(REFEREED RESEARCH)

DEVELOPMENT OF WATER VAPOR RESISTANCE FEATURE OF POLYESTER WOVEN FABRICS BY USING PERLITE ADDITIVE

PERLİT KATKISI KULLANILARAK POLİESTER DOKUMA KUMAŞLARIN SU BUHARI DİRENCİ ÖZELLİĞİNİN GELİŞTİRİLMESİ

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ABSTRACT

The aim of this study is to improve the water vapor permeability of woven fabrics produced from polyester yarns including perlite additive. Commercial perlite material with micron size was reduced to nano size by grinding and various physical and thermal analysis were made to characterize the new material. As a result of analysis it was determined that available water adsorption feature in perlite structure was protected and even increased. Polyester yarns which were produced by melt spinning process with the addition of perlite material were used for production of woven fabrics. In order to evaluate the effect of perlite additive on water vapor permeability of the fabric, water vapor resistance test was applied to fabrics with perlite additive and to reference fabrics produced with same parameters. According to the data obtained, it was concluded that water vapor resistance of the woven fabric decreased by 22% due to perlite containing polyester yarns.

Key Words: Perlite, Polyester, Woven fabric, Water vapor resistance.

ÖZET

Bu çalışmanın amacı, perlit katkısı içeren poliester ipliklerden oluşmuş dokuma kumaşların su buharı geçirgenliği özelliğinin geliştirilmesidir. Piyasadan temin edilen miron boyutlu perlit malzemesi öğütülerek nano boyuta indirilmiş ve yeni malzemenin karakterize edilmesi için çeşitli fiziksel ve termal analizler yapılmıştır. Analizler sonucunda, perlitin yapısında var olan su adsorbsiyonu özelliğinin artarak korunduğu tespit edilmiştir. Eriyik çekim işleminde perlit malzemesi ilave edilerek üretilmiş poliester iplikler dokuma kumaş üretiminde kullanılmıştır. Perlit katkısının kumaşın su buharı geçirgenliği üzerindeki etkisini görmek amacıyla perlit katkılı ve aynı parametrelerle oluşturulmuş referans kumaşlara su buharı direnci testi uygulanmıştır. Elde edilen verilere göre, perlit katkılı poliester iplikler sayesinde dokuma kumaşın su buharı direncinin %22 oranında düştüğü sonucuna varılmıştır.

Anahtar Kelimeler: Perlit, Poliester, Dokuma kumaş, Su buharı direnci.

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1. INTRODUCTION

About 40% of the world's annual fiber consumption is polyester which has a share of approximately 75% of synthetic fibers; it also has an essential importance from all kinds of garments to furnishing and technical textiles in the textile industry. The reasons for preferring polyester fibers in textile materials can be listed as; low cost, easy processability, low density, high strength and chemical resistance. On the other hand, polyester fibers are water repellent featured hydrophobic fibers. The hydrophobic nature of fibers causes a high electrostatic behavior as well as getting greasy dirt from polluted air. Therefore, fiber needs cross sectional alteration or modification by adding various additives in polymer melt and coating onto fiber surface that will cause water absorption (1-7).

Raw perlite is fairly small, round, glassy volcanic particles which are formed as a result of cooling and breaking of lava which is acidic phase of magma. The world's total perlite reserves is 6.7 billion ton and 4.5 billion tones of this reserve (about 70%) are located in Turkey. USA, Greece and Japan are other countries rich in perlite resources. Perlite ore is produced by open mining method; by crushing, grinding, classification and releasing the contained water in vapor form at 700-1200°C, its volume expands 4-30 times which followed by conversion into a highly porous and low density expanded perlite powder (8-13).

Perlite is an oxide mixture which contains approximately 70-75% of SiO_2 and 12-18% of Al_2O_3. Due to having too much air space (porosity) in the structure, perlite shows some features such as being the light weight, heat and sound insulation, highly resistant to chemicals and heat. Porosity property and silica content of perlite cause absorption and surface adsorption features (12, 14-17).

Due to its physical and chemical characteristics of the expanded perlite, it is used as lightweight aggregates for insulation in construction industry, moisture control material in horticulture, absorbent material for metal ions and organic solvents in chemical industry, filter material for filtering operations and filling material for variety of filling processes (9, 18-20). Although perlite grain size varies depending on area of use, particle size above 15-20 microns can be obtained by conventional manufacturing methods (21).

Perlite is only used for washing and for giving effect on denim fabrics in textile field. Due to the water absorption within cavities in the structure of perlite during washing, its intensity increases and leads to a proper stoning effect (18). In addition, there are studies (22) on adsorption of dye chemicals from textile effluents.

In this paper, commercially available perlite material was provided in powder form; reduced to nano level dimensions and added to polyester filament in the form of masterbatches during melt spinning process. Water vapor resistance characteristic of woven fabrics made of these filaments were tested and compared to woven fabrics made of standard polyester filaments produced under the same conditions. The purpose was to contribute water absorbency properties of polyester fibers with nano perlite additives and to develop a new product to use in technical textiles. The study presented in this paper has a significant characteristic in terms of being the first experimental study and literature on both characterization of nano perlite and its use as an additive for fibers.

2. MATERIALS AND METHODS

2.1. Materials

Expanded micronized perlite powder material which was the smallest sized commercial product known as Perfil 0, used in this study was provided from GENPER Inc. Company (Turkey), Polyester (PET) cips used to produce PET filament was obtained from Korteks Inc. (Turkey) as a commercially available textile grade produced from poly(ethylene) terephthalate polymer. In order to see the contribution effect of perlite at the end of the study, titanium dioxide free dry chips were used.

2.2. Methods

For producing of nano perlit containing polyester multifilament yarn with the melt spinning method, in order to reduce the grain size of micronized perlit which is commercially available at least about 15-20 microns to the nano level, wet milling process at 1-SDM Model Laboratory Style Attritor was carried out under the conditions given in Table 1.

Table 1. Grinding conditions of perlite material

Operating speed	1000 rev/min
Operating media	Water bath
Heating	None
Mixer ball material	Zirconium oxide
Mixer ball size	0.4-0.6 mm
Operating time	16 hours

Milling process of micronized perlite powder for nano scale size reduction has been neither a commercial application nor an academically research, yet. Therefore, there is not any available review on the characterization of nano perlite material. The material whose grain size reduced to nano levels need to be re-characterized in order to detect the changes in physical and thermal properties of the material. For this purpose, following tests and analyzes were carried out:

1. Dimensional analysis: Determination of particle size of perlite material was carried out by Microtrac S3000 Particle Analyzer before and after the milling process.

2. Fourier transform infrared (FTIR) analysis: In order to evaluate the structural changes and the water adsorption property in perlite as a result of grinding, infrared (IR) spectrums of milled and unmilled perlite material were taken by Perkin Elmer Spectrum 100 FTIR Spectroscopy.

3. Pore size distribution analysis: In order to determine the changes in existing porosity feature of perlite thereby the adsorption capability as a result of milling process, unmilled and milled perlite pore size distribution analysis was carried out. The total pore volume and pore size data was obtained by the DFT method on Quantachrome Nova 2200E Instrument

4. Scanning electron microscope (SEM) analysis: For a better understanding of the dimensions and porous structure, both unmilled and milled perlite powders were analyzed and photographed by JEOL 840 model SEM.

5. Surface area measurement: In order to see the effect of the grinding process on perlite material, specific surface area measurements for both unmilled and milled perlite materials was done by using the BET (Brunauer, Emmmett and Teller) nitrogen (N_2) absorption technique on Quantachrome Nova 2200E Device.

6. Termogravimetric analysis (TGA): TGA studies of milled and unmilled perlite powders were carried out on Mettler Toledo Stare System TGA/SDTA 851e Device regarding to the ISO 11358 standard.

In order to ensure homogeneous dispersion of perlite into polyester polymer, perlite powder material was formed into solid granules by using masterbatch method. Masterbatch production was carried out on a laboratory scale Rondol twin-screw extruder. Poly(butylenes) terephthalate (PBT) was used as a carrier polymer and masterbatches containing 25% weight ratio of perlite was obtained.

Perlite masterbatches were dosed with a ratio of 5% in Spinboy II-CC Melt Spinning Unit and mixed with PET cips and then polyester filament production containing 1.25% perlite was performed. Trilobal cross sectional nozzle system was used to produce super bright FDY multifilament yarn with 300 denier 96 filaments. In order to see the contributional effect of perlite, FDY polyester multifilament yarn was produced as the reference yarn by using the same production parameters but without any perlite. The production parameters of fiber extrusion unit are given in Table 2.

Table 2. Production parameters of polyester yarn

Take-up speed	3450 m/min
Extruder speed	88 rpm
Pressure at extruder	100 bar
Pressure at filter	42 bar
Type of nozzle hole	Trilobal
Diameter of nozzle hole	20 micron
Draw ratio	1.6
Temperature of godets	90/135 °C

Cross sectional images of perlite containing polyester multifilament yarns and reference polyester multifilament yarns were obtained from Projectina Video Microscope and tests which standards and device information are given in Table 3 were carried out.

In order to test the contribution of perlite on water vapor resistance feature, two pieces of woven fabrics were produced, one from reference polyester yarns and the other one from perlite containing polyester yarns. In the production of woven fabrics, 75 turns/m twisted multifilament polyester yarns produced in this study and 660 turns/m twisted, 70 denier 48 filaments commercial polyester multifilament yarns with trilobal cross section were used as weft and warp yarns, respectively. Weft faced sateen (1/5) weave was preferred for weaving process. After the production, woven fabrics were fixed at 100°C in stenter machine for 60 seconds at their own width. The production parameters of the woven fabrics are given in Table 4.

Water vapor resistance tests were carried out on Sweating Guarded Hotplate test apparatus by using hot plate method and regarding to TS EN ISO 31092 standard and the test was repeated three times. In order to see the effect of perlite additive on water vapor resistance of woven fabric, data were evaluated statistically according to single factor variance analysis.

Water vapor resistance is the ratio of water vapor pressure difference between two surfaces of a material to evaporating heat flow per unit area, in the direction of the pressure variation. Its unit is m² Pa/W. Overall heat resistance of the water vapor transfer is calculated from Formula 1 (23).

$$R_{e,t} = (P_s - P_a)\ A / H \qquad (1)$$

$R_{e,t}$: Total heat resistance of vapor heat transfer provided by fabric system and air ($m^2 Pa\ W^{-1}$)

A: Plate test area (m^2)

P_s: Water vapor pressure on the plate surface (Pa)

P_a: Water vapor pressure in air (Pa)

H: Power input (W)

3. RESULTS AND DISCUSSION

3.1. Characterization Analysis Results of Perlit Material

3.1.1. Dimensional analysis results

Measured average grain size of perlite material was 28.42 micron but it was reduced to 0.47 micron after grinding in an aqueous medium. After grinding, grain size of 95% of the all material was reduced below 1 micron.

SEM images which obtained for better understanding of the size distribution of perlite additive material used for polyester yarn production have been analyzed. SEM images of unmilled and milled perlite material are given in Figure 1 and Figure 2, respectively.

As can be seen clearly in SEM images, while unmilled perlite powder was large and fine plates, it was crumbled and became dust particles in nano levels after grinding.

3.1.2. Fourier transform infrared (FTIR) analysis results

IR spectrums of unmilled and milled perlite material were given in Figure 3 and Figure 4, respectively.

Table 3. Tests applied on polyester yarns

Test name	Apparatus / Method / Standard used
Determination of yarn count	Yarn wheel / Skein Method / DIN EN ISO 2060
Determination of unevenness	Uster Tester 3 / Half-inert %
Determination of breaking elongation	Statimat / Statimat / DIN EN ISO 2062
Determination of tensile strength	Statimat / Statimat / DIN EN ISO 2062

Table 4. Production parameters of woven fabric

Parameters	Fabric with perlite additive	Reference fabric
Weft yarn	300 den / 96 f perlite containing polyester yarn	300 den / 96 f reference polyester yarn
Warp yarn	70 den / 48 f commercial polyester yarn	70 den / 48 f commercial polyester yarn
Weft density	30 yarns/cm	30 yarns/cm
Warp density	99 yarns/cm	99 yarns/cm
Fabric pattern	Weft faced sateen (1/5)	Weft faced sateen (1/5)
Fabric width	140 cm	140 cm
Fabric weight	194.64 g/m²	194.64 gr/m²

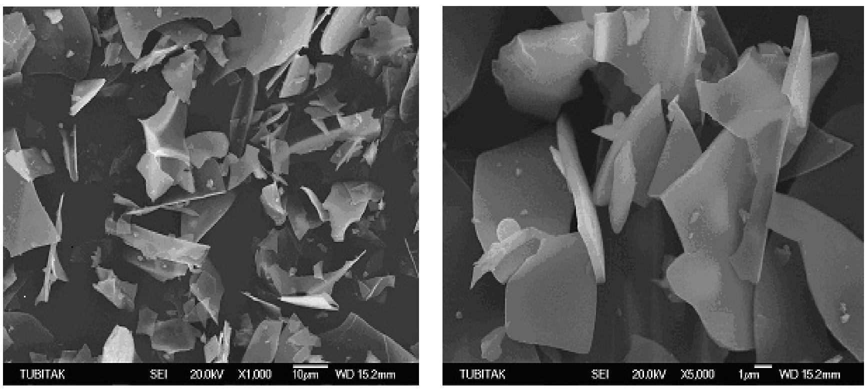


Figure 1. SEM images of unmilled perlite material

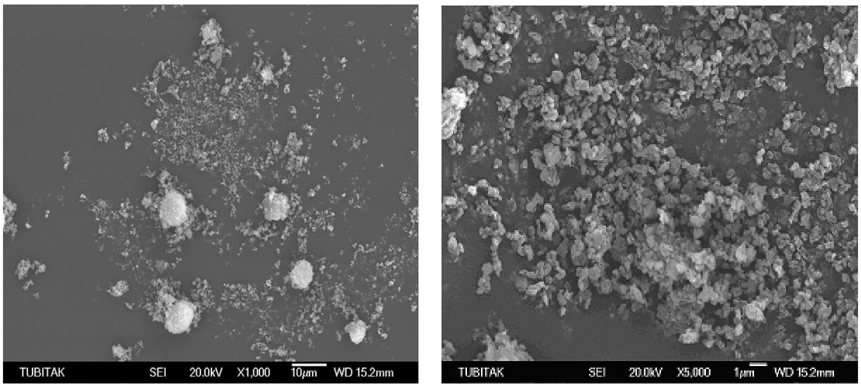


Figure 2. SEM images of milled perlite material

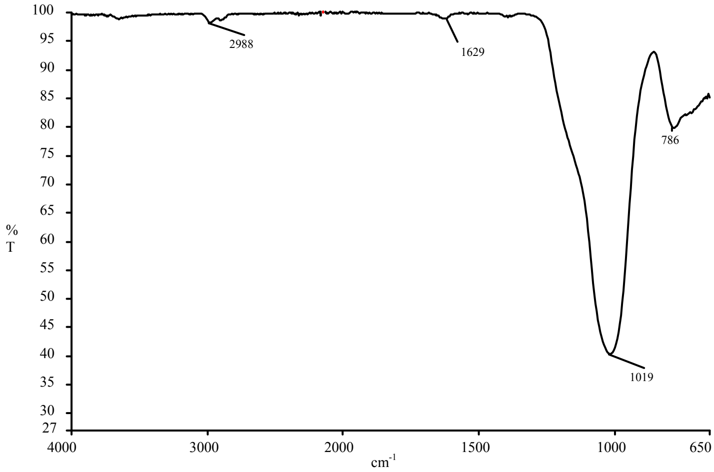


Figure 3. IR spectrum of unmilled perlite material

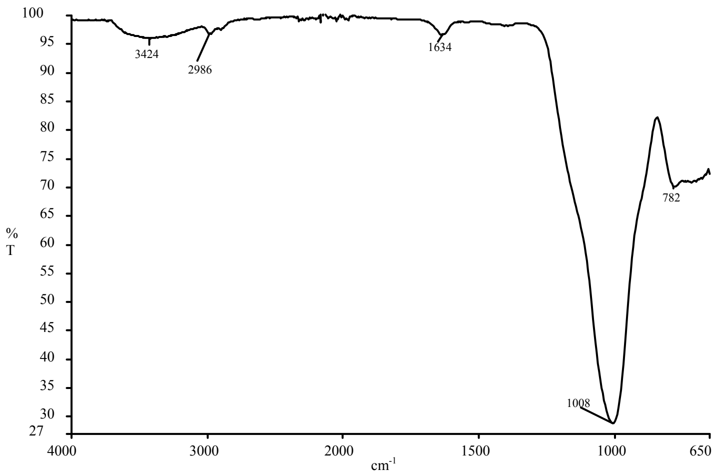


Figure 4. IR spectrum of milled perlite material

Evaluation of obtained spectrums was done by taking into account specific characteristic peaks, vibration modes and regions extrapolated from IR spectrums of perlit used for previous researches (9, 24, 25), and was carried out by using the values given in Table 5 as reference.

According to the results, the most important differences of milled perlite material when compared to the unmilled one were that the existence of the hydroxyl peak observed in adsorbed water at 3424 cm-1 wave length, the peak of physically adsorbed water content at about 1650 cm-1 wave length and intensive peak resulted of Si-O tension at 1020 cm-1 wave length. This data meant that surface of milled perlite was much polar. The more polar structure of perlite particles could be explained by the increase of the surface area after grinding.

Table 5. Vibration modes and regions of IR spectrum for perlite material

Region	Vibration mode	Specification
3000-3750 cm^{-1}	Vibration of hydrogen-bonded hydroxyl groups on surface	Wide band
3520±200 cm^{-1}	Hydroxyl group of absorbed water	Band
2900-3200 cm^{-1}	C-H stretching band	Wide band
1650 cm^{-1}	Hydroxyl bending frequency and physically adsorbed water	Peak
800-1250 cm^{-1}	Si-O vibrations	Peak
1020 cm^{-1}	Si-O tension in Si-O-Si groups	Sharp band
750-790 cm^{-1}	Si-O-Al vibrations	Band

3.1.3. Pore size distribution analysis results

The results of SEM and pore size distribution analysis that were carried out for the detection of change on porous structure of perlite and so its existing adsorption characteristic after the milling process, are given in Figure 5 and Table 6, respectively.

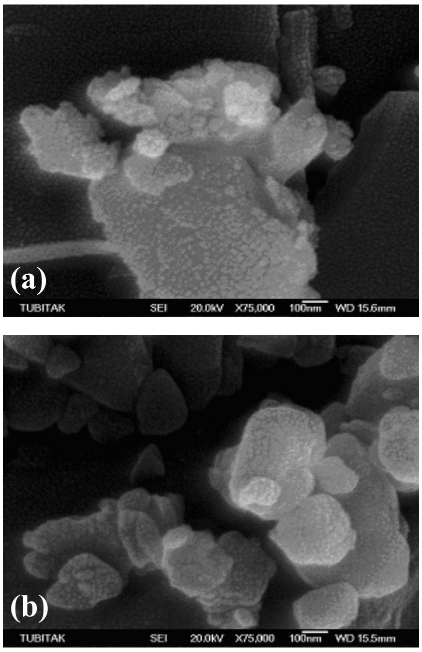


Figure 5. Porous structure of perlite material; (a) unmilled perlite, (b) milled perlite

Table 6. Analysis results of pore size distribution of perlite material

Material	Total pore volume (cc/g)	Half-width of pore (Å)
Unmilled perlit	0.015	16.576
Milled perlit	0.085	15.846

According to the data obtained, no significant change was seen in the pore width of the perlite material whose dimensions reduced by milling, but the total pore volume was increased of about 6 times. This could be expressed that the milling process which occurred among the balls in the atritor had no effect on the pore size; however the pore volume increased due to the increase in surface area which resulted by breakage of large-sized particles into smaller particles. In fact, this was a predicted result which was also confirmed by SEM images (Figure 5). The increase in pore volume was resulted an increase in the surface polarity, therefore, an increase in adsorption characteristic ascertained in FTIR analysis.

3.1.4. Surface area measurement results

While unmilled perlite material's surface area was 28.832 m^2/g, specific surface area value was obtained as 92.879 m^2/g for milled perlite material. According to this, specific surface area of milled perlite material was about 3 times higher than that of unmilled perlite material.

Pore size distribution analysis and surface area measurement results indicated an increase in water adsorption characteristic of nano perlite material.

3.1.5. Termogravimetric analysis (TGA) results

Figure 6 and Figure 7 were obtained from TGA analysis carried out for unmilled and milled perlite powders, respectively.

There was no degradation peak in TGA thermograms obtained up to 1000°C for milled and unmilled perlite powders. This was an expected result since melting temperature of perlite material is above 1000°C. However, thermogram curves showed slight differences. It was though that this was caused by the change in adsorbed moisture by perlite material after milling process.

According to TGA thermograms, while 2.30% mass reduction occurred in unmilled perlite material, it was about 8% for milled perlite material. Mass loss of milled perlite material during the test continued upto 600°C. The reason of the high mass loss of milled perlite material could be explained as high moisture content in its structure.

3.2. Physical Test Results of Polyester Yarns

Physical test results carried out for reference polyester yarn and perlites containing polyester yarn produced with the same parameters are given in Table 7.

When the obtained results were evaluated, it was seen that while unevenness and elongation values have been increased in perlite containing polyester yarns, its tenacity was decreased. Commercial FDY yarn produced in Spinboy unit should have 2.5-4.0 cN/dtex tenacity and 30-60% elongation values (26). According to these values, while obtained perlite containing polyester yarn met the commercial elongation value, its tenacity was slightly lower. Nevertheless, no problem was faced during woven fabric production.

When the cross sectional images of reference polyester yarn and perlite containing polyester yarn (Figure 8) were compared, it was seen that perlite particles were dispersed into polyester yarn.

3.3. Water Vapor Resistance Test Results of Polyester Fabrics

Water vapor resistance of fabric structure is significantly effective on wet processes applied onto fabric and thermal properties of fabric. The thermal properties of fabric are significantly effective on the end users' comfort conditions. Transportation and the removal of excess water occurring in a fabric are desirable in terms of comfort.

Water vapor resistance is the resistance of fabric against the water vapor per unit area of fabric. Fabric structure having a low numeric value presents a water vapor permeable fabric and a comfortable environment. Water vapor resistance test results of the fabrics made of perlite containing yarns and reference yarns are given in Table 8.

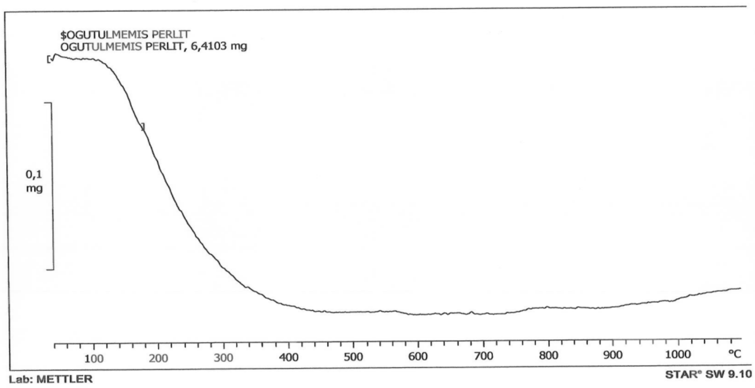


Figure 6. TGA termogram of unmilled perlite material

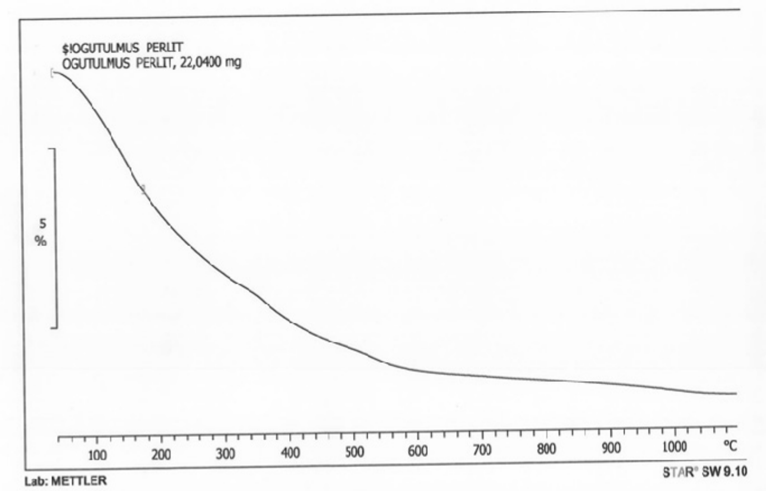
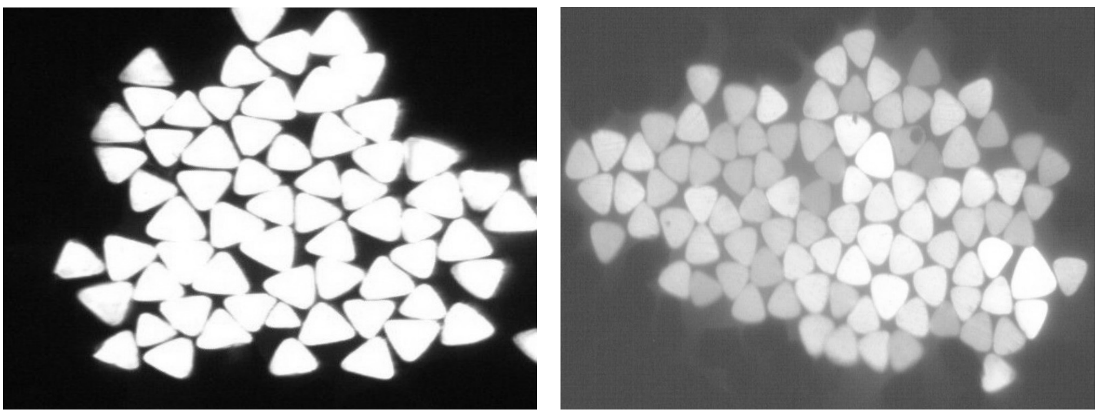


Figure 7. TGA termogram of milled perlite material

Table 7. Physical test results of polyester yarns (mean ± Standard deviation)

Property	Reference yarn	Perlite containing yarn
Count (dtex)	345	347
Unevenness (U%)	1.83 ± 0.05	2.19 ± 0.06
Elongation (%)	41.59 ± 2.67	44.50 ± 6.31
Strength (cN/dtex)	2.83 ± 0.09	2.06 ± 0.09



(a) **(b)**

Figure 8. Cross sectional images of produced polyester yarns; (a) reference polyester yarn, (b) perlite containing polyester yarn

Table 8. Water vapor resistance test results of woven fabrics (mean ± standard deviation)

Material	Water vapor resistance (m²Pa/W)
Reference fabric	3.9473 ± 0.3560
Perlite containing fabric	3.0656 ± 0.1058

According to the results, water vapor resistance of perlite containing fabric was about 22% lower than that of reference fabric and this result pointed out an important development in water vapor permeability of the fabric. Also, according to statistical analysis results performed on the data, $f_{statistical}$ and p values were 16.886 and 0.0147 respectively. Consequently, the results of water vapor resistance of perlite containing fabric and reference fabric were statistically different from each other.

When it was taken into consideration that structural parameters of reference fabric and perlite containing fabric were the same, it could be said that the decrease in the water vapor resistance occurred as a result of porous structure of highly adsorption perlite material added into polyester yarns.

4. CONCLUSIONS

In the last decade, the developments in nanomaterials and nanotechnology have influenced the modification of polymer based synthetic fibers with different characteristics. Due to having 70% of the world's reserves in Turkey, its low cost and water adsorption property which contributes hydrophobic characteristic of polyester in positive way, in this study, perlite containing polyester yarn and fabric were produced and the effect of the additive on water vapor resistance of the fabric was investigated.

Perlite material was obtained from the market in micron size then reduced to nano size and characterized. Thus, perlite particles with an average size of 28.42 micron were reduced to an average of 0.47 micron. As a result of the analysis done to re-characterize the nano perlite material, in addition to the remaining inherent porosity, it was identified that water adsorption characteristic of the material increased with 6 times increase in pore volume and 3 times increase in surface area.

In order to see the effect of perlite additive on water vapor permeability of the fabric, water vapor resistance test was performed. According to test results, the water vapor resistance of perlite containing fabric decreased by 22%. Thus, perlite containing yarns which made up the fabric, allowed water vapor passage and led to better breathable fabrics.

Through this work, it can be said that addition of perlite, which has very good handling characteristics and available in low cost, into synthetic polymer structure will contribute to the development of high value-added products.

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