INFLUENCE OF NANOPARTICLES ON THE MECHANICAL AND THERMAL PROPERTIES OF POLYMER NANOCOMPOSITES

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Abstract. This article studies the effect of different types of nanoparticles on the mechanical and thermal properties of polymer nanocomposite materials. In the framework of the study, nanoparticle components such as silicon oxide (SiO_2), aluminum oxide (Al_2O_3), and carbon nanotubes were added to the polymer matrix (main polymer) in different concentrations, and experiments were conducted on the prepared samples. The mechanical (tensile, bending) and thermal properties were determined and their changes were observed. The results showed that the optimal amount of nanoparticles plays an important role in strengthening the polymer matrix and increasing heat resistance. High efficiency can be achieved using the nanoparticles and dispersion methods selected in the study.

Keywords: polymer nanocomposites, nanoparticles, mechanical properties, thermal properties, SiO_2, Al_2O_3, carbon nanotubes, aggregation.

Annotatsiya. Ushbu maqola turli turdagi nanopartikullarning polimer nanokompozit materiallarining mexanik va termal xususiyatlariga ta'sirini o'rganadi. Tadqiqot doirasida polimer matritsaga (asosiy polimer) turli konsentratsiyalarda kremniy oksidi (SiO_2), alyuminiy oksidi (Al_2O_3) va uglerod nanotubalari kabi nanozarracha komponentlar qo‘shildi va tayyorlangan namunalar ustida tajribalar o‘tkazildi. Mexanik (uzilish, egilish) va issiqlik xossalari aniqlanib, ularning o'zgarishi kuzatildi. Natijalar shuni ko'rsatdiki, nanozarrachalarning optimal miqdori polimer matritsasini mustahkamlash va issiqlikka chidamliligini oshirishda muhim rol o'ynaydi. Tadqiqotda tanlangan nanozarrachalar va dispersiya usullari yordamida yuqori samaradorlikka erishish mumkin.

Kalit so'zlar: polimer nanokompozitlari, nanozarrachalar, mexanik xususiyatlar, issiqlik xossalari, SiO_2, Al_2O_3, uglerod nanotubalari, agregatsiya.

Аннотация. В данной статье изучается влияние различных типов наночастиц на механические и термические свойства полимерных нанокомпозитных материалов. В рамках исследования в полимерную матрицу (основной полимер) в различных концентрациях добавлялись такие компоненты наночастиц, как оксид кремния (SiO_2), оксид алюминия (Al_2O_3) и углеродные нанотрубки, и проводились эксперименты на приготовленных образцах.

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Определены механические (растяжение, изгиб) и термические свойства, а также наблюдались их изменения. Результаты показали, что оптимальное количество наночастиц играет важную роль в укреплении полимерной матрицы и повышении термостойкости. Высокая эффективность может быть достигнута с использованием выбранных в исследовании наночастиц и методов диспергирования.

Ключевые слова: полимерные нанокомпозиты, наночастицы, механические свойства, термические свойства, SiO_2, Al_2O_3, углеродные нанотрубки, агрегация.

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Polymer materials are widely used in modern industry, as they are lightweight, inexpensive, and easy to form. However, many polymers are not resistant to high mechanical loads and extreme temperature conditions, which limits their use in some strategic industries, in particular, in the aviation, automotive, construction, and electronics industries. To overcome these shortcomings, polymer-based composite materials are being created. In recent years, polymer nanocomposites have attracted special attention. Nanocomposites contain nanoparticles with a size of 1–100 nm, which can dramatically improve the structural, mechanical, and thermal properties of the matrix. For example, nanoparticle types such as SiO_2, Al_2O_3, TiO_2, and carbon nanotubes are effective in increasing indicators such as strength, elasticity, and thermal stability.

The introduction of nanoparticles in polymer nanocomposites at different concentrations, their dispersion, and interfacial bonding significantly affect the overall properties of the material. For example, a low amount of well-dispersed nanoparticles creates new bonds in the structure of the material, strengthening it. However, at high concentrations, they agglomerate and form nuclei, creating points of mechanical weakness. This article analyzes in depth how these changes - namely, the amount and type of nanoparticles - affect the mechanical and thermal properties of the polymer. It also discusses the potential applications of these materials in industry.

Research and method: Polypropylene (PP) was chosen as the main polymer in the study because it is lightweight, recyclable, and widely used in industry. SiO_2 (5, 10, 15 wt%), Al_2O_3 (5, 10 wt%) and carbon nanotubes (1, 2, 3 wt%) were selected as nanoparticles. Each combination was prepared separately and homogenized by ultrasonic dispersion before addition. Samples were prepared by extrusion and pressing. Dog-bone-shaped probes for mechanical testing (ASTM D638) and small cross-sections for thermal analysis (Differential Scanning Calorimetry, thermogravimetric analysis) were taken from each composite sample.

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Experimental conditions were established at constant temperature (25 °C) and 50% relative humidity.

Mechanical tests were performed on a universal testing machine. Tensile strength, flexural strength and hardness were recorded. Thermal properties were determined using DSC (Differential Scanning Calorimetry) and TGA (Thermogaphic Analysis). While the melting point and heat capacity were determined by differential scanning calorimetry, the mass loss and thermal stability were evaluated by thermogaphic analysis. The table below shows some of the test results:

Table 1.

Effect of nanoparticle amount on mechanical properties

Sample	Gravitational force (MPa)	Bending force (MPa)	Hardness (Shore D)
Pure PP	32	45	68
PP + 5% SiO_2	38	52	72
PP + 10% SiO_2	42	57	76
PP + 2% CNT	48	60	80

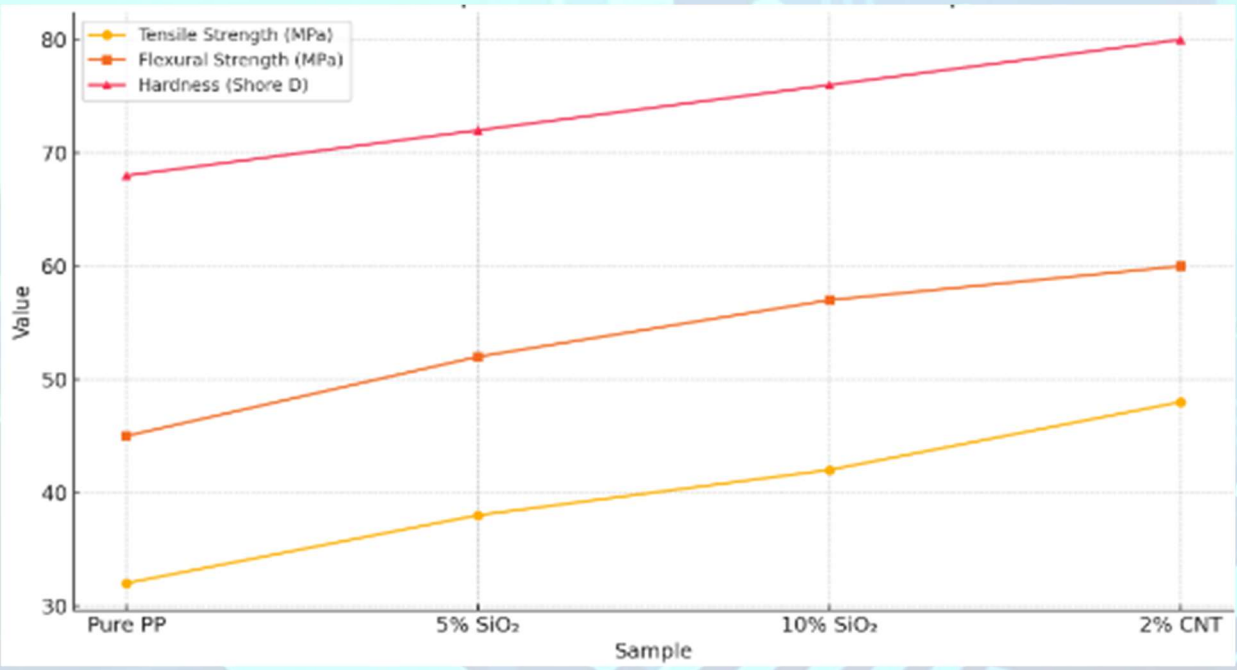


Figure 1. SEM image of CNT dispersion and aggregation (The image shows well-dispersed and agglomerated states of carbon nanotubes.)

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The tensile strength, bending strength, and hardness of polymer samples containing different types of nanoparticles were compared.

Results and discussion: The results of the study showed that the addition of low and medium amounts of nanoparticles significantly improves the mechanical and thermal properties of polypropylene-based composites. For example, in a sample with 10% SiO_2, the tensile strength increased from 32 MPa to 42 MPa, while a 2% content of carbon nanotubes increased this indicator to 48 MPa. It was observed that the long cylindrical shape of CNTs and their high surface area ensured their strong bonding with the matrix. At the same time, the DSC results showed a slight increase in the melting temperature, and Thermogravimetric Analysis showed a delay in mass loss, which indicates increased thermal stability. However, aggregation was observed at high concentrations of nanoparticles, particularly at 15% SiO_2 or 3% CNT. This phenomenon is also clearly visible in SEM images. The agglomerated nanoparticles caused stress concentration in one place, leading to the appearance of mechanical weak points. As a result, the bending strength and elasticity of the material decreased. It can be concluded that the presence of an optimal number and well-dispersed nanoparticles in polymer nanocomposites provides the best results. Surface modification or chemical coupling reagents can be used to improve the dispersion.

Conclusion: The results of this study show that the type, amount, and dispersion quality of nanoparticles play an important role in improving the mechanical and thermal properties of polymer nanocomposites. The addition of nanoparticles such as SiO_2, Al_2O_3, or carbon nanotubes in an optimal amount strengthens the structure of the polymer and increases its tensile, flexural, hardness, and heat resistance. At the same time, aggregation states that occur at high concentrations can weaken the properties of the material. Therefore, special attention should be paid to dispersion technology and methods for improving interfacial bonding in nanocomposite production. Polymer nanocomposites have wide potential, especially in the automotive, electrical, and construction industries, and research should be continued to commercialize and make them environmentally friendly in the future.

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