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Investigation of the effects of perlite additive on some comfort and acoustical properties of polyester fabrics

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ABSTRACT: Natural perlite material was added for the first time into a polyester filament yarn structure. The water absorption and heat and sound insulation properties of the fabrics produced from textured and twisted polyester yarns containing 1.25% perlite additive were tested, and the results were compared with those obtained on the fabrics produced from reference polyester yarns. Although there are differences between the mechanical properties of the polyester yarns, the yarns including perlite remained within commercial usage limits. The thermal resistance values of polyester sateen fabrics obtained from perlite-containing yarns were higher than those of the reference fabrics. The contribution of perlite led to a marked improvement, especially in the hydrophilicity and sound insulation of the polyester fabrics. © 2016 Wiley Periodicals, Inc. J. Appl. Polym. Sci. **2016**, *133*, 43128.

KEYWORDS: fibers; polyesters; properties and characterization; textiles; thermal properties

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INTRODUCTION

Polyester fibers have essential importance in the textile industry, from all types of garments to furnishing and technical textiles. The reasons for preferring the use of polyester fibers in textile materials include their low cost, easy processability, low density, high strength, and chemical resistance.[1–3] However, polyester fibers have a hydrophobic character that is due to their lack of polar groups, presenting disadvantages like low moisture regain, high electrostatic behavior, pilling, and soiling. To improve the physical, chemical, and performance properties of polyester fibers, various modification methods have been performed, such as changing the cross-sectional shape and blending with different additives or polymers.[4–7] The most common additive materials are inorganic nanoparticles that have a high surface-to-volume ratio. The incorporation of additive materials into a polymeric matrix can change the physical, thermal, and chemical properties, such as the strength, brightness, soil and water repellency, insulation, flame retardance, absorbency, UV resistance, and antibacterial properties of the composite product.[8,9]

In recent years, polyester composite fibers that include inorganic nanoparticles such as carbon-based materials,[4] iron,[10] titanium dioxide,[11] montmorillonite,[12] calcium silicate,[13] magnesium hydroxide,[14] and silica[15] have attracted the attention of many researchers.

Raw perlite is made of fairly small, round, glassy volcanic particles that are formed as a result of the cooling and breaking of lava, which is the acidic phase of magma. Perlite is an oxide mixture that contains approximately 70–75% SiO_2 and 12–18% Al_2O_3. Because of the significant air space (porosity) in the structure, expanded perlite is lightweight, heat and sound insulating, water adsorbent, and highly resistant to chemicals and heat. Approximately 65% of the perlite produced today is used as lightweight aggregates for insulation in the construction industry. The other portion is used as a moisture-control material in horticulture, an adsorbent material in the chemical industry, a filter material for filtering operations, a filling material for a variety of filling processes, a catalyst and corrosive material in chemical reactions, and an acoustic in the dyeing industry.[16–20] Perlite is used as a bleaching agent for effects in denim fabrics in the textile industry. The particle sizes of perlite used in many sectors without any harmful side effects to health vary depending on the usage area, and it is available in all sizes starting from 10 microns.[21,22]

In this study, which constitutes the first basis for the addition of perlite to a textile fiber structure, commercially available perlite material was procured in powder form, reduced to nanolevel dimensions, modified with a chemical agent, and added to polyester filament yarn during the melt-spinning process. After the mechanical and thermal properties of the yarns were determined, the water absorption and heat and sound insulation properties of the woven fabrics produced from polyester yarns containing perlite additive were tested and compared to those of fabrics woven with reference polyester yarns produced under

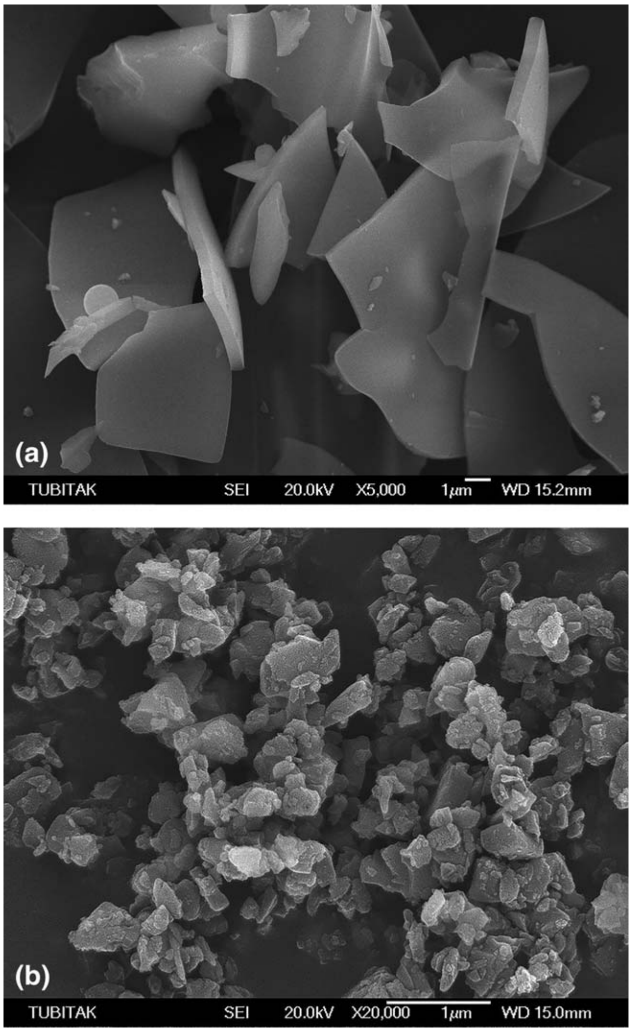

Figure 1. SEM images of (a) unmilled and (b) milled perlite material.

the same conditions. Satisfactory results were obtained in terms of the investigated properties.

EXPERIMENTAL

Materials

The expanded perlite material used in the study was provided by Genper, Inc. (İstanbul, Turkey) as a micronized powder. Polybutylene terephthalate (PBT) chips were provided by Sinochem Jiangsu Co., Ltd. (Nanjing, China), for use as a carrier polymer in the masterbatch stage. To produce the polyester filament yarns, titanium dioxide–free, dry polyethylene terephthalate (PET) chips supplied by Korteks, Inc. (Bursa, Turkey) were used.

Methods

To reduce the grain size of the micronized perlite to the nanolevel, a milling process was performed in a 1-SDM Model Laboratory Type Attritor (Union Process, Akron, Ohio). First, wet milling was applied to the perlite material, and then drying and dry remilling were applied. A surface modification process was implemented to prevent agglomeration after milling.

The size analyses of the micronized perlite before milling and the nanoperlite after milling were performed on a Microtrac S3000 Particle Size Analyzer (Microtrac, Montgomeryville, Pennsylvania) and their surface analyses were performed on a JEOL 840 model scanning electron microscope (SEM) (Jeol, Peabody, Massachusetts). The milling process reduced the average size of the perlite material from 28.4 microns to 0.4 microns. After milling, 95% of the perlite grains were smaller than 1 micron. The perlite grains that were on the micron level in thin plates before milling were crumbled and became granules on the nanolevel after milling (Figure 1).

For mixing with PET chips in the extruder, the milled and modified perlite material was transformed to masterbatch granules. Masterbatch production was carried out on a Leistritz 44 L/D masterbatch machine with twin screws so that it would contain 25% perlite using PBT as the carrier polymer (Leistritz, Nuernberg, Germany).

The perlite masterbatches were dosed at a ratio of 5% in the extruder of a Spinboy II-CC Melt Spinning Unit by Korteks, Inc. to mix with the PET chips, and polyester filament yarn production was carried out. FDY polyester yarns of 150 denier and 36 filaments with circular cross sections, containing 1.25% perlite, were produced. Half of the produced yarns were subjected to a texturing process, and the other half were subjected to a twisting process at 350 tpm. To see the effect of the perlite additive, reference textured and twisted polyester FDY yarns without perlite were produced using the same production parameters.

To compare the perlite-containing and reference yarns, tensile tests on a Statimat according to DIN EN ISO 2062 and a differential scanning calorimetry (DSC) thermal analysis on a Mettler

Table I. Fabric Construction Properties and Codes

Fabric code	Yarn type	Fabric pattern	Warp density (cm^{-1})	Weft density (cm^{-1})
RWP	Reference twisted yarn	Plain	60	22
PWP	Perlite containing twisted yarn	Plain	60	22
RXP	Reference textured yarn	Plain	60	22
PXP	Perlite containing textured yarn	Plain	60	22
RWS	Reference twisted yarn	Sateen	60	25
PWS	Perlite containing twisted yarn	Sateen	60	25
RXS	Reference textured yarn	Sateen	60	25
PXS	Perlite containing textured yarn	Sateen	60	25

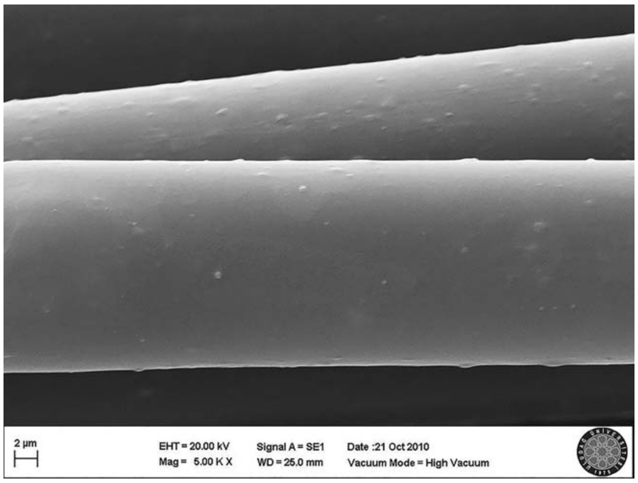

Figure 2. SEM image of perlite containing polyester filaments.

Table II. Tensile Test Results of the FDY Polyester Yarns (Mean ± Standard Deviation)

Yarn type	Breaking strength (cN/dtex)	Breaking elongation (%)
150D/36f Reference FDY PET	3.98 ± 0.06	30.64 ± 1.23
150D/36f Perlite containing FDY PET	3.16 ± 0.11	33.63 ± 1.61

Toledo DSC 823 according to ISO 11357-7 were carried out (Mettler Toledo, Greifensee, Switzerland).

Plain and sateen (1/5) woven fabrics were produced using perlite-containing and reference polyester yarns in both the warp and weft directions. Thus, four different polyester fabrics containing perlite additive and four different reference polyester fabrics were obtained with the same production parameters. The construction properties and codes of the fabrics are given in Table I.

To determine the effects of the perlite additive on the properties of the polyester fabrics, tests were conducted as detailed below for all fabrics.

Water Absorption Test. The water absorption times of the fabrics in seconds were determined according to AATCC 79-2010. The tests were repeated five times, and the results were evaluated statistically using a single-factor variance analysis on the Costat package (CoHort, Monterey, California).

Thermal Resistance Test. Thermal resistance values of the fabrics were obtained by using a Togmeter device according to ISO 5085-1; 1989 (SDL Atlas, Rock Hill, South Carolina). The tests were repeated three times, and a single-factor variance analysis using the Costat package was carried out on the results.

Sound Absorption Coefficient Measurement. The sound absorption coefficients of the fabrics were measured using a Bruel Kjaer impedance tube according to TS EN ISO 10534-2:2003 at a frequency interval of 100–6300 Hz (Bruel Kjaer, Naerum, Denmark).

RESULTS AND DISCUSSION

Properties of the Polyester Yarns

The settlement and distribution of the perlite nanoparticles in the structure of the polyester filaments are shown in the SEM image in Figure 2.

The aim of the polyester yarn production with perlite additive was the inclusion of the perlite into the filament structure at a maximum rate without significantly impairing the tensile

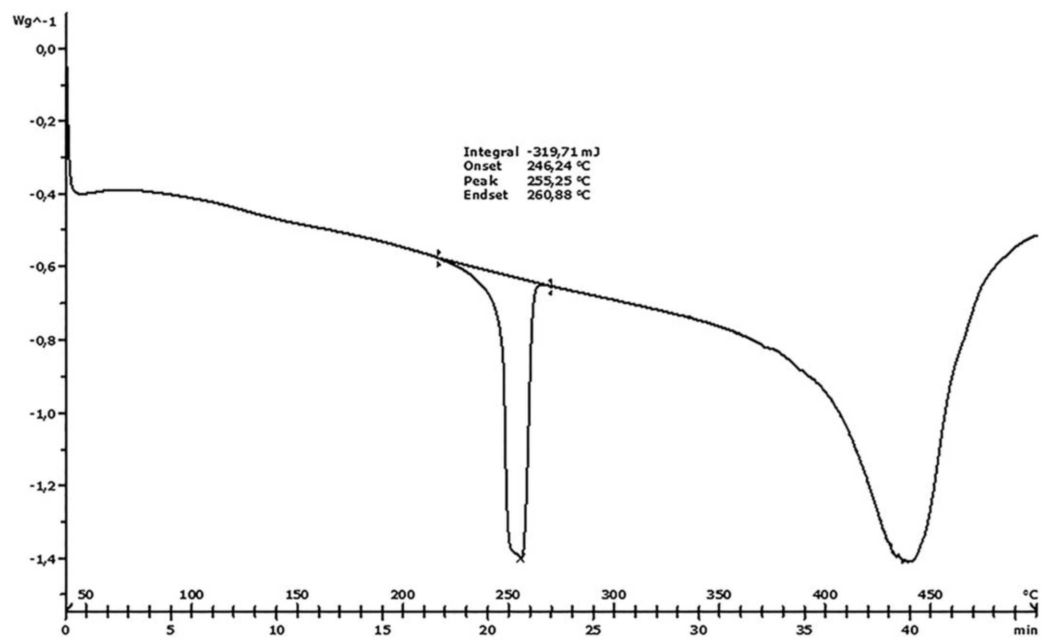

Figure 3. DSC graph of reference FDY polyester yarn.

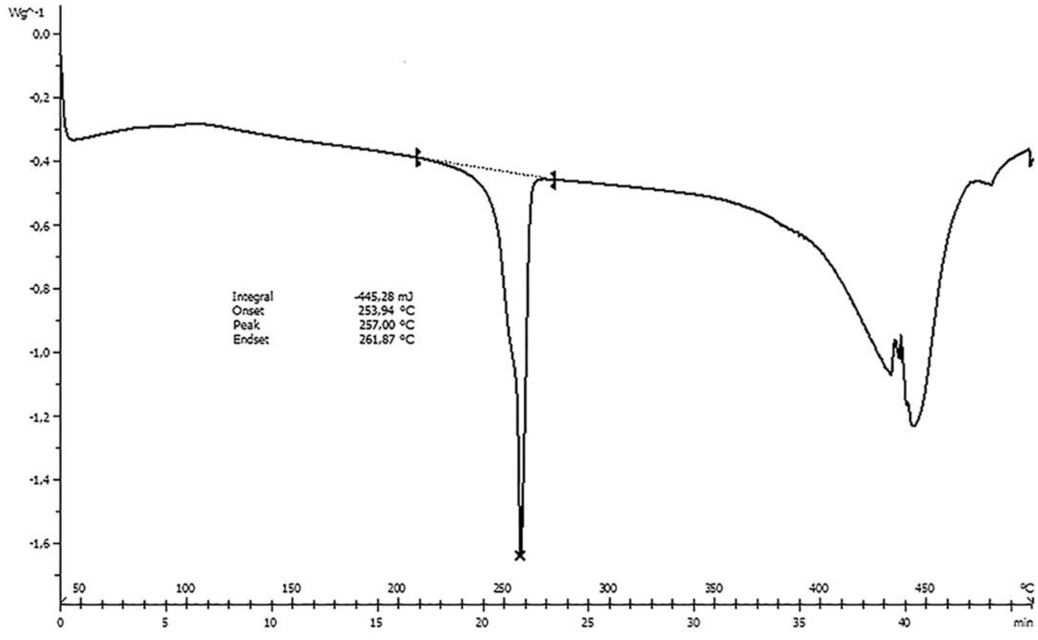

Figure 4. DSC graph of perlite containing FDY polyester yarn.

properties of the yarns. When the tensile test results given in Table II for the reference and perlite-containing FDY polyester yarns were evaluated, it could be assumed that there was no significant difference between the breaking elongation values of the polyester yarns. However, the breaking strength value of the polyester yarn including perlite decreased by approximately 20% compared to the reference yarn. It was observed in some other studies that the strength properties of nanocomposite filaments containing additives were reduced. This was attributed to the disruption of fiber structure during spinning,[23,24] to the weak interaction between additives and the polymer,[25,26] and to the formation of large agglomerates in the polymer.[27,28] A similar result was also obtained in this study. However, there is a general conviction that the minimum acceptable strength and elongation values of a commercial polyester FDY yarn are 3.0 cN/dtex and 30%, respectively. Accordingly, it could be concluded that the polyester yarns including perlite additive were suitable for commercial use.

The temperature–heat flow graphs obtained from the DSC analysis of the perlite-containing and reference FDY polyester yarns are given in Figure 3 and 4. In both DSC graphs, an endothermic melting peak belonging to the polyester was observed at approximately 255°C. While the melting began at 246°C and finished at 260°C in the DSC graph of the reference polyester yarn, in the DSC graph of the polyester yarn with perlite additive, the endothermic peak of the melting began at 254°C and finished at 262°C. The increase of 8°C for the onset point of the melting curve of the polyester yarn with perlite additive was evaluated to reflect the effect of the perlite on the melting temperature of the polyester yarn. As both types of polyester yarns were fully drawn, the exothermic peak of crystallization did not occur. It was concluded that the second peak at approximately 450°C in both graphs occurred during the pyrolysis of the PET polymer. No peak related to the perlite material, which does not degrade below 1000°C, was observed.

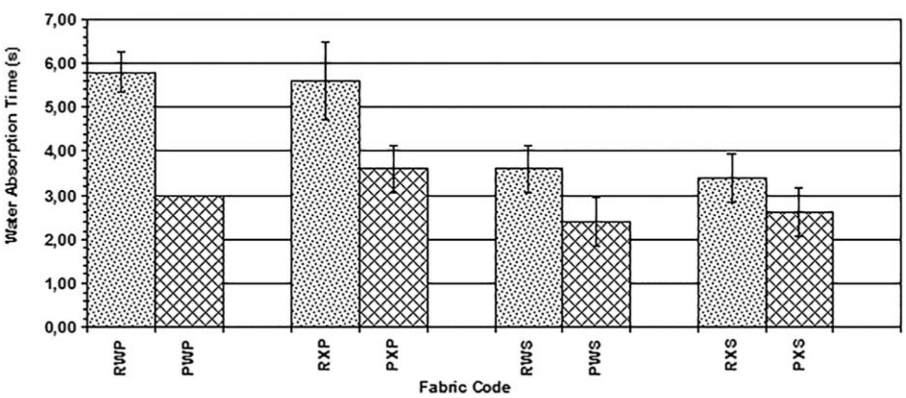

Figure 5. Water absorption test results of the fabrics.

Table III. Variance Analysis Results for Water Absorption Test

Fabric code	*F* value	*P* value	Statistical significance
RWP − PWP	196.00	0.0000	a
RXP − PXP	18.18	0.0027	a
RWS − PWS	12.00	0.0085	a
RXS − PXS	5.33	0.0497	a

[a] Statistically significant for $\alpha = 0.05$ level.

Table IV. Variance Analysis Results for Thermal Resistance Test

Fabric code	*F* value	*P* value	Statistical significance
RWP − PWP	0.18	0.6870	ns
RXP − PXP	0.11	0.7589	ns
RWS − PWS	28.52	0.0059	a
RXS − PXS	6.82	0.0593	ns

ns, not significant.
[a] Statistically significant for $\alpha = 0.05$ level.

Properties of the Polyester Fabrics

Water absorption test results of the reference fabrics and the fabrics obtained from perlite-containing yarns and the single-factor variance analysis results are given in Figure 5 and in Table III, respectively. The water absorption time of the perlite-containing fabrics decreased at a rate that reached up to 54% compared to the reference fabrics. It could be said that the perlite additive made a significant contribution to the water absorbency of the polyester fabrics. It was detected that the differences between the water absorption values of the reference fabrics and the perlite-containing fabrics were statistically significant for both plain and sateen fabrics.

The most important disadvantage of a standard polyester fabric is that it absorbs a very small amount of water (0.4–0.5%) into its structure. Although all of the construction parameters of the reference fabrics and the perlite-containing fabrics were the same, it was concluded that the decrease of the water absorption time occurred because of the high adsorption property of the perlite particles that is due to their porous structure.

The thermal resistance results for the reference fabrics and the fabrics obtained from perlite-containing yarn are given in Figure 6. The results of a single-factor variance analysis carried out to see the effect of the perlite additive are shown in Table IV. The

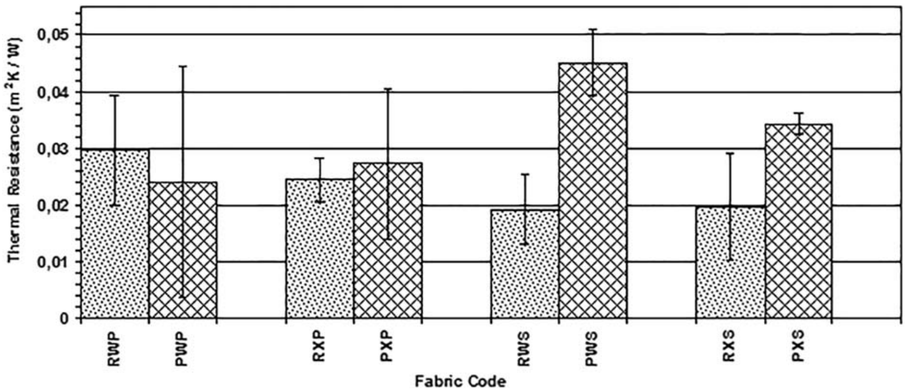

Figure 6. Thermal resistance test results of the fabrics.

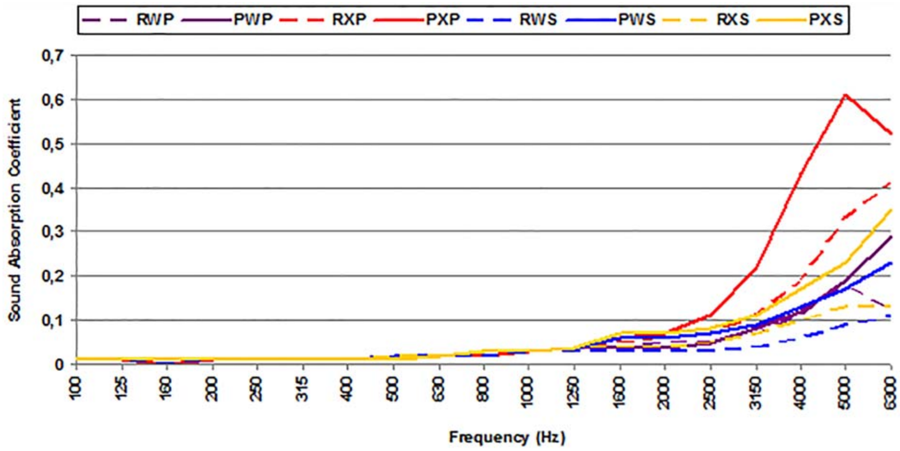

Figure 7. Sound absorption coefficient test results of the fabrics. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

thermal conductivity of a fabric is inversely proportional to its thermal resistance. Therefore, a high thermal resistance means a low thermal conductivity. When the results were analyzed, it was observed that the fabrics obtained from the perlite-containing yarns had a higher thermal resistance than the reference fabrics for sateen fabrics, while a significant correlation between the thermal resistance values was not observed for the plain fabrics. According to the statistical analysis results, the difference between the thermal resistance values of the reference and perlite-containing fabrics was significant only for sateen fabrics made from twisted yarns. The differences for the other fabric types were not statistically significant.

It was concluded that this situation resulted from variations in the fabric construction parameters. Porosity is one of the factors affecting the thermal conductivity, and enclosed pores reduce the conductivity because of the low thermal conductivity of air.[21] Although the inclusion of perlite into the yarn structure increased the total porosity of the fabric, and the porous structure of the perlite was expected to affect the thermal resistance of the polyester yarn and also the fabric, it might be said that the low ratio (1.25%) of the perlite in the yarn could not show an effect that exceeds the effect of the variations related to the fabric construction.

The sound absorption coefficient results at different frequencies are given in Figure 7. The sound absorption coefficients of all the fabrics were almost the same up to a frequency of approximately 1500 Hz. After this interval, it was observed that there were significant differences between the sound absorption coefficients of the reference and perlite-containing fabrics. Accordingly, the perlite-containing fabrics had an obviously higher sound absorption coefficient compared to the reference fabrics.

Expanded perlite is very suitable as a sound-absorbing material because of its open pore structure. When sound waves of a certain wavelength enter these pores, the pores absorb the sound energy, and therefore the sound wave that cannot exit the pore is absorbed.[19] When taking into consideration that the human hearing range is an interval of 20–20,000 Hz, it could be thought that the differences between the sound absorption coefficients in the region where the measurement was carried out from approximately 1500 Hz to 6300 Hz would have a significant reducing effect on the audible sound intensity.

CONCLUSIONS

In this study, polyester yarns and fabrics were produced by using perlite additive, and the effects of perlite on the water absorption and heat and sound insulation properties of the fabrics were investigated.

It was concluded that the breaking strength and elongation values of perlite-containing FDY polyester yarns were at a level that would not cause any commercial problems. The addition of perlite caused a small increase in the melting-onset temperature of the polyester yarns. It was observed that the water absorption time of the perlite-containing fabrics decreased significantly compared with the reference fabrics. The differences between the water absorption time values of the reference fabrics and perlite-containing fabrics were statistically significant. According to the results of the thermal resistance of the fabrics, especially for the sateen weave, the fabrics containing perlite had better thermal insulation properties. The differences between the thermal resistance values of the reference and perlite-containing fabrics were statistically significant only for sateen fabric produced from twisted yarns. It was observed that the perlite-containing fabrics had significantly higher sound absorption coefficients after 1500 Hz compared with those of the reference fabrics.

As a result, perlite material, which is used in the construction, food, pharmaceutical, and agricultural sectors because of its unique technical properties such as high thermal resistance, heat and sound insulation, resistance to chemicals, and low cost, provided improvements to some comfort and acoustical properties of polyester fabrics as an additive in the filament structure.

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