MECHANICAL PROPERTIES OF POLYETHYLENE/NANO CALCIUM CARBONATE NANOCOMPOSITES

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Abstract. This study is devoted to the investigation of the mechanical properties of nanocomposites by introducing nano-calcium carbonate (nano-$CaCO_3$) into polyethylene and gradually increasing its content. Nanocomposites were obtained by incorporating laboratory-prepared nano-$CaCO_3$ particles with sizes ranging 1 μm into the polyethylene matrix. Nano-$CaCO_3$ was added to polyethylene at concentrations of 5%, 10%, and 15%, and the physico-mechanical properties of the samples were studied. Compared to pure polyethylene, the composites demonstrated up to a twofold increase in Young’s modulus, while tensile strength values remained almost unchanged, and elongation at break decreased by nearly four times.

Keywords: Polyethylene, Nano-$CaCO_3$, physico-mechanical properties, nanocomposite.

Abstract Ushbu tadqiqotda polietilen matritsasiga nano-kalsiy karbonat (nano-$CaCO_3$) qo‘shilishi va uning miqdori oshirilishi natijasida hosil bo‘lgan nanokompozitlarning mexanik xususiyatlariga ta’siri o‘rganildi. Laboratoriya sharoitida olinib, o‘rtacha 1 mkm o‘lchamga ega nano-$CaCO_3$ zarrachalari polietilen tarkibiga 5 %, 10 % va 15 % massaviy ulushlarda kiritilib, kompozit namunalari tayyorlandi. Tahlillar shuni ko‘rsatdiki, toza polietilen bilan solishtirilganda kompozitlarning Yung moduli qariyb 2 barobargacha oshgan, mexanik kuchlanish qiymatlarida sezilarli o‘zgarish kuzatilmagan, nisbiy uzayish esa taxminan 4 barobargacha kamaygan. Bu esa nano-to‘ldiruvchining polietilenning qattiqligi va qovushqoqligiga kuchli ta’sir ko‘rsatishini tasdiqlaydi.

Kalit so‘zlar: Polietilen, Nano-$CaCO_3$, fizik-mexanik xususiyati, nanokompozit.

Аннотация. Данное исследование посвящено изучению механических свойств нанокомпозитов при введении нанокарбоната кальция (нано-$CaCO_3$) в полиэтилен и постепенном увеличении его содержания. Нанокомпозиты были получены путём введения в полиэтилен лабораторно синтезированных частиц нано-$CaCO_3$ размером 1 мкм. Нано-$CaCO_3$ вводился в количестве 5%, 10% и 15%, после чего были исследованы физико-механические свойства образцов. По сравнению с чистым полиэтиленом, композиты показали увеличение модуля Юнга до 2 раз, при этом значения прочности на растяжение практически не изменились, а относительное удлинение уменьшилось почти в 4 раза.

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Ключевые слова: полиэтилен, нано-$CaCO_3$, физико-механические свойства, нанокомпозит.

Introduction

The growing interest in polymer nanocomposites has led to the consideration of calcium carbonate nanoparticles as one of the alternative nanofillers to widely used analogues, and intensive research in this area continues [1, 2].

Linear low-density polyethylene (PE) with high elasticity is widely used in the production of containers, pipes, cables, etc. [3, 4]. However, the application of PE is limited by its main disadvantages, such as low hardness, poor heat resistance and low softening point. Therefore, initially, fillers were used to reduce the cost of polymers, but as the cost of polymers and the requirements of modern products increase, more attention is paid to increasing functionality [5–7]. Currently, "functional fillers" are most widely used in the polymer industry. The main condition for functional fillers is complete dispersion (disintegration of agglomerates into primary particles) and uniform spatial distribution in the polymer matrix, since agglomerates trap air and act as a place for the onset of deterioration, which leads to premature failure of the material [8, 9]. The incorporation of fillers into the polymer composition primarily depends on the size of the filler being introduced, which has a significant impact on the thermal mechanical properties of the composite [10, 11]. So far, little attention has been paid to the influence of the chemical composition and stability of nano-CaCO3 on the overall mechanical and thermal stability of PE.

In this study, the physical and mechanical properties of PE nanocomposites filled with nano-calcium carbonate (nano-CaCO3) particles were investigated. The polyethylene composition contained 5% to 15% nano-calcium carbonate. The samples of the calcium carbonate-reinforced polyethylene composites were compared with pure polyethylene. The differences in mechanical strength, deformation behavior and modulus of the material with the nano-CaCO3 particles are discussed.

MATERIALS AND RESEARCH METHODS

Materials

Low density linear PE (F-0320) with a liquid flow index (LWI) = (2.16 kg, 210ºC) of 3 g/10 min was provided by Uz-Kor Gas Chemical LLC JV. Nanocalcium carbonate (nano-CaCO3) was obtained in the laboratory with a size of 1 μm.

Preparation of nano-CaCO3/PE nanocomposites

The components were melted in a Brabender Plastograph (Germany). After first melting the PE in a plastograph at 180 ºC, nano-CaCO3 was added and mixed for 8 minutes to ensure better mixing of the components. Then, the samples were

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injected at 180 ºC for mechanical studies in a Mercator 1971 (Poland) injection molding machine. Nanocomposites were obtained by adding 5%, 10% and 15% of nano-CaCO3 particles to the PE composition.

Mechanical Analysis

Tensile tests were performed on a Shimadzu AG-X PLUS (Japan) in accordance with the international standard ASTMD 638. Tests were performed at a speed of 1 mm/min up to 0.3% deformation to measure the elongation modulus (E), followed by a speed of 20 mm/min to measure the yield stress ($\boldsymbol{\sigma}$) and deformation ($\boldsymbol{\varepsilon}$).

RESULTS AND DISCUSSION

Introducing calcium carbonate as a filler into polyethylene and obtaining nanocomposites, it is appropriate to conduct analyses based on the results presented below to evaluate the effect of particle size on mechanical properties. The mechanical properties results presented in Figure 1 are obtained under laboratory conditions for composites obtained with the participation of nano-$CaCO_3$ particles, with 5%, 10% and 15% PE content and the results of changes in mechanical strength values are presented.

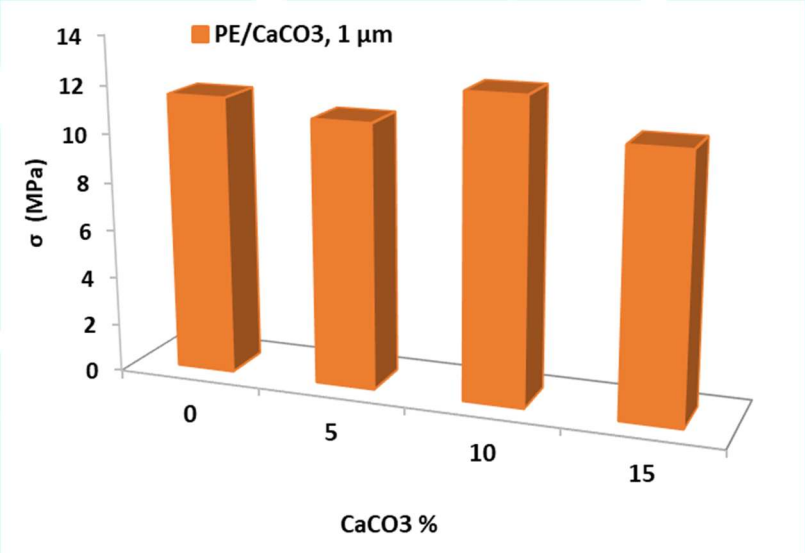


Figure 1. Effect of the proportion of calcium carbonate in polyethylene on mechanical strength values

As can be seen in Figure 1, significant changes in the mechanical properties of polyethylene were observed with an increase in the calcium carbonate content. The addition of nano calcium carbonate obtained in laboratory conditions and with a size range of 1 µm resulted in the changes in the mechanical properties of polyethylene shown in Figure 1. Initially, when 5% $CaCO_3$ was added, the yield stress (σ) decreased slightly, from 11.5 MPa to 11.2 MPa. This small decrease indicates that the nanoparticles were not completely dispersed in the polymer matrix due to the large particle size. At 10% $CaCO_3$, the strength increased to 13 MPa. However, when the $CaCO_3$ content reached 15%, the stress decreased again

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and amounted to 11 MPa, which indicates that the particles were not evenly distributed in the matrix due to the formation of particle agglomerations at high concentrations.

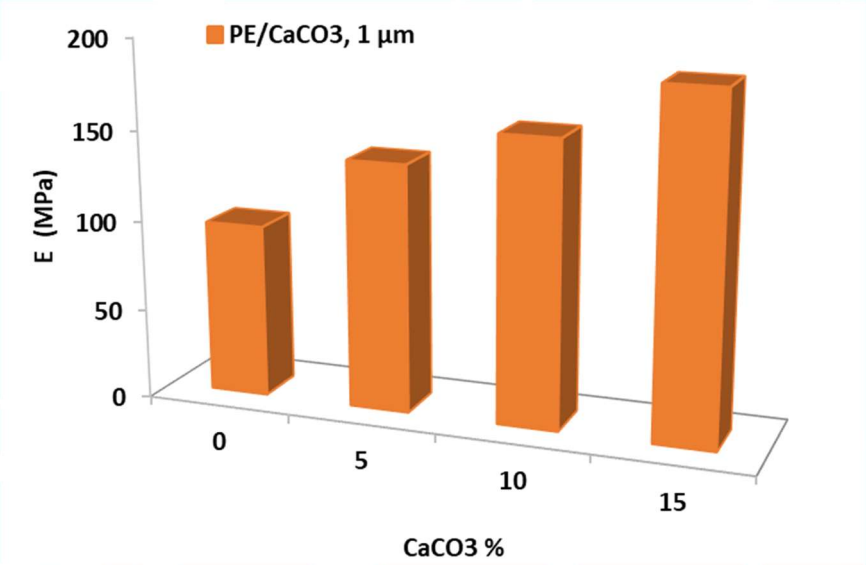


Figure 2. Effect of calcium carbonate content in polyethylene on Young's modulus values

It was found that the Young's modulus values, which represent the strength and stiffness of the material, also increased in composites with an increase in the proportion of nano-CaCO3 in the PE composition. In the composites obtained in laboratory conditions with the participation of nano-CaCO3, the initial value was 96.2 MPa, but with the addition of 5% $CaCO_3$ it increased to 140.2 MPa, at 10% - to 159.6 MPa, and at 15% - to 192.3 MPa. This confirms the role of the particles in increasing the stiffness.

Although the particles increase the stiffness in the polymer matrix, they do so at the expense of elasticity and ductility. As the material becomes stiffer and stronger, its elasticity decreases, which ultimately affects the material's elongation at break (Figure 3).

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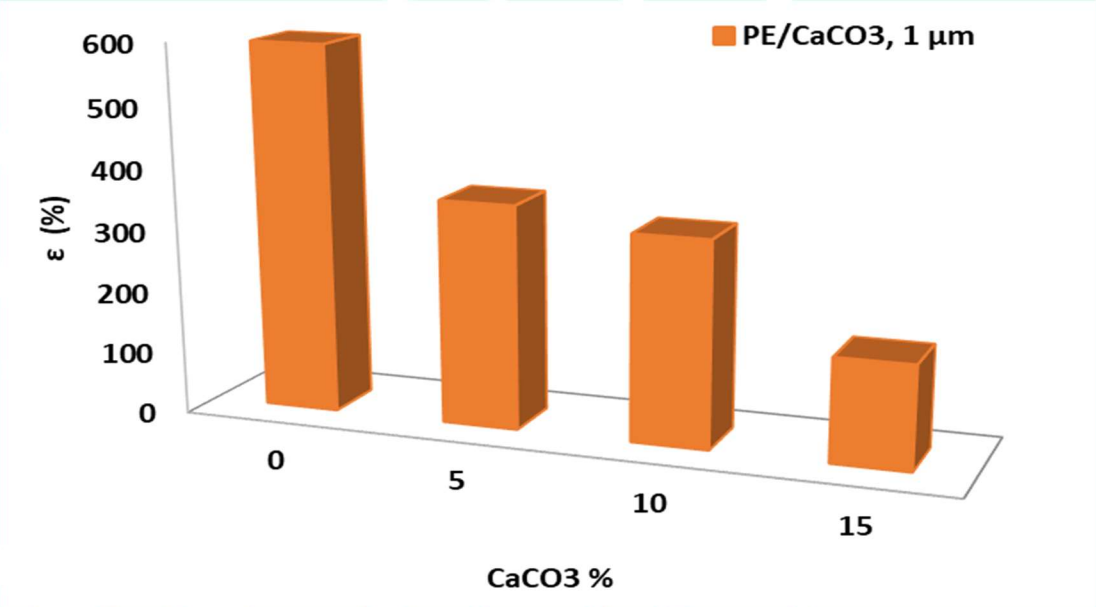


Figure 3. The effect of the proportion of calcium carbonate in the composition of polyethylene on the values of relative elongation at break

The effect of filler particle size on the elongation at break of the composite of PE and nano-CaCO3 was clearly visible. The elongation at break (ε) of the composite obtained with nano-CaCO3 in laboratory conditions was 596.1% for the original polyethylene, but decreased to 358.9% with the addition of 5% $CaCO_3$, and to 164.5% with a 15% loading. These changes indicate a decrease in the elasticity and flexibility of the composites. In particular, a significant decrease in plasticity was observed with increasing particle size, indicating that the material became brittle.

The results obtained show that the addition of calcium carbonate significantly changes the mechanical properties of polyethylene. Samples with 5% and 10% $CaCO_3$ addition maintained the optimal balance between strength and flexibility. However, when the $CaCO_3$ content was increased to 15%, although the strength increased, a decrease in elasticity was observed. These results are consistent with previous studies, for example, studies on high-density polyethylene and calcium carbonate-based composites also showed an increase in Young's modulus and a decrease in elasticity with increasing $CaCO_3$ content [2]. The addition of nanoparticle $CaCO_3$ in the size range of 1 µm increases the hardness and strength properties of PE-based nanocomposites to some extent, but these changes occur at the expense of plasticity. It is observed that particles of this size cannot transmit stress effectively due to their dispersion properties, relatively small surface area, and tendency to agglomerate. Therefore, these composites are suitable for applications where strength is required but low elasticity is required. The results showed that the addition of $CaCO_3$ increases the hardness and strength of the material, but reduces elasticity. Samples with 5-10% $CaCO_3$ addition showed

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optimal results, which suggests that this may be the most suitable range for practical applications.

CONCLUSION

The above analysis shows that the mechanical properties of polyethylene-based nanocomposites are directly dependent on the amount of $CaCO_3$ particles added to the composition. Under the influence of nano-$CaCO_3$ particles with a size of 1 μm, the composites had relatively low strength, and the elasticity decreased sharply. Although the Young's modulus increased in all cases, these indicators led to the embrittlement of the composite. From a practical point of view, by adding $CaCO_3$ in an amount of 5–10%, it is possible to obtain polyethylene composites with high strength and a sufficient level of elasticity. This allows them to be effectively used in various packaging materials, film products or other industrial sectors where strong but flexible elements are required.

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