

PERLITE-REINFORCED COMPOSITES BASED ON POLYETHYLENE WASTE

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Annotation

In this study, the chemical structure and functional groups of composite materials based on polyethylene waste were studied. According to the results of FTIR analysis, it was found that the intensity of the peak at a certain wave number increased with an increase in the amount of perlite, which indicates that the perlite was evenly distributed in the matrix. The mechanical properties of composites are closely related to the degree of perlite distribution. A moderate amount of perlite increases strength, but if it is too much, it is poorly dispersed and agglomerated, which leads to a decrease in mechanical properties. The addition of perlite also improves the thermal insulation properties of composites. When the temperature increases, the hardness of the materials decreases, but the perlite particles restrict movement within the matrix and strengthen it. This makes the composites stronger and more stable.

Keywords

Perlite, high-density polyethylene, composite, dispersion, thermal insulation and deformation

Introduction

Today, the recycling of plastic solid waste and its reuse as quality products is an important issue. The chemical industry is increasingly interested in the production of plastics, which is why various commercial products are being produced from plastics and consumer demand is being met. Plastic waste does not decompose easily under normal conditions and takes several decades to decompose[1;4].

Plastics are widely used in packaging films, packaging materials, shopping and garbage bags, storage containers, clothing, toys, household and industrial products, and construction materials. The main raw materials for plastic products are HDPE (high-density polyethylene)/LDPE (low-density polyethylene). Plastics

constitute a significant part of solid household waste and often consist of waste packaging and discarded appliances and goods [2].

In addition, virgin plastic material can only be recycled 2-3 times, because after each recycling, the strength of the plastic material decreases due to thermal degradation[3;5].

Nowadays, polymer matrix composites, which contain inorganic fillers as fillers in the waste PE matrix, are gaining popularity due to their good mechanical properties, heat resistance, chemical resistance properties, etc. These properties make polymer matrix composites a convenient material in various fields, including the automotive, construction, and packaging industries. Currently, inorganic fillers such as glass, CaCO₃, talc, etc. are among the widely used fillers[6].

In addition to these inorganic fillers, one filler that should not be overlooked is perlite, a glassy amorphous volcanic rock, which is also of great importance as an alternative inorganic filler in polymeric composites[7].

Table 1
Chemical and physical properties of perlite

SiO ₂ (%)	Al ₂ O ₃ (%)	K ₂ O (%)	MgO (%)	CaO (%)	Fe (%)	Pore (%)	Average particle size (mkm)	Specific surface area (m ² /g ⁻¹)
74,0	14.3	5.0	0.3	0,5	1.0	85	34.4	2.1

It should be noted that when perlite is heated to a temperature of 600-1000 °C, it can be expanded 7-16 times its original volume. Perlite has a low density and is widely used in many industries due to its low price. Perlite is used in the production and construction industries as an insulating material, especially in lightweight gypsum and mortar, insulation and tiles, while expanded perlite is used in construction and other industrial sectors. Turkey has a total of 7700 million tons of perlite reserves, which is 74% of the total perlite reserves in the world[7;8;9]. Currently, in Uzbekistan, raw materials are imported from Turkey and are processed into perlite in special kilns, which are used for various purposes in the production sector.

2. Materials and Methods

2.1 Materials

High density polyethylene (PE) waste was used as raw material in the study. The average density of the materials is around 0.950 g cm⁻³ and the melt flow index

is 0.4-0.8 g 10 min⁻¹. As perlite, we used a product recommended by the local production campaign. Perlite was dried in an oven at 100 °C for 1.5 hours to remove moisture. The average perlite particle size was measured by Malvern Mastersizer-2000. Also, the specific surface area of perlite was measured by Quantachrome Autosorb-1 equipment, and based on these, some chemical and physical properties of perlite are given in Table 1. The particle size distribution of perlite is shown in Figure 1. According to the particle size analysis, they were found to be 10.8, 34.4 and 78.1 µm, respectively.

2.2 Composite material production

A laboratory thermokinetic mixer was used to produce the composite material filled with perlite. Perlite and PE were first physically mixed and when the mixture became soft, it was mixed in a thermokinetic mixer at a speed of 2000 r/min for about 25 seconds. The weight fractions of perlite to PE were selected as 5, 10, 15, 25%.

Composite sheets were obtained from the mixture using a hydraulic hot and cold press. After heating the hot press to the processing temperature (180 °C), the produced mixtures were placed in the mold cavity (10 × 10 cm²) between the metal plates of the hot press. The samples were held at 180 °C for 60 seconds under a pressure of 40 bar. After hot pressing, the samples were pressed in a cold press for 120 s at room temperature at 120 bar.

2.3 Infrared analysis

The spectra of the PE composite samples filled with perlite were recorded in the transmission mode as a function of wavenumber.

2.4 X-ray diffraction analysis

X-ray diffraction (XRD) analysis was performed with a Bruker D2 Phaser; the X-ray diffractometer system was equipped with Ni-filtered copper K radiation ($\lambda = 1.54$ Å) and operated at 45 kV and 40 mA. The diffracted X-rays were collected by the detector between 20 - 5 ° and 80 °. The step size was taken as 0.02 °.

2.5 Scanning electron microscopy analysis

The surface of the PE composite samples filled with perlite was deposited using a plasma spray apparatus. Next, scanning electron microscopy (SEM) analyses of the perlite-filled PE composites were performed using a scanning electron microscope (FEI Quanta FEG 250, Thermo Fischer Scientific, UK) operating at 4 kV.

2.6 Thermal conductivity measurements

The thermal conductivity of PE and its composites was measured at 25 °C using a C-Therm TCi thermal conductivity analyzer (C-Therm Technologies, Canada).

2.7 Dynamic mechanical analysis

The storage modulus of PE waste and its composites were evaluated using a DMA Q800 (TA Instruments Inc., New Castle). A single cantilever and multi-frequency tension module mode were selected to test all samples at temperatures ranging from 25 to 130 °C.

2.8 Mechanical analysis

Tensile test specimens with a thickness of 2 mm were obtained using a plate-cutting die according to ASTM D638. A SHIMAD AGT-X 8kN tensile testing machine (Shimadzu Corp.) was used for the perlite-filled PE composites at room temperature at a shear rate of 50 mm min⁻¹. Six specimens were tested for each composite formulation to obtain reliable average tensile properties and their corresponding standard deviations.

The flexural modulus and flexural strength of the specimens were tested on a SHIMAD AGT-X 8kN according to DIN 178, which includes a three-point bending test at a shear rate of 1 mm min⁻¹. The size of the specimens was 25 × 40 mm².

3. Results and discussions

3.1 FTIR (Fourier Transform Infrared Spectroscopy) Analysis

FTIR was performed to determine the functional groups and chemical modifications of the PE waste-based composite.

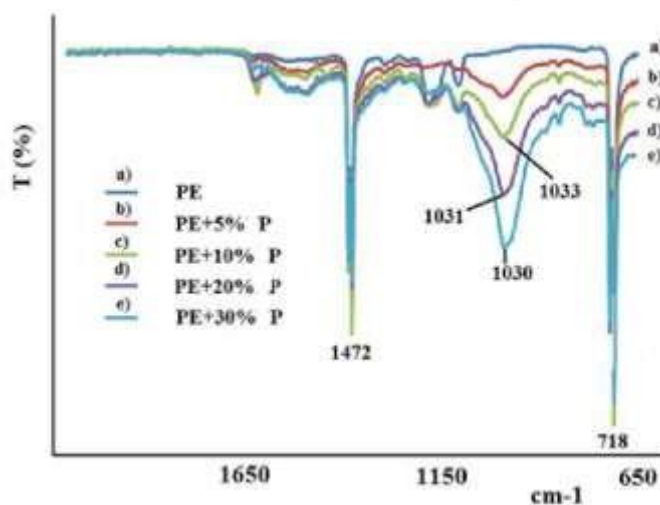


Figure 1. How to determine the functionality of a PE and perlite mixture through FTIR spectrum

For the PE sample, the CH₂ deformation vibrations were detected at approximately 1472 cm⁻¹ and the CH₂ external rotation vibration was detected at 718 cm⁻¹. These vibrations are typical characteristics of the PE polymer chain. For the samples with added perlite, a new peak appeared around 1030 cm⁻¹. This peak is associated with the asymmetric stretching vibration of Si–O–Si (silicate) in the perlite.

As the pearlite content increased, the intensity of this peak at 1030 cm^{-1} was observed to increase. This confirms the uniform distribution of pearlite in the PE matrix and its presence.

3.2 Mechanical properties

Tensile strength

The tensile strength of PE was observed to be 21.4 MPa.

In the PE composites with added pearlite, a significant increase in tensile strength was observed when 5% perlite was added. This is due to its good dispersion in the matrix and its positive effect on the composite structure.

However, when more than 10% perlite was added, the tensile strength began to decrease.

Tensile strength

In the composites filled with perlite, the composites with 5%, 10%, and 15% perlite had higher tensile strength than PE, and the PE filled with 25% perlite reduced the tensile strength by about 7%, which is also due to the poor dispersion of perlite.

Young's modulus

The Young's modulus of PE is about 760 MPa, which means that the hardness of PE increases with the addition of perlite, since the filler material strengthens the polymer matrix. However, the increase in the perlite content limits the mobility of the materials and reduces their elasticity.

Flexural strength

The flexural strength of PE is 25.7 MPa, and the flexural strength increases in the composites with perlite.

The highest flexural strength was observed in the composite with 15% perlite addition - approximately 36.9 MPa, and in composites with more than 25% perlite, the flexural strength decreased. This may be a result of poor dispersion or agglomeration of perlite, since agglomerates concentrate stress and reduce the strength of the material. The mechanical properties of composites depend on the perlite content and its distribution in the matrix. The addition of 5-15% perlite increases the strength of the composite, but the addition of high amounts of perlite (more than 25%) leads to a decrease in mechanical properties due to poor dispersion and agglomeration. Therefore, it is necessary to ensure good dispersion of perlite.

3.3 Thermal Conductivity

The thermal conductivity of composite materials based on PE waste can be reduced by adding perlite. The porous structure of perlite increases the insulating

properties of the material, which improves the thermal insulation quality of composite materials.

Table 2

Thermal conductivity of PE waste and perlite-filled composites.

N°	Samples	Thermal conductivity (W) ⁻¹
1	PE	0.560
2	PE + 5% P	0.529
3	PE + 10% P	0.525
4	PE + 15% P	0.519
5	PE + 25% P	0.515

Here, when 5% perlite is added, the thermal conductivity can be reduced by 5.5%, and when 25% perlite is added, the thermal conductivity can be reduced by 8%, which helps to create composite materials with high insulation properties.

3.4 XRD (X-ray diffraction) analysis

The material has strong peaks at approximately 22.3° and 24.6°, which correspond to the (110) and (200) crystal lattice planes, which means that PE has a crystalline structure and has ordered molecular layers. The XRD profiles of the composites with 5% and 10% perlite are almost similar to those of PE, which means that the crystal structure has not undergone significant changes. However, when 15% and 25% perlite are added, the peak of the (200) plane shifts from 24.6° to 24.5°, indicating a slight structural change.

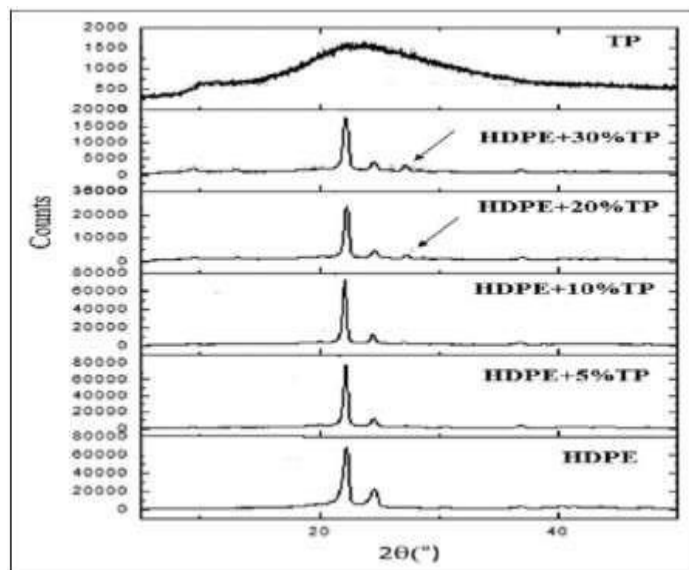


Figure 2. X-ray diffraction (XRD) of PE composites prepared with perlite filler

In general, the crystalline structure of PE is stable and does not undergo significant deformation with the addition of perlite, which helps to maintain the structural integrity of the composite material.

3.5 SEM (Scanning Electron Microscope) Analysis

The fracture surfaces of the PE composites filled with perlite after tensile testing were analyzed using SEM. The SEM micrographs in Figure 4 illustrate the surface morphology of the samples with different perlite weight fractions.

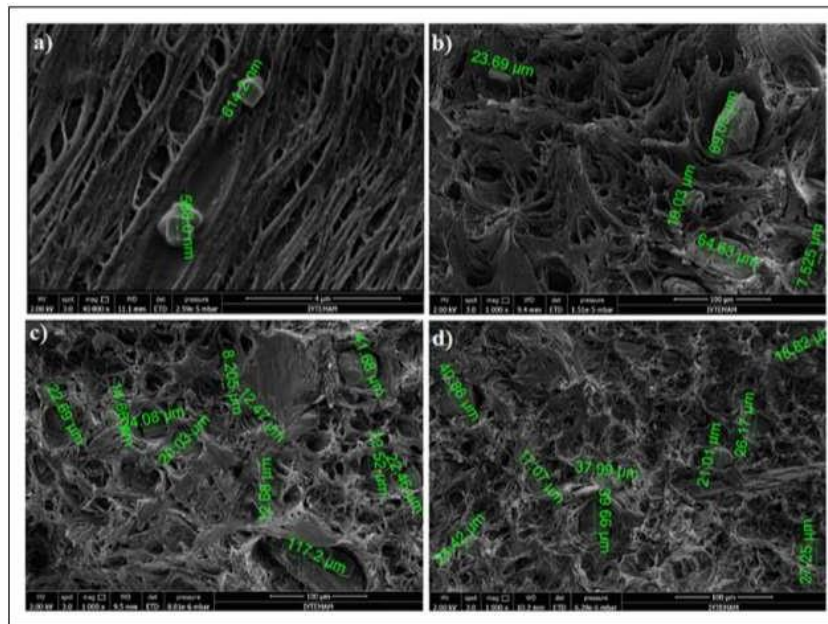


Figure 3. SEM micrographs of (a) PE + 5% P, (b) PE + 10% P, (c) PE + 15% P and (d) PE + 25%P perlite composites

Here (a) shows a PE sample with 5% perlite added. In this case, the perlite particles are distributed in the nanometer range and are well dispersed in the matrix. Therefore, the particle size is small and the interfacial forces with the matrix are high.

However, as the perlite content increases, for example, up to 10%, 15% and especially up to 25% (Figure 3 (b), (c) and (d)), it was observed that the particle size increases to the micrometer scale and the distribution is not uniform. For example, the lowest particle size for the 15% sample was 4.08 μm , while for the 25% sample it reached 17.07 μm . This indicates that the perlite is agglomerated in the PE matrix.

In general, at low concentrations (5%) the addition of perlite provided good dispersion of the particles, which led to an increase in tensile strength. However, at higher concentrations (15–25%), the particles agglomerated and acted as stress concentrators, which led to a decrease in mechanical properties, especially tensile strength and toughness.

3.6 Dynamic Mechanical Analysis (DMA)

DMA was used to study how the mechanical response of the composites changes with temperature. This analysis is based on two main parameters:

Storage modulus (E') – indicates the stiffness of the material and its ability to store elastic energy, and loss modulus (E'') – indicates the loss of energy in the form of heat due to the movement of molecules within the material, i.e. viscoelasticity or internal friction.

As the temperature increases, the stiffness of PE and its composites decreases, which leads to a decrease in E' . However, as the amount of pearlite increases (i.e. 5%, 10%, 15%, 25%), the value of E' increases. This strengthens the matrix and makes the material stiffer. This is because the pearlite particles restrict the internal motion, which hinders the movement of PE molecules, increasing the stiffness.

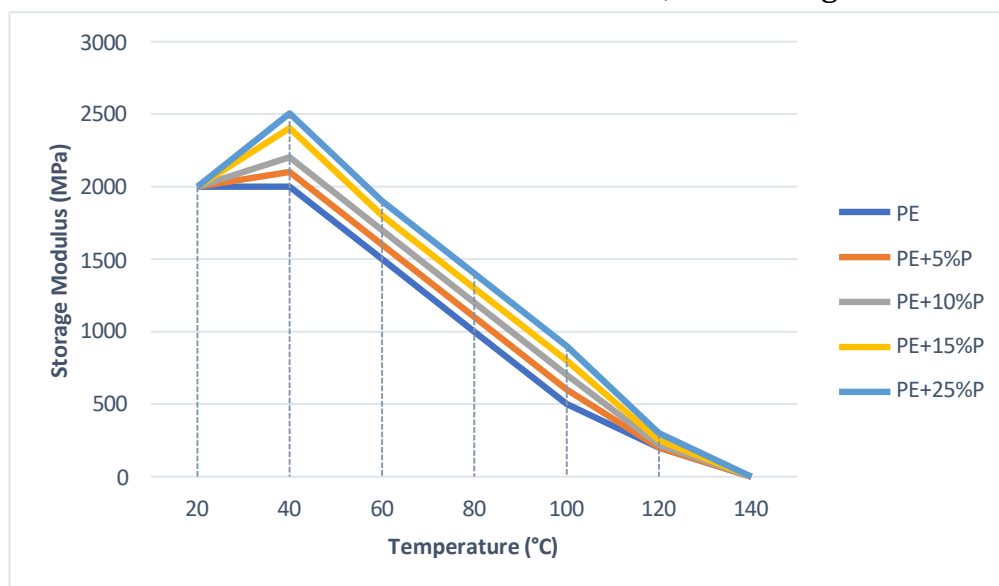


Figure 4. Variation of storage moduli of PE and its composites with temperature

For each sample, the α -relaxation peak (the point of transition of the material to mobility) is located in the range of approximately 49–56 °C. At this point, the motion of the PE segments increases.

At the same time, the segmental motion is limited, which leads to an increase in the loss modulus and a decrease in flexibility. The internal motion of the material with a very high 25% pearlite content is significant.

Conclusion

FTIR was performed to determine the functional groups and chemical modifications of the composite based on PE waste. It was observed that the intensity of this peak at 1030 cm^{-1} increased with increasing pearlite content. This confirms the uniform distribution of pearlite in the PE matrix and its presence. The mechanical properties of the composites depend on the pearlite content and its distribution in the matrix. A mixture of 5-15% pearlite increases the strength of the

composite, but the addition of a high amount (more than 25%) of perlite leads to a decrease in mechanical properties due to poor dispersion and agglomeration. Therefore, it is necessary to ensure good dispersion of perlite. If 5% perlite is added, the thermal conductivity can be reduced by 5.5%, while when 25% perlite is added, the thermal conductivity is reduced by 8%, which helps to create composite materials with high insulating properties. As the temperature increases, the stiffness of PE and its composites decreases, which leads to a decrease in the storage modulus (E'). However, when the amount of perlite increases (i.e. 5%, 10%, 15%, 25%), the E' value increases. This strengthens the matrix and makes the material stiffer. This is because the perlite particles restrict the internal movement, which hinders the movement of PE molecules and increases the stiffness.

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