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High-density polyethylene composites with treated perlite: Thermal and mechanical properties

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ABSTRACT

This study explores the development of high-density polyethylene (HDPE) composites reinforced with stearic acid-treated expanded perlite (TEP) to examine their thermal, mechanical, and processing properties. The composites were fabricated using a plastograph at 200°C, incorporating perlite concentrations from 5% to 20% by volume. The effects of stearic acid (SA) treatment and perlite content were analyzed through SEM, melt flow index (MFI), tensile and impact testing, and thermal analysis (DSC, TGA, and Vicat softening temperature). SEM analysis revealed that untreated perlite exhibited a highly porous structure, while HCl treatment induced fragmentation. At 5% SA, perlite particles were well dispersed with a thin coating, whereas at 10% SA, the coating was more pronounced, leading to agglomeration. The MFI increased with perlite loading, reaching 12.3 g/10 min at 20% perlite, compared to 8.88 g/10 min for neat HDPE. Mechanical testing showed that the elastic modulus increased by 36% (786 MPa) at 5% perlite, dropped to 460.8 MPa at 15%, and rose again to 707.7 MPa at 20%, suggesting structural reinforcement. Moderate perlite content (5-10%) preserved ductility, while higher concentrations (15-20%), especially with 10% SA, increased brittleness due to reduced interfacial adhesion. Thermal analysis showed a slight decrease in melting temperature and a slight increase in crystallization temperature with the addition of treated perlite, while thermal stability improved and the Vicat softening temperature remained unchanged. These results highlight the potential of SA-treated expanded perlite as a viable alternative to conventional fillers, offering a balance between stiffness, ductility, and thermal resistance. The developed composites are promising for lightweight and cost-effective applications in energy management and construction.

Keywords: Expanded perlite; composites; HDPE; chemical treatment; stearic acid.

INTRODUCTION

Technological advancements over the past decades have significantly driven the development and adoption of polymer composite materials across diverse sectors, including automotive, aerospace, construction, and food packaging [1,2]. These materials offer unparalleled versatility, allowing their properties to be tailored to specific application requirements through variations in polymer matrices, filler types, and processing conditions [1-4]. Among these materials, high-density polyethylene (HDPE)-based composites have gained substantial interest for their lightweight, thermal stability, and mechanical performance.

Mineral fillers such as silica, talc and calcium carbonate ($CaCO_3$) are widely used to improve polymer properties due to their availability and cost-effectiveness [5]. In contrast to the well-studied potential of calcium carbonate and clay fillers, the use of perlite as a filler remains little explored. This is mainly due to the difficulties encountered in achieving uniform dispersion in the polymer matrix, which affects interfacial compatibility and overall composite performance [6-8]. In addition, the high density of calcium carbonate can increase the weight of final materials, making it less desirable for lightweight applications. Advanced fillers such as carbon nanotubes and graphene offer superior properties, but are often excessively expensive and complex to process on a large scale [7,8].

Perlite, a natural volcanic glass, offers a compelling alternative thanks to its unique properties, including low density, high porosity and excellent thermal insulation [9]. When expanded at 850-1100°C, perlite undergoes rapid vaporization of trapped water, forming a lightweight honeycomb structure, which improves its thermal resistance and acoustic insulation [10]. Despite these advantages, the use of perlite as a filler in HDPE composites remains limited. One of the main difficulties lies in its inherently hydrophilic nature, which reduces compatibility with hydrophobic polymers such as HDPE, resulting in poor dispersion and interfacial adhesion. This in turn affects mechanical properties, necessitating surface treatments to improve polymer-filler interactions [11,12].

Several studies have explored the incorporation of perlite into polymer matrices, highlighting both its potential and limitations. G. Akin-Öktem et al. [10] studied HDPE composites reinforced with perlite treated with silane coupling agents, reporting significant improvements in modulus and tensile strength due to better interfacial adhesion. However, the composites became brittle, with reduced elongation at break as the filler content increased. L. Lapčík et al. [13] observed similar trends in HDPE/perlite nanocomposites, where a 15% perlite concentration increased the Young's modulus by 37%. They also noted that while perlite improved thermal stability and crystallinity, it reduced impact strength and ductility, highlighting the need for optimized dispersion techniques. A. de Oliveira et al. [14] studied polystyrene (PS)/perlite composites and found that perlite significantly improved the elastic modulus and reduced viscosity, enhancing processability. However, the composites exhibited reduced elongation at break, a common trade-off in perlite-filled systems. Collectively, these studies demonstrate the reinforcing potential of perlite but also highlight issues such as agglomeration, poor dispersion, and increased brittleness.

Chemical treatments have been widely used to address these challenges. Among these, stearic acid is a cost-effective and accessible solution. By forming a hydrophobic coating on the surface of the filler, stearic acid improves compatibility with hydrophobic matrices such as HDPE, reduces filler agglomeration, and promotes better dispersion [15]. Unlike silane-based treatments, which can involve higher costs and complex processing, stearic acid offers a simpler approach, particularly suited for large-scale applications.

This study focuses on the development of HDPE composites reinforced with stearic acid-treated expanded perlite to achieve a balance between mechanical strength, thermal stability, and ease of processing. The novelty of this work lies in the systematic evaluation of the effects of perlite concentration (5%-20% by volume) and stearic acid treatment levels (5% and 10%) on composite properties. Through a comprehensive investigation involving scanning electron microscopy (SEM), melt flow index (MFI) measurement, tensile and impact testing, and thermal analyses (DSC and TGA), this study aims to provide insights into the mechanisms governing the performance of these innovative composites.

By addressing the limitations of untreated perlite and leveraging the benefits of chemical treatments, this work advances the development of HDPE-based composites tailored for lightweight, heat-resistant applications. Furthermore, the study bridges critical gaps in understanding the trade-offs between rigidity, ductility, and processability, making it relevant for applications in energy management, construction, and other demanding sectors.

EXPERIMENTAL

Materials

The expanded perlite used in this study was supplied by TAOUAB Construct (Algeria). Its chemical composition was determined using X-ray fluorescence spectrometry (XRF, JSX-3201Z) and is shown in Table 1. The general physical characteristics of the raw perlite, including apparent density and pH, are summarized in Table 2, according to the supplier's data sheet [16]. High-density polyethylene grade F00952, supplied by SABIC (Saudi Arabia), was used as the polymer matrix. This material is a high molecular weight HDPE copolymer, specifically designed for blown film extrusion. It has a broad molecular weight distribution. The material has an MFI of 0.07 g/10 min (190°C, 2.16 kg) and a density of 0.95 g/cm³, according to ISO 1133 standards. SA, used for perlite surface treatment, was an ENSIGN brand, manufactured in China.

Table 1. Chemical composition of expanded perlite.

Constituent	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**CaO**	**Na_2O**	**K_2O**	**MgO**
Rate (%)	71.4	10.0	2.08	2.94	3.85	9.25	0.163

Table 2. Expanded perlite characteristics according to TAOUAB data sheet [16].

Apparent density	50-80 kg/m^3
Compacted density	60-100 kg/m^3
PH value	7- 9
Color	White
Quantity of SiO_2	60-80 %

Methodology

HCl Pre-treatment of Perlite

The raw perlite was subjected to hydrochloric acid treatment to enhance its surface area and reactivity. The process included:

- Drying perlite at 100°C for 24 hours to remove residual moisture.
- Immersion in 10% HCl solution for 12 hours.
- Neutralization using 0.1 N NaOH until pH 7, followed by rinsing with distilled water.
- Filtration and calcination at 500°C for 2 hours to eliminate impurities and activate the porous structure.

Stearic Acid Surface Treatment

After HCl pre-treatment, the perlite was further modified using SA at concentrations of 5% and 10% by volume to improve compatibility with HDPE. The modification process followed these steps:

- Melting SA in a water bath at 80°C.
- Gradually adding perlite under continuous agitation using a helical mixer for 15 minutes to ensure uniform coating.
- Storing the treated perlite in airtight containers for use in composite preparation.

Bulk Density of Perlite

In addition to the apparent density provided in Table 2, the bulk density of perlite was experimentally determined using the tapping method before and after surface treatment. The procedure involved:

- Placing 1 g of perlite in a 10 ml graduated cylinder.
- Tapping the cylinder vertically until the material reached its maximum compaction.

The bulk density was then determined by dividing the sample mass by the tapped volume.

The measured bulk densities are reported in Table 3, showing a significant increase after SA treatment.

Table 3. Measured bulk density of treated perlite using the tapping method.

	Before treatment	**After treatment**
Bulk Density of Perlite (g/cm³)	0.12	0.23

Preparation of Composites

The composites were prepared using a Brabender® CE Plastograph at 200°C for 6 minutes at 40 rpm. The chamber, with a volume of 55 cm³, was filled with a mixture of HDPE and treated perlite. Correct filling is ensured on the basis of the density of each component at 200°C. The composites were prepared with volumetric perlite concentrations of 5%, 10%, 15%, and 20%. Table 4 summarizes the composition of each formulation. To ensure a uniform thermal history across all samples, neat HDPE was also processed in the plastograph under the same conditions as the composite formulations.

Table 4. Masses and volumetric/mass percentages of components (HDPE and TEP) for different composite formulations.

volumetric % HDPE/TEP	**Mass (g) HDPE/TEP 5% SA**	**Mass % HDPE/TEP 5% SA**	**Mass (g) HDPE/TEP 10% SA**	**Mass % HDPE/TEP 10% SA**
100/00	44/00	100/ 00	44/00	100/00
95/5	41.8/0.52	98.8/1.2	41.8/0.55	98.7/1.3
90/10	39.6/1.04	97.4/2.6	39.6/1.10	97.5/2.7
85/15	37.4/1.57	96.0/4.0	37.4/1.65	95.8/4.0
80/20	35.2/2.09	94.1/5.9	35.2/2.10	94.4/5.6

Characterization Methods

Electron Microscopy Analysis

The morphology of raw and treated perlite, as well as the fractured surfaces of impact-tested composites, was analyzed using scanning electron microscopy (SEM) with a JEOL JSM-7200F microscope (Akishima-shi, Tokyo, Japan). Perlite images were acquired at an accelerating voltage of 20 kV, with magnifications ranging from ×10 to ×1,000,000, to examine surface characteristics, particle dispersion, and the effects of chemical treatment. Additionally, the analysis of the fractured surfaces of impact-tested composites allowed for the assessment of perlite dispersion within the HDPE matrix, filler-matrix adhesion, and fracture morphology.

Melt Flow Index (MFI)

MFI was measured according to ISO 1133 using a Controlab Model 5 tester (190°C, 21.16 kg). Samples were pre-dried at 100°C for 24 hours.

Mechanical Properties

a) Tensile Test

Performed on a ZWICK/Roell machine with a 10 kN load cell, at 20 mm/min. Specimens (2.0 mm thick, 5.0 mm wide) were prepared using a CARVER hydraulic press (12 minutes at 200°C, 11 bars).

b) Impact Resistance

Izod impact tests were conducted on notched specimens (2.2 mm thick, 12.5 mm wide, 1 mm notch) using a RESIL IMPACTOR.

Thermal Properties

- Differential Scanning Calorimetry (DSC) and Thermogravimetric Analysis (TGA)

  The thermal analyses were conducted using a PerkinElmer STA 8000 coupled DSC-TGA instrument under a nitrogen atmosphere.

  - DSC: Differential scanning calorimetry (DSC) was performed using two heating cycles and a single cooling cycle. The sample was first heated from 25°C to 250°C at a rate of 10°C/min, followed by a 2-minute isothermal hold at 250°C. It was then cooled back to 25°C at the same rate (10°C/min). A second heating cycle was subsequently carried out under the same conditions. The melting temperatures (T_m) were determined from the second heating cycle, while the crystallization temperatures (T_c) were obtained from the first cooling cycle. The results are presented in the following section.
  - TGA: After cooling, the same sample was immediately subjected to thermogravimetric analysis. This step involved a second heating from 25°C to 600°C at 10°C/min, still under a nitrogen atmosphere, with a 25-minute isothermal hold at 25°C before measurement to ensure thermal stabilization.
- Vicat Softening Temperature

  Measured using a CEAST HV3 instrument, following ISO 306 and ASTM D1525 standards. Specimens were heated at a rate of 120°C/hour and evaluated until a penetration depth of 1 mm was reached.

RESULTS AND DISCUSSION

Scanning Electron Microscopy Analysis

Morphology of Raw and Treated Perlite

SEM images (Figure 1) reveal distinct morphological differences between raw and treated perlite. The raw perlite (Figure 1a) exhibits a fragmented structure with irregular debris and open porosity. Following HCl treatment (Figure 1b), the perlite shows a fractured structure with plate-like fragments, indicating an increase in surface area and potential reactivity. When treated with stearic acid (SA), further modifications are observed: at a 5% SA concentration (Figure 1c), the perlite particles are uniformly coated, maintaining clearly distinguishable platelets, while at a 10% SA concentration (Figure 1d), the coating becomes more pronounced, leading to noticeable particle agglomeration. This structural evolution suggests that HCl treatment enhances surface roughness and potential interaction sites, whereas SA treatment improves compatibility with hydrophobic matrices such as HDPE.

Given these modifications in morphology and surface properties, the effect of incorporating these treated perlites into the HDPE matrix was further investigated. The dispersion of the filler, the adhesion between the perlite and the polymer, and the fracture mechanisms of the composites under impact stress were analyzed through SEM imaging of the fractured surfaces.

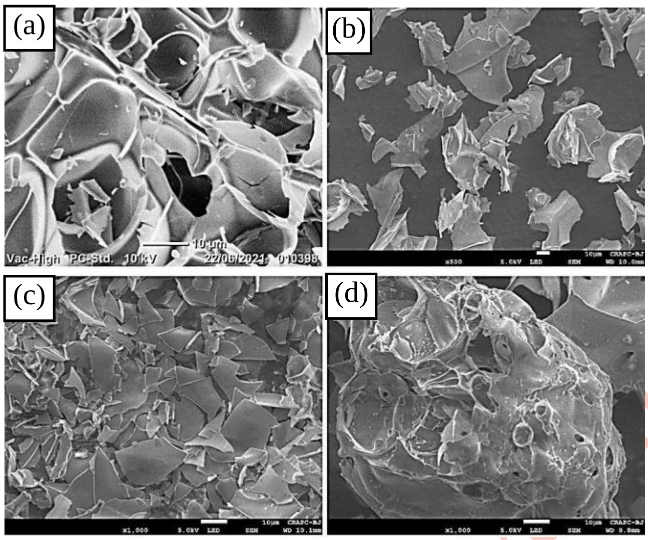

Figure 1. SEM images of raw expanded perlite (a), perlite after HCl treatment (b), perlite treated with 5% SA (c), and perlite treated with 10% SA (d).

Fracture Morphology of Impacted Composites

SEM images of the impacted surfaces (Figure 2) provide insight into the fracture behavior of pure HDPE and HDPE/perlite composites. The image of pure HDPE (Figure 2a) reveals an almost intact surface that seems no significant signs of deformation or fracture. This behavior is expected, as HDPE is an inherently ductile material that efficiently dissipates impact energy without undergoing brittle failure, as evidenced by the absence of rupture in all tested specimens.

For the HDPE/Treated Perlite composites, the fracture morphology evolves significantly depending on the perlite content and the stearic acid treatment level. The composite containing 5 vol% perlite treated with 5% SA (Figure 2b) exhibits a homogeneous distribution of perlite particles within the polymer matrix, with rough fracture surfaces indicative of a ductile-brittle behavior. At a higher perlite content (20 vol% treated with 5% SA, Figure 2c), a gradual transition toward a more brittle response is visible. In both cases, perlite particles remain well embedded in the matrix, indicating strong filler-matrix adhesion.

However, when the perlite is treated with 10% SA, the fracture morphology changes noticeably. The composite with 5 vol% perlite treated with 10% SA (Figure 2d) shows signs of partial detachment of perlite platelets from the polymer, suggesting a reduction in filler-matrix adhesion. In the composite with 20 vol% perlite treated with 10% SA (Figure 2e), perlite particle agglomeration becomes particularly pronounced, leading to a less effective dispersion of the mineral filler within the HDPE matrix. This structural heterogeneity could negatively impact the mechanical properties of the composite, particularly by reducing its ability to dissipate impact energy, potentially promoting a transition toward more brittle behavior.

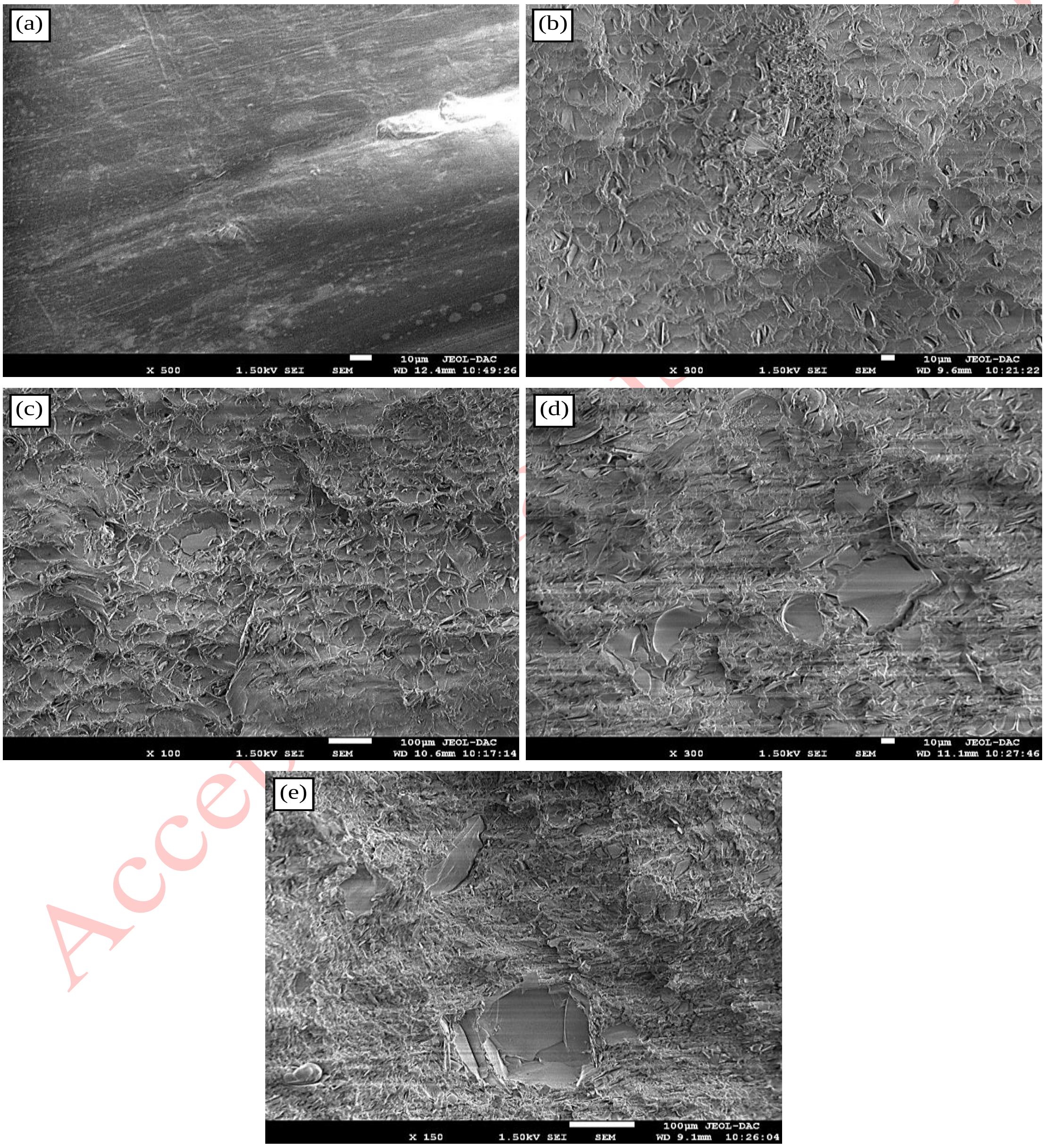

Figure 2. SEM images of impact-fractured surfaces of (a) neat HDPE, (b) HDPE/5%TEP with 5% SA, (c) HDPE/20%TEP with 5% SA, (d) HDPE/5%TEP with 10% SA, and (e) HDPE/20%TEP with 10% SA.

Composite Fluidity

The MFI of HDPE composites (Figure 3) increased with perlite content, rising from 8.88 g/10 min for neat HDPE to 12.3 g/10 min at 20% perlite (5% SA). A similar trend was observed for 10% SA, with slightly higher values, indicating improved lubrication and reduced polymer chain entanglement. The SA coating probably improves perlite dispersion, further facilitating flow.

In line with Oliveira et al [14], perlite reduces viscosity and improves processability. This study shows that SA treatment amplifies these effects, optimizing the material for extrusion and injection molding processes.

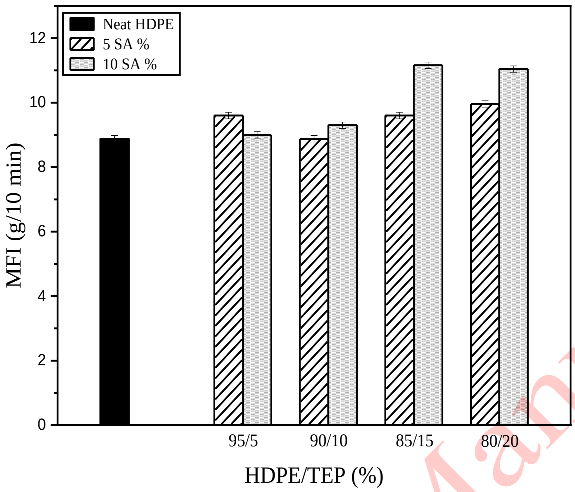

Figure 3. Melt flow index of HDPE/TEP composites based on perlite content and stearic acid treatment.

Mechanical Properties

Elastic Modulus

The elastic modulus of the composites varied depending on the perlite content and the SA treatment, as shown in Figure 4. For composites containing 5% perlite, the modulus increased by 36%, reaching 786 MPa with 5% SA treatment compared to neat HDPE (577 MPa). This significant improvement demonstrates enhanced stiffness, attributed to better filler dispersion and stronger interaction between the treated perlite and the HDPE matrix. However, at 15% perlite, the modulus decreased to 460.8 MPa, likely due to particle agglomeration, which impairs effective stress transfer within the composite. Interestingly, at 20% perlite, the modulus exhibited a notable recovery, reaching 707.5 MPa, suggesting the formation of a structural network that compensates for the agglomeration effect and enhances stiffness. Overall, lower SA concentrations (5%) provided better results, likely due to more uniform dispersion and improved compatibility between the treated perlite and the polymer matrix.

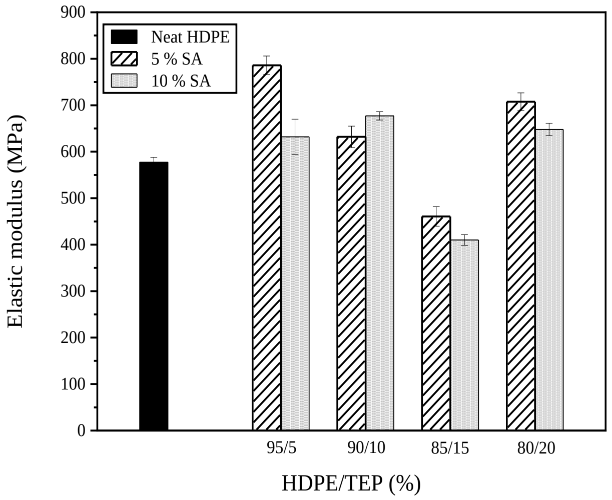

Figure 4. Effect of treated perlite on the elastic modulus for HDPE/TEP composites.

Maximum Stress

The results shown in Figure 5 indicate that the maximum stress of neat HDPE is 31.8 MPa. Adding 5% perlite treated with SA increases this stress to 33.3 MPa with 5% SA and 33.9 MPa with 10% SA, demonstrating the reinforcing effect of treated perlite. At 10% perlite, the maximum stress decreases slightly to 28.8 MPa for 5% SA and 31.6 MPa for 10% SA, likely due to reduced interfacial adhesion or partial agglomeration. A more significant decrease is observed at 15% perlite, reaching 27.6 MPa (5% SA) and 27.3 MPa (10% SA), indicating insufficient dispersion. Interestingly, at 20% perlite, the maximum stress exhibits a slight recovery, increasing to 28.5 MPa with 5% SA but declining further to 25.6 MPa with 10% SA, likely due to significant agglomeration.

Overall, the 5% SA treatment provides more consistent reinforcement, especially at low and high concentrations, while the 10% SA treatment is more effective at moderate perlite contents. These results highlight the importance of optimizing the treatment level to balance the mechanical performance of HDPE/perlite composites.

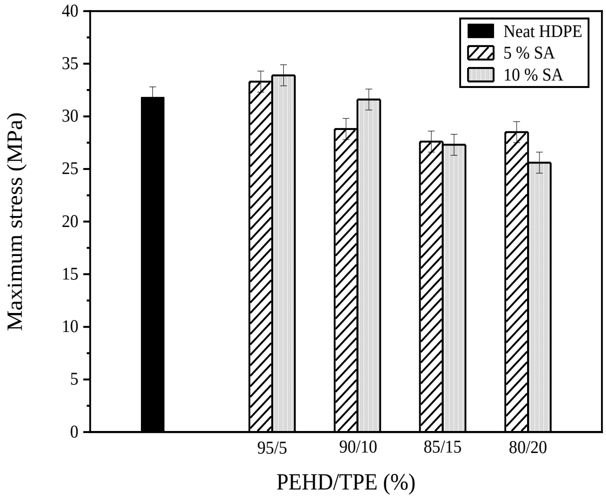

Figure 5. Effect of treated perlite on the maximum stress for HDPE/TEP composites**.**

Elongation at break:

As shown in Figure 6, the addition of 5% perlite improves the elongation at break by 15.6% (545.5% with 5% SA, 542.6% with 10% SA) compared to 472% for neat HDPE. At 10% perlite, elongation remains high (511.6% and 530%), but decreases slightly at 15% (450% and 460%). At 20%, elongation drops sharply (30.2% and 31.1%), indicating more brittle failure, likely due to poor dispersion or excess perlite.

The 5% SA treatment improves the dispersion of perlite, as shown by the SEM images, where homogeneous particle coating was observed. This promotes better interaction between the perlite and the polymer matrix, explaining the improved ductility at low and moderate perlite concentrations. However, at 10% SA, although the coating is complete, SEM images revealed agglomeration of perlite particles, which hinders dispersion within the matrix and leads to a decrease in the composite's ductility.

In conclusion, the integration of treated perlite into HDPE composites improves the elastic modulus and maximum stress while maintaining satisfactory ductility at low and moderate perlite concentrations. These results are partly in agreement with those of M. Atagür et al. [12] and M.N. Khalaf et al. [17], who also observed an improvement in the elastic modulus but a reduction in elongation at break with increased perlite content. However, our results show that treated perlite, especially at low and moderate concentrations, provides a better balance between stiffness and ductility, thanks to the improved dispersion and adhesion of perlite in the polymer matrix, facilitated by stearic acid, as shown by the SEM images.

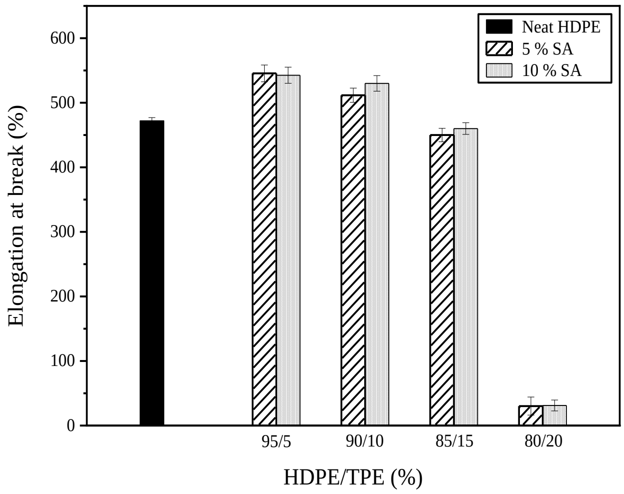

Figure 6. Variation of elongation at break for HDPE/TEP composites.

Thermal Properties

Vicat Softening Temperature

The results presented in Table 5 indicate that the Vicat softening temperature of HDPE/TEP composites remains relatively stable across different perlite contents and SA treatment levels (5% or 10%). This stability is primarily due to the dominance of the continuous HDPE phase, which governs the overall thermal behavior of the composite despite the increasing perlite content.

Table 5. Vicat softening temperatures of HDPE/TEP composites.

HDPE/TEP (%)	**100/00**	**95/5**	**90/10**	**85/15**	**80/20**
5 % SA	124 ± 0.15 (°C)	124 ± 0.2 (°C)	124 ± 0.2 (°C)	124 ± 0.2 (°C)	124 ± 0.2 (°C)
10 % SA	-	125 ± 0.2 (°C)	126 ± 0.2 (°C)	124 ± 0.2 (°C)	125 ± 0.2 (°C)

Differential Scanning Calorimetry (DSC)

a) Melting Temperature (T_m)

The incorporation of treated expanded perlite induces a slight variation in the melting temperature of HDPE/TEP composites (Figure 7). For composites containing 5% stearic acid, Tm slightly decreases from 137.8°C for pure HDPE to 135.5°C at 10% perlite content before increasing again to 137.4°C at 20%. This non-linear variation could be related to local fluctuations in the distribution of perlite particles and stearic acid within the polymer matrix, irregularly influencing HDPE crystallization.

In contrast, for composites treated with 10% SA, T_m gradually decreases from 137.8°C to 135°C as the perlite content increases. This more consistent trend could be attributed to the excess stearic acid, which promotes particle agglomeration and alters HDPE crystallization in a more pronounced and systematic manner.

Lapčík et al. (2020) reported a slight increase in T_m with higher filler concentrations, attributed to stronger interactions between the polymer and perlite particles. However, in this study, the observed variations do not systematically follow this trend and remain moderate. At a low SA concentration (5%), its primary role appears to be that of a compatibilizing agent, promoting better particle dispersion and optimized interfacial adhesion, as confirmed by SEM observations.

At 10% SA, however, the excess treatment agent leads to more pronounced perlite particle agglomeration, reducing their homogeneous dispersion within the polymer matrix. This redistribution affects how the particles interact with HDPE and could explain the more gradual and consistent decrease in Tm observed in this case.

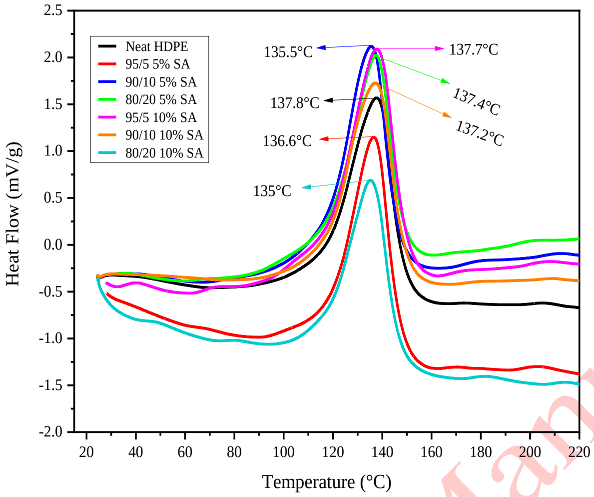

Figure 7. DSC thermograms of HDPE/TEP composites from the second heating cycle showing melting temperatures.

b) Crystallization Temperature (T_c)

The crystallization temperatures of the composites follow a trend similar to that of the melting temperatures (Figure 8). For composites containing 5% stearic acid (SA), T_c varies irregularly with the perlite content, whereas with 10% SA, a more gradual trend is observed, with a slight increase in T_c as the perlite fraction increases. These results suggest that, as with T_m, the influence of surface treatment on the crystallization of HDPE differs depending on the SA content used. However, the variations in T_c remain moderate, indicating that while the treatment affects crystallization, it does not induce major changes.

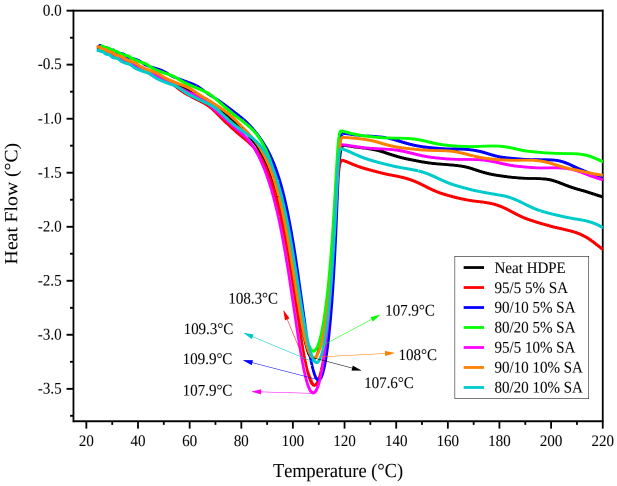

Figure 8. DSC thermograms of HDPE/TEP composites from the first cooling cycle showing the crystallization temperatures.

Thermogravimetric Analysis

The data from Table 6 and Figure 9 indicate that the incorporation of TEP enhances the thermal stability of HDPE-based composites compared to neat HDPE. The maximum degradation temperature (T_d) of neat HDPE, initially measured at 452 °C, increases with the addition of TEP. For formulations containing 20% perlite treated with 5% SA, Td reaches 463 °C. In contrast, in formulations treated with 10% SA, the increase in T_d is less consistent, peaking at 5% perlite before slightly decreasing (from 461 °C to 458 °C) at 20% perlite. This trend suggests that the 10% SA treatment is more effective at low perlite content, while at higher perlite concentrations, the stabilizing effect of perlite may be partially hindered by the excess stearic acid. Conversely, formulations treated with 5% SA exhibit a continuous increase in T_d with rising perlite content, indicating a more uniform and sustained stabilizing effect.

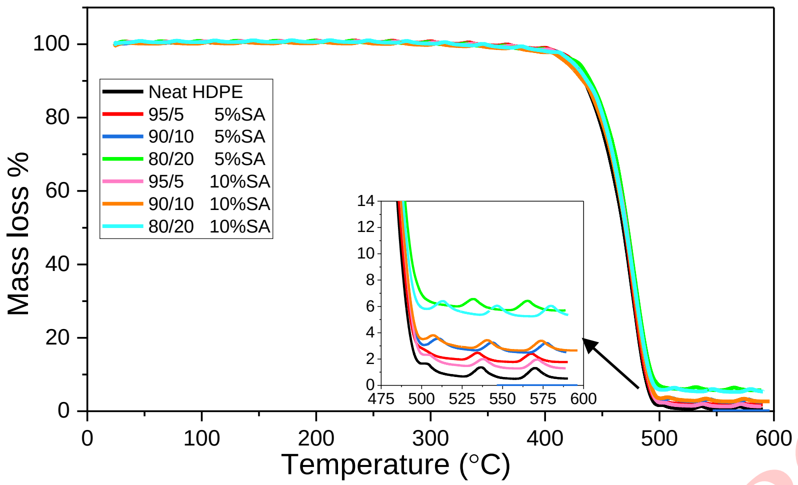

Figure 9. Mass loss as a function of temperature for HDPE/TEP composites.

Table 6. Effect of treated perlite on the Td and mass loss of HDPE composites.

Parameter **Formulation**	**T_d (°C)**
Neat HDPE	452
95/5 % ; 5% SA	459
90/10 % ; 5% SA	461
80/20 % ; 5% SA	463
95/5 % ; 10% SA	461
90/10 %; 10% SA	455
80/20 % ; 10% SA	458

CONCLUSION

This study confirmed the potential of stearic acid-treated expanded perlite as a reinforcement in high-density polyethylene (HDPE) composites. The incorporation of perlite increased the melt flow index (MFI) from 8.88 g/10 min for neat HDPE to 12.3 g/10 min for composites containing 20% treated expanded perlite (TEP) with 5% stearic acid (SA), likely due to the lubricating effect of treated particles. Mechanically, the elastic modulus increased significantly at low perlite contents, reaching 786 MPa with 5% perlite treated with 5% SA. However, at higher concentrations (15-20%), particle agglomeration caused a decline in modulus before stabilizing at 707.5 MPa at 20%. While moderate perlite contents maintained ductility, increased brittleness was observed at higher levels, likely due to insufficient dispersion, as reflected in maximum stress and elongation at break.

SEM analysis confirmed these trends, showing that at 5% SA, perlite particles were well dispersed and embedded in the polymer matrix, promoting good adhesion and mechanical performance. However, at 10% SA, particle agglomeration was more pronounced, especially at higher perlite contents, weakening interfacial adhesion and increasing brittleness. The SEM images further revealed a progressive transition from ductile to brittle failure as the perlite content increased, particularly at 10% SA, due to particle clustering and weaker filler-matrix adhesion. At low perlite contents (5%), good dispersion ensured cohesion and stress transfer, while higher contents (15-20%) led to voids and interfacial debonding, reducing mechanical performance.

Thermal analysis indicated slight variations in the melting temperature (T_m) of HDPE/TEP composites, ranging between 137.8°C and 135°C depending on filler content and surface treatment. Although chemical treatment did not significantly alter Tm, it improved polymer-filler interaction at low SA concentrations. The maximum degradation temperature (T_d) increased to 463°C for composites containing 20% perlite treated with 5% SA, compared to 452°C for neat HDPE. The Vicat softening temperature remained stable across all compositions, indicating that the continuous HDPE phase dominated.

These findings emphasize the importance of surface treatment and filler dispersion in balancing mechanical properties and processability in HDPE/perlite composites. Stearic acid-treated perlite, particularly at 5% SA, provides an effective, lightweight reinforcement and a promising alternative to conventional fillers like calcium carbonate. The resulting composites exhibit improved mechanical and thermal stability, making them suitable for energy management, construction materials, and lightweight packaging. Future research could focus on optimizing chemical treatment to minimize agglomeration at high filler contents and exploring alternative polymeric matrices to expand the application range of these composites.

CONFLICT OF INTEREST

The author declares that there is no conflict of interest regarding this study.

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ABBREVIATIONS

HDPE: High-Density Polyethylene

SA: Stearic Acid

TPE: Stearic Acid-Treated Expanded Perlite

MFI: Melt Flow Index

DSC: Differential Scanning Calorimetry

TGA: Thermogravimetric Analysis

SEM: Scanning Electron Microscopy

REFERENCES

1. Feldman D (2016) Polymer nanocomposites in medicine. J Macromol Sci A 53: 55-62 [CrossRef]
2. Müller K, Bugnicourt E, Latorre M, Jorda M, Echegoyen Sanz YE, Lagaron JM, Miesbauer O, Bianchin A, Hankin S, Bölz U, Pérez G, Jesdinszki M, Lindner M, Scheuerer Z, Castelló S, Schmid M (2017) Review on the processing and properties of polymer nanocomposites and nanocoatings and their applications in the packaging, automotive and solar energy fields. Nanomaterials 7: 74 [CrossRef]
3. Osman AF, Alakrach AM, Kalo H, Azmi WNW, Hashim F (2015) In vitro biostability and biocompatibility of ethyl vinyl acetate (EVA) nanocomposites for biomedical applications. RSC Adv 5: 31485-31495 [CrossRef]

4. Rajak DK, Pagar DD, Menezes PL, Linul E (2019) Fiber-reinforced polymer composites: Manufacturing, properties, and applications. Polymers 11: 1667 [CrossRef]

5. Shojaei A, Khasraghi SS (2021) Self-healing and self-sensing smart polymer composites. In: Composite materials: Manufacturing, properties and applications. Elsevier, 307-357 [CrossRef]

6. Ahmad Fauzi AA, Osman AF, Alrashdi AA, Mustafa Z, Abdul Halim KA (2022) On the use of dolomite as a mineral filler and co-filler in the field of polymer composites: A review. Polymers 14: 2843 [CrossRef]

7. Barçin S, Sen S, Thomas V, Pillay S, Ning H (2024) Mechanical behaviors and flammability of perlite filled recycled high-density polyethylene composites. J Thermoplast Compos Mater [CrossRef]

8. Sahraeian R, Hashemi SA, Esfandeh M, Ghasemi I (2018) Preparation of nanocomposites based on LDPE/perlite: Mechanical and morphological studies. Polym Polym Compos 20: 639-646 [CrossRef]

9. Sadik C, Albizane A, El Amrani IE (2013) Production of porous firebrick from mixtures of clay and recycled refractory waste with expanded perlite addition. J Mater Environ Sci 4: 981-986

10. Akin-öktem G, Tincer T (1994) Preparation and characterization of perlite-filled high-density polyethylenes. I. Mechanical properties. J Appl Polym Sci 54: 1103-1114 [CrossRef]

11. Sahraeian R, Esfandeh M, Hashemi SA (2013) Rheological, thermal and dynamic mechanical studies of the LDPE/Perlite nanocomposites. Polym Polym Compos 21: 243-250 [CrossRef]

12. Atagür M, Sarikanat M, Uysalman T, Polat O, Elbeyli İY, Seki Y, Sever K (2018) Mechanical, thermal, and viscoelastic investigations on expanded perlite–filled high-density polyethylene composite. J Elast Plast 50: 747-761 [CrossRef]

13. Lapčík L, Vašina M, Lapčíková B, Staněk M, Ovsík M, Murtaja Y (2020) Study of the material engineering properties of high-density poly(ethylene)/perlite nanocomposite materials. Nanotechnol Rev 9: 1491-1499 [CrossRef]

14. de Oliveira AG, Jandorno Jr JC, da Rocha EBD, de Sousa AMF, da Silva ALN (2019) Evaluation of expanded perlite behavior in PS/Perlite composites. Appl Clay Sci 181: 105223 [CrossRef]

15. Mattausch H, Laske S, Cirar K, Flachberger H, Holzer C (2014) Influence of processing conditions on the morphology of expanded perlite/polypropylene composites. AIP Conf Proc 1593: 482-486 [CrossRef]

16. SARL TAOUAB (2025) Perlite construct, poudre, Kouba, Alger. Available online: https://www.taouab.com/powder_details.html (accessed Jan 13, 2025)

17. Khalaf M (2012). Mechanical properties of filled high density polyethylene. J Saudi Chem Soc 19: 88-91 [CrossRef]