 1.91±0.05 mm, respectively. Furthermore, measurements of thermal conductivity coefficient, density and thickness of samples at the room temperature are given in Table 3.

According to Table 3, thickness and density influence thermal conductivity coefficient of samples. Moreover, the results show that the increase in density decrease thermal conductivity coefficient. The decrease in thickness gives rise to the increase in density. The amount of fiber per square meter increases with the increase in density inasmuch as the decrease in thickness in the same area. In other words, the increase in the amount of fiber can be deemed as the increase in density, which, in turn, is considered as the decrease in thermal conductivity coefficient. In addition, the results demonstrate that the increase in pumice stone concentration causes the decrease in thermal conductivity coefficient of samples as well as in polyacrylic ester based material. Figure 4, 5, 6 and 7 shows thermal conductivity coefficients of samples coated with the mixture of polyurethane based material and pumice stone powder without polyacrylic based coating.

The results demonstrate that thermal conductivity coefficient of samples decreases with the increase in the concentration of pumice stone. This decrease can be attributed to micro pores, silicate, calcium oxide, iron oxide and aluminum oxide within pumice stone. The micro pores within pumice stone are full with the air which has lower thermal conductivity coefficient (0.026 W/m K). Therefore, the increase in the amount of pumice stone powder in samples gives rise to the increase in the amount of micro-sized air gap. The porous structure of pumice stone can be seen in Figure 8.

Table 3. Density, thickness and thermal conductivity coefficient of samples

Sample code	Thickness (mm)	Density (kg/m^3)	Thermal conductivity coefficient(W/m K)
NW PP	3.05±0.05	224±0.05	1.27
NW PP+G	3.55±0.05	256±0.05	1.18
NW PP+5%PS	3.05±0.05	224±0.05	1.245
NW PP+5%PS+G	3.55±0.05	256±0.05	1.135
NW PP+15%PS	3.05±0.05	224±0.05	1.205
NW PP+15%PS+G	3.55±0.05	256±0.05	1.115
TPP	1.20±0.05	444±0.05	0.311
TPP+G	1.70±0.05	445±0.05	0.306
TPP+5%PS	1.20±0.05	444±0.05	0.309
TPP+5%PS+G	1.70±0.05	445±0.05	0.301
TPP+15%PS	1.20±0.05	444±0.05	0.306
TPP+15%PS+G	1.70±0.05	445±0.05	0.287
HTPP	1.41±0.05	428±0.05	0.605
HTPP+G	1.91±0.05	434±0.05	0.590
HTPP+5%	1.41±0.05	428±0.05	0.555
HTPP+5%+G	1.91±0.05	434±0.05	0.547
HTPP+15%	1.41±0.05	428±0.05	0.550
HTPP+15%+G	1.91±0.05	434±0.05	0.475

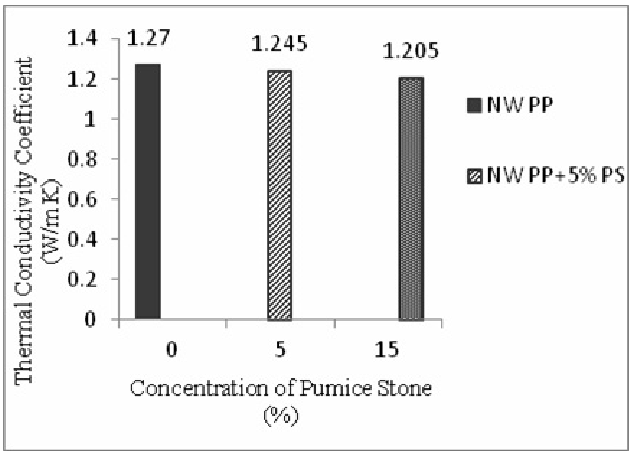


Figure 4. Thermal conductivity coefficient of nonwoven PP fabrics

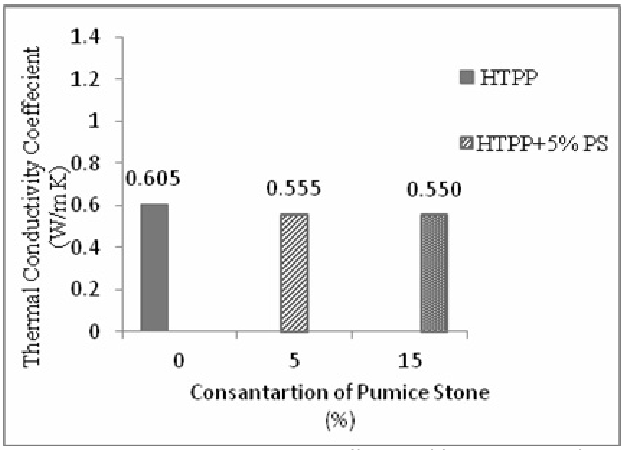


Figure 6. Thermal conductivity coefficient of fabrics woven from texture PP weft yarn produced hollow fiber

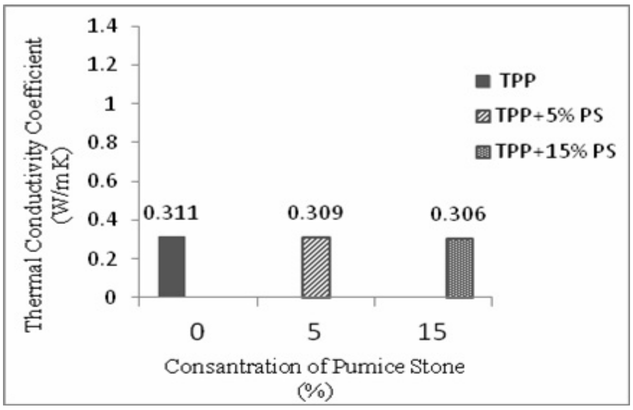


Figure 5. Thermal conductivity coefficient of fabrics woven from texture PP weft yarn

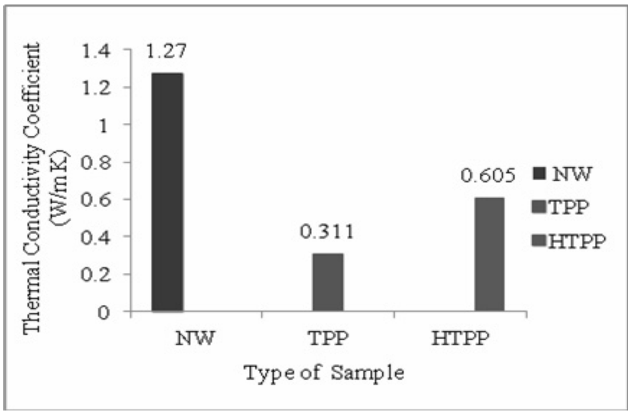


Figure 7. Thermal conductivity coefficient of fabrics in accordance with fabric type

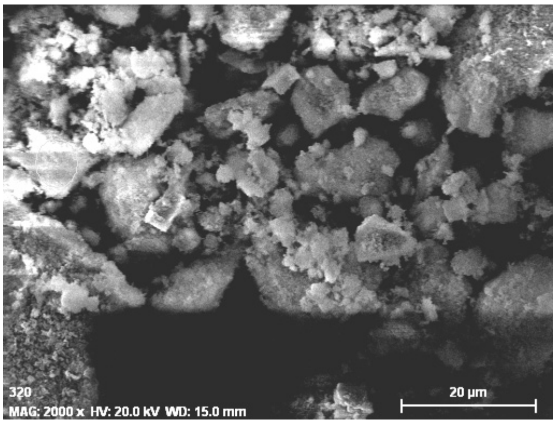


Figure 8. SEM view of pumice stone

In addition to the increase in the amount of micro-sized air gap, the increase in pumice stone in samples causes the increase in the amount of silicate with the thermal conductivity coefficient 0.212-0.405 W/m K (23). The silicate based structure of pumice stone reduces thermal conductivity coefficient of samples insomuch as having low thermal conductivity coefficient. The chemical structure of silicate refers to the reason why silicate has lower thermal conductivity coefficient.

Figure 9 shows that, thermal conductivity coefficient of the samples, each of whose one side was coated with the mixture of polyurethane dispersion and pumice stone and the other side was coated with and without polyacrylic ester, respectively, decreases with the increase in the concentration of pumice stone. The porosity and chemical structure of pumice stone causes the decrease in thermal conductivity coefficient of fabrics. In addition, the results demonstrate that polyacrylic ester based coating decreases thermal conductivity coefficients of samples, which, in turn, is likely to be attributed to atomic, molecular and chain structure of polyacrylic ester. Besides, the results in accordance with Table 3 show that density of samples increases by use of polyacrylic ester. Thermal conductivity coefficient decreases with the increase in the density of materials (24). Thermal conductivity coefficients of the insulation materials in the present and previous studies are given in Table 4.

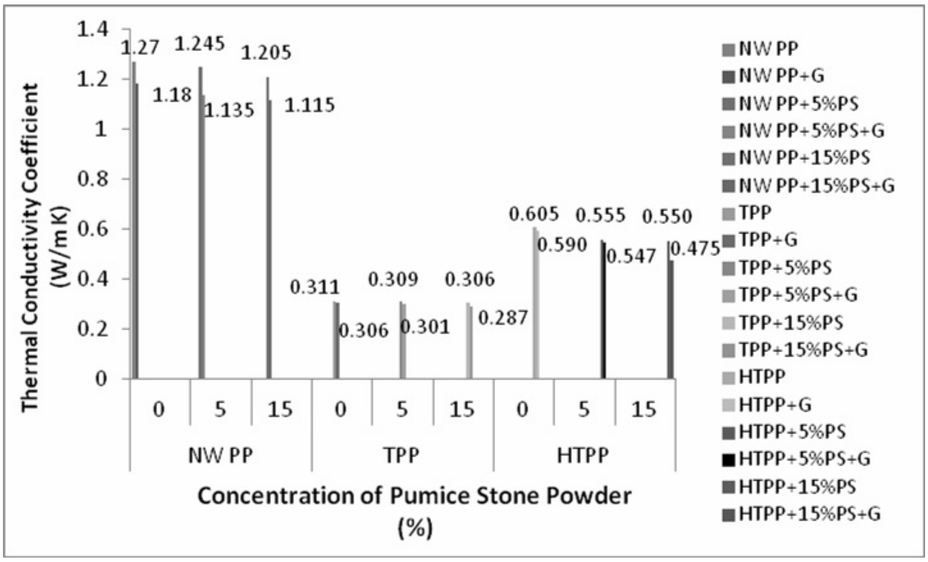


Figure 9. Thermal conductivity coefficient of the samples each of whose one side is coated with and without polyacrylic ester, respectively

Table 4. Thermal conductivity coefficients of the insulation materials under investigation

Material	Density (kg/m^3)	Thermal conductivity coefficient (W/m K) (24-29)
Molded polystyrene	19±1	0.034
Molded polystyrene	23±1	0.033
Extruded polystyrene	28±1	0.032
Extruded polystyrene	34±2	0.032
Injected polystyrene	20±2	0.034
Injected polystyrene	34±1	0.032
Polyurethane board	28±1	0.023
Polyurethane board	33±2	0.023
Lightweight concrete	551±3	0.120
Glass wool	20	0.038
Gypsum board	625	0.031
Concrete block (Pumice aggregates)	664	0.14
Fiberglass	27	0.0352
Fiberglass	47	0.0335
Fiberglass	66	0.0325
Fiberglass	84	0.0324
Rock wool	46	0.0397
Rock wool	120±1	0.037
Mineral wool	145	0.0358
Plywood	544	0.12
Polyurethane foam	32	0.0270
Perlite concrete	750	0.1380
Brick tile	1892	0.798
Cement mortar	1648	0.719
Cement plaster	1762	0.721
TPP+15%PS+G	**445±0.05**	**0.287**
TPP+15%PS	**444±0.05**	**0.306**

In this study, the comparison between the samples with the optimum thermal conductivity coefficient and the former samples whose thermal conductivity coefficients were investigated indicates that, thermal conductivity coefficients of the former were found at intermediate levels. Thermal conductivity coefficient of materials not only depends on density, temperature and moisture of materials but also depends on the material atomic, macro molecular and chain structure as well as arrangement of molecular chain of fiber.

3.2. Analyze of adhesion properties

In order to determine adhesion behavior of the samples, a testing apparatus was prepared. The samples were prepared in the area of 100 cm^2 to evaluate adhesion properties. Then these samples were adhered onto the wall after 2.5 kg mass were hanged for 60 minutes, at the relative humidity of 65±2% and at the temperature of 20±2^oC. In conclusion, all the fabrics still maintained their adhesive position on the wall.

4. CONCLUSION

Along with the increase in energy prices and demand for energy, the use of thermal insulation became inextricable and more widespread in building construction. Furthermore, thermal insulation materials have been employed so as to decrease heat loss, considering high energy costs. In this regard, upon research of the literature regarding the application of thermal insulation, texture PP yarn, hollow PP fiber and PP nonwoven fabric were chosen as the optimum raw materials. Subsequently, the fabrics were used along with the mixture of PU based material and pumice stone powder to enhance thermal insulation properties. Consequently, the samples were coated with polyacrylic ester based material to further adhesion properties, after which thermal conductivity coefficients of samples were analyzed. The results demonstrate that the use of pumice stone powder decreases thermal conductivity coefficients of samples due to the structure of silicate and its micro pores. The increase in the amount of pumice stone was observed to give rise to the decrease in thermal conductivity coefficient. In particular, thermal conductivity coefficient is higher on the nonwoven sample which does not include pumice stone powder. Moreover, density of the fabrics also affects thermal conductivity coefficient. After coating with polyacrylic ester based material, thermal conductivity coefficients of the samples decrease, which, in turn, indicates that the use of polyacrylic ester increases density of samples. In addition, the chemical structure of polyacrylic ester decreases thermal conductivity coefficient. In particular, polyacrylic ester based coating provides all kinds of fabrics with the property of adhesion onto walls, reducing significantly heat loss. The coordinative used of pumice stone powder and polyacrylic ester based material on samples, each of which served for different aims, jointly achieved thermal insulation. In conclusion, the fabrics produced can be employed in buildings, reducing the heat transfer out of buildings and having the ability to adhere onto walls.

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