Study of The Dispersion Effect on the Mechanical Properties of Polypropylene Composites Reinforced With Polystyrene Nanofibers

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ABSTRACT

The purpose of this study was to construct a polypropylene composite reinforced with various weight ratios of polystyrene filaments and to examine the influence of the dispersion process on the mechanical characteristics of the finished composites. Utilized were polystyrene filaments with weight ratios ranging from 2% to 10%, with a weight increase of 0.2%. The influence of the polystyrene filament weight ratio on the final composite's mechanical characteristics, including Shore D hardness, density, modulus of elasticity, impact strength, and tensile strength, was investigated. According to the results, raising the weight ratio of polystyrene filaments enhanced all mechanical characteristics. The modulus of elasticity increased from 30 GPa with a reinforcement ratio of 2% to 90 GPa with a reinforcement ratio of 8%, and then decreased to 75 GPa with a 10% wt. whereas the density fell from 0.90 to 0.85 g/cm3 with a weight ratio of 2 percent to 10 percent filaments. When the weight percentage of fiber was raised from 2% to 8%, the impact strength rose to 3. 5 kJ/cm2 when 10% polystyrene nanofibers were present. In addition, the Shore hardness was enhanced from 30 to 50 by increasing the ratio of polystyrene nanofibers from 2% to 10% by weight. The material's tensile strength was also enhanced. When the filament weight ratio was raised from 2% to 8%, the tensile strength reduced from 32 MPa to 26.5 MPa. For all weight ratios of polystyrene filaments, the dispersion technique improved mechanical parameters such as tensile strength, impact strength, Shore D hardness, Young's modulus, and composite density.

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1. Introduction

In recent years, composite materials are used in almost every sector of society, including civic and military uses. Due to the advantages of these materials offer, such as light weight, convenience, and ease of use [1-2], they are considered key alternatives to many materials used in related industries as a result of the growth of science and technology. Composite materials were manufactured using two different phases . The first is the matrix material that charachterized by some properties such as lower density, elastic modulus, and stiffness than the other materials which was called the reinforcement ohase [3] . Reinforcing material, which can come in a range of shapes and sizes, including fibers [4], particles [5], and sheets [6] . The mechanical properties of the reinforcing material must be superior to those of the matrix material, such as ductility, elasticity modulus, and stiffness [7]. The matrix material can be polymer [8], ceramic [9] , or metal [10]. One of the easiest technical materials to use as a matrix for composites is polymer , Due to the presence of Van der Waals forces, the polymer has poor engineering properties; however, because it is a highly flexible material, it can be coupled with another strong material, such as ceramic or metal, to generate a high-strength material. The electrospinning technology, which depends on the electrical forces that can be created by external power supply sources, is a unique way to generate micro and nanofibers with high efficiency. Due to the large number of variables that can be controlled, including solution and processing conditions, this method has a high degree of controllability for creating nanofibers with various morphologies. [11] There have been a number of previous studies that looked into the impact of strengthening on the mechanical properties of polymers. In 2016, Aldabbagh et al. published a study on the effects of adding sawdust (4 and 2%) by weight to various sizes of natural rubber latex, including (5,3 and 7%), which were added to Asphalt type (40/50), which is produced from the Dora refinery at a temperature of 160 qC, and each additive was added to the asphalt separately. Then the two additives were combined to improve the properties of the asphalt binder and its performance during asphalt concrete . The mixture was tested physically and mechanically in accordance with ASTM specifications, and the results showed a significant improvement, including an increase in softening and increasing viscosity, which means more resistance to flow, as well as an improvement in cohesion and adhesion properties [12] . An investigation by Hameed et al. in 2021 aimed to study the effect of natural sisal fibers affected the mechanical properties of polymethyl methacrylate (PMMA) . 90 specimens were produced for use in this study. The samples are split into three primary groups: experimental groups consisting of 60

heat-cured PMMA samples with salinized sisal fibers in two different weight percentages (5% and 10% wt) and 30 heat-cured PMMA samples without additives (control). To assess the flexural strength of the specimens, a three-point bending test is used; impact testing is used to assess the impact strength of specimens. According to ASTM D-638, Charpy's machine and tensile test are conducted. For statistical analysis, the analysis of variance (ANOVA) test is employed. Results revealed that when reinforced specimens were compared to control specimens, the Impact test indicated a highly significant difference. After fiber reinforcing, tensile strength considerably improves. There is no statistically significant difference in flexural strength between the reinforced groups and the control group [13]. Impact strength is very important property ,it expressed in terms of the amount of energy absorbed before fracture, and it can calculated by [14]:

$$I.S = U/A \quad \ldots(1)$$

I . S = Impact strength (kJ / cm2) , U = Energy of fracture , A = cross-sectional area

On the other hand, surface hardness is very important property for experimental application, is a measurement of a surface's resistance to scratching , it can be calculate by Shore D hardness method.

2. Materials and Method

2.1 Materials

As a matrix phase, atactic polypropylene was utilized. It has the chemical formula [(H3C6)n], a density of 0.9 g/cm3, and a melting point of (160 ^{o} C) , it was obtained from Sigma Aldrich. As a reinforcement phase, polystyrene nanofibers PSNFs with a diameter of 75–100 nm were employed. PSNFs were created by the electrospinning method . The polymeric solution was kept in a syringe with a metallic needle with a diameter of 0.24 mm, which was coupled to a syringe pump to maintain a steady flow of fluid through the needle at 1 ml/hr. The needle was fitted with a positive electrode of the high voltage power supply HV. The negative electrode of the HV was connected to a grounded collector [15]. The conditions of the preparation of electrospun nanofibers include solution parameters were fixed at (0.1 w/v concentration of solution, 1.4 vescosity of solution and 0.1 µS/cm conductivity of solution) and systematic parameter were fixed at (HVPS = 20 kV, Distance =17 cm , Flow rate = 1 ml/hr, and Needle diameter = 0.24 mm) , as well as the rough collector was used. Figure 1. Show the set up of electrospinning system .

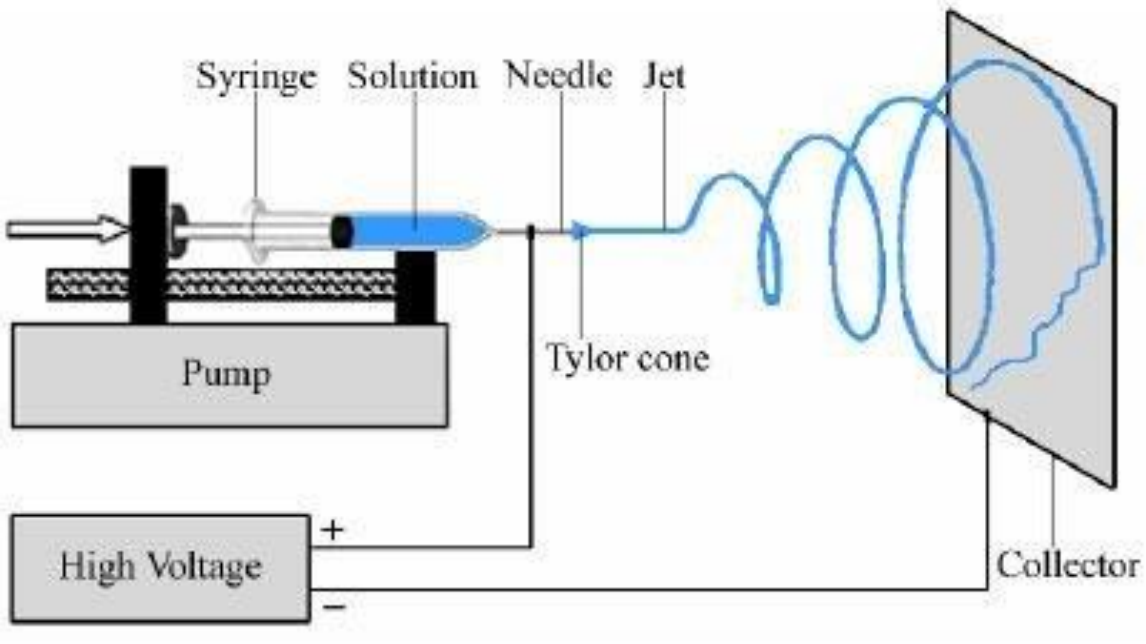

Figure 1. Electrospinning Set up

2.2 Methods

The polypropylene, PP and Polystyrene nanofibers were extruded at a temperature of 170 ° C. The materials were prepared for tensile testing using the (ASTM D638-87 technique) and assessed using a (computerized universal testing machine type) (WDW-50E, Jinan Shijin Group Company). Tensile testing were performed at room temperature at a constant strain rate of 10 mm/min. Tensile stress was identified and a stress-strain curve was produced as a sample lay untill it failed. After three checks, the results of each sample were averaged.. A tensile test was performed to limit the samples' Young's modulus. The density of the composites was determined using Archimedes' law. Shore D hardness was determined using a Durometer.

3. Results and discussion

3.1. Morphology of Polystyrene Nanofibrs by SEM images

Figure 2. showed the images of prepared polystyrene nanofibers by electrospinning technique**.** Free beads suggested nanofibers with a diameter of about 100 nm were obtained due to the stability of the injection cycle and a high stability between the conditions selected for the system operation, as the selection of appropriate conditions reduces the effect of rheological forces and the effect of

electric fields to connect the surface tension forces of the solution, reducing the effect of unrest in the pumping process [16].

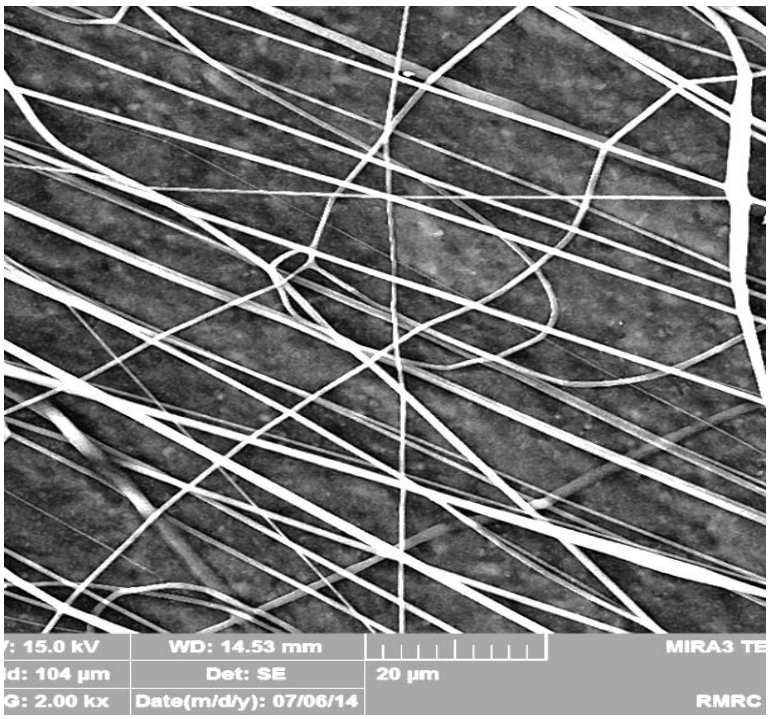

Figure 2: PS nanofibers by Electrospinning Technique

3.2 Shore D Hardness

The relationshipe between the contents of polystyrene nanofibers and the Shore D hardness of composites was depicted in Figure 3. The hardness of a composite rises as the proportion of polystyrene nono fibers in the composite rises. Polystyrene nanofibers are more crystallin than the PP matrix, and there is more contact between the matrix and polystyrene nanofibers, which increases the hardness of composites . The hardness of composites increases as the quantity of PSFNs increases. Crystalline microstructures enhance hardness, which leads to the formation of hardness. This is because the ability of microfibers to interact with polymer matrix and enhance PP and Polystyrene nanofiber interfaces leads to stronger linking and increased strength It is clear that the dispersion process increases hardness since the resulting composites are more homogeneous and have more compact surface contents. A similar variation was observed in ref.[17]

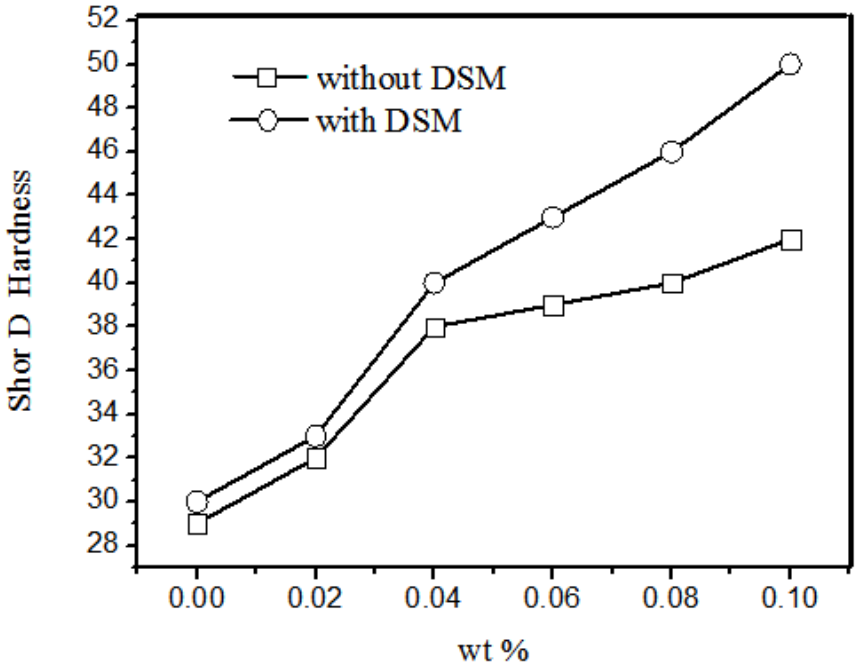

Figure 3: Relationship between Shore D hardness and Polystyrene nanofibers contents

3.3 Density

Figure 4 shows the density of the composite samples. We observe that decreasing the density of the composite results from increasing the weight ratio of polystyrene nanofibers in the composite. The composite sample adheres to the mixing rule since nanofibers are less dense than PP. The dispersion method (DSM) also yields lower density because the composites have good homogeneity and little agglomeration of the reinforcing phase [18].

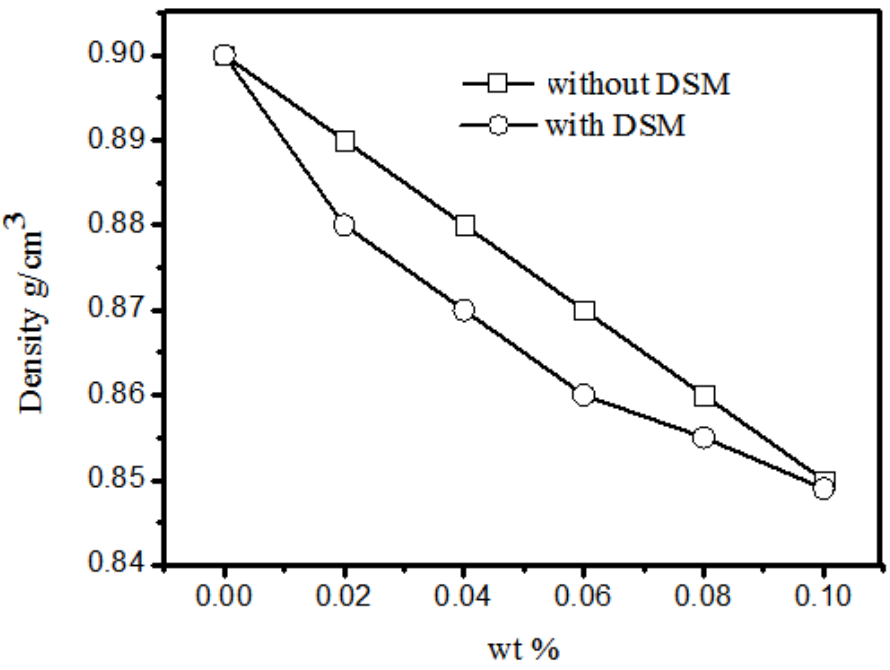

Figure 4: Relationship between the density and Polystyrene nanofibers contents

3.3 Tensile strength and Young's Modulus

The relationship between tensile strengths and nanofiber content is shown in Figure 5. Before the dispersion process, the tensile strength of PP/polystyrene nanofibers composites decreased from 32 MPa to 26 MPa as the percentage of polystyrene nanofibers increased from 2% to 8%. This is because brittle fracture was accured due to the aggregation of nanofibers [19] . We also find that the effect of the dispersion procedure on the tensile strength of nanocomposites appears as the tensile strength of nanocomposites increases. When the weight ratio of PS nanofibers is increased from 2% to 10%, the tensile strength of nanocomposites increases from 30 MPa to 45 MPa. This is due to polystyrene nanofibers has small agglomeration and more hemoginouse distribution in the matrix materials , this is leads to ductile fracture [19].

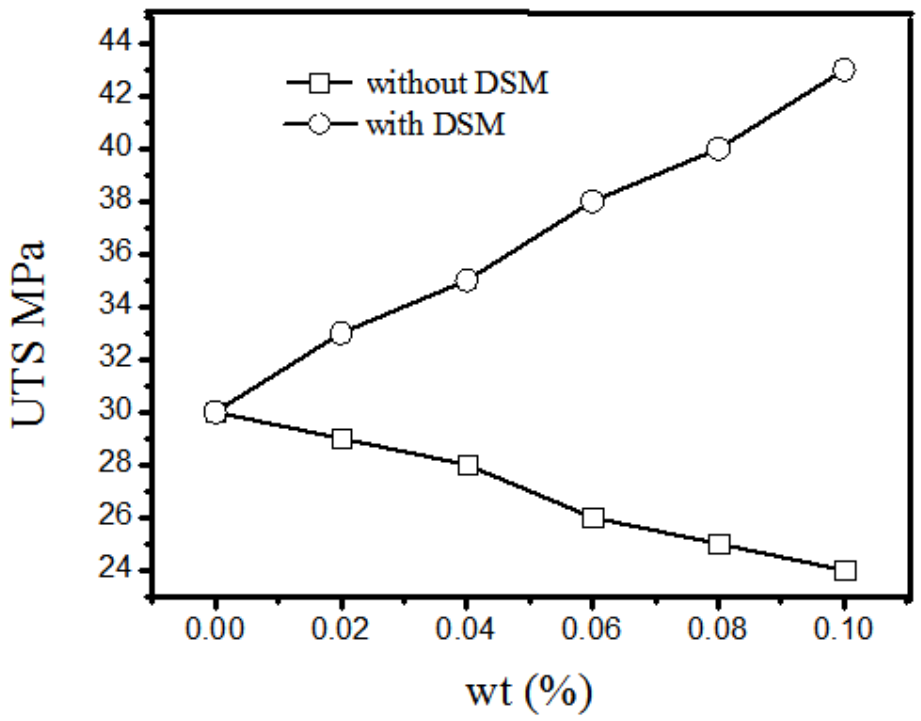

Figure 5. Relationship between the tensile strength and Polystyrene nanofibers contents

The weak chemical bond between the matrix and the fibers , which makes it impossible to transport randomly oriented fibers with sharp corners, could be to blame for the tensile strength drop induced by adding polystyrene fibers without using a dispersion procedure. Young's modulus increases when the weight ratio of Polystyrene nanofibers is increased from 2% to 8% wt, as seen in Figure 6. The effective dispersion of PS nano fibers into the polypropylene matrix to fill the gaps created by the composites sample preparation process accounts for the increased Young modulus values. As the content of Polystyrene nanofibers grows to 10% wt, the Young's modulus drops due to aggregation of the nanofibers at high content ratios, However, similar variation was observed by othe resarchers [19].

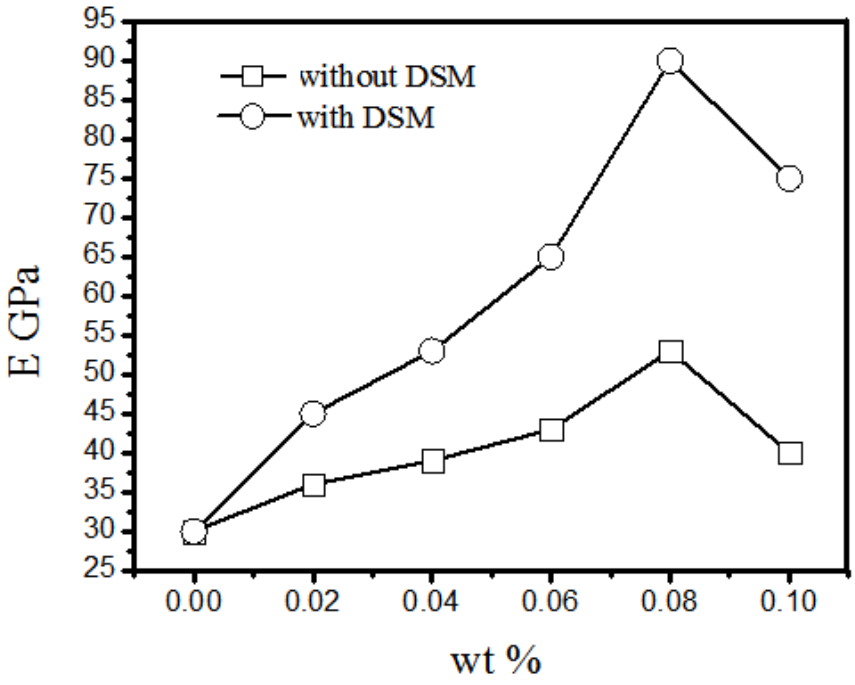

Figure 6: Relationship between the Young's modulus and Polystyrene nanofibers contents

3.4 Impact Strength

Figure 7 shows how a decrease in impact strength occurs as the weight ratio of polystyrene nanofibers rises from 2% to 8% wt (before dispersion). This is because aggregation of fibers creates cavities during the preparation process, which causes a crack to form. When the weight ratios of nanofibers are increased after dispersion , the impact strength increases. As a result of the fibers restraining the crack's extension by the materials composite and the dislocation, the fracture will change its direction and shape, and cracks will become micro cracks. As crack behavior changes and crack energy is lost, toughness increases. On the other hand, increasing the weight ratio of Polystyrene nanofibers to 10% causes brittle fracture, which reduces the impact strength of nanocomposite, A similar variation was observed in ref. [20]

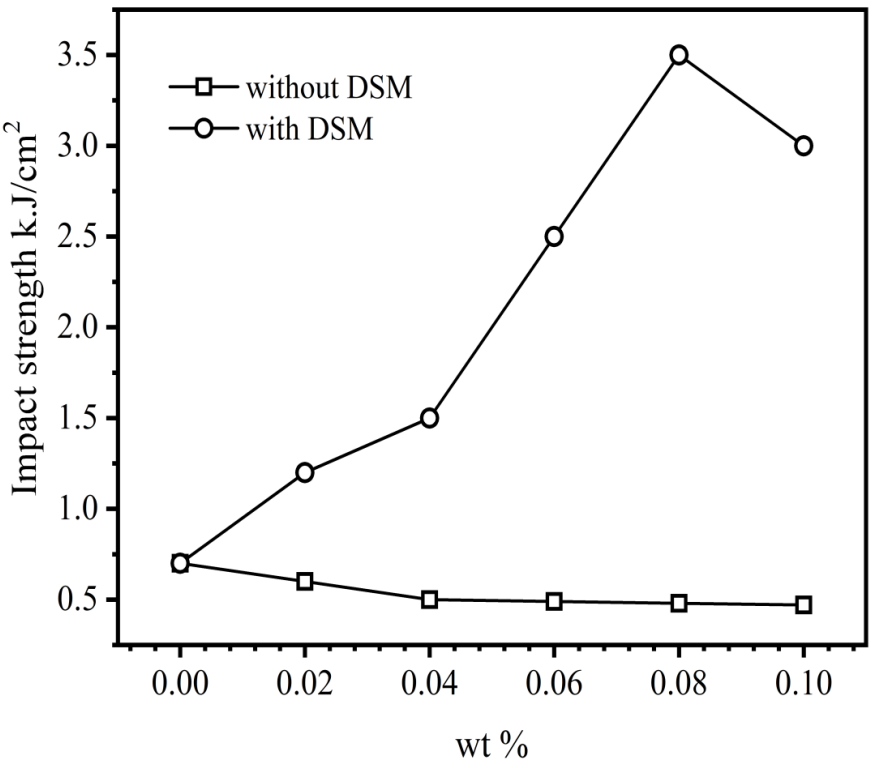

Figure 7: Relationship between the Impact strength and Polystyrene nanofibers contents

4. Conclusions

The mechanical characteristics of PP composites are enhanced by adding polystyrene nanofibers in the suitable amounts. The mechanical properties, such as density, impact strength, tensile strength, Young's modulus, and hardness, were dramatically enhanced following the dispersion of Polystyrene nanofibers throughout a PP matrix.

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دراسة تاثير التشتيت على الخواص الميكانيكية لمتراكبات البولي بروبلين المسلحة بالياف البولي ستايرين النانوية

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المستخلص

يهدف البحث الى و تطوير مركب البولي بروبلين المقوى بنسب وزنية مختلفة من الياف البوليسترين النانوية ، وكذلك دراسة تأثير عملية التشتت على الخواص الميكانيكية للمتراكب. تم دراسة زيادة النسبة الوزنية للالياف النانوية في المدى 2% الى 10% مع زيادة الوزن بنسبة 0.2٪ ، حيث تم دراسة تأثير نسبة وزن الياف البوليسترين النانوية على الخواص الميكانيكية للمتراكب ، والتي تشمل صلادة شور D ، والكثافة ، ومعامل المرونة ، ,مقاومة الصدمة ، وقوة الشد. اظهرت النتائج ، إن زيادة نسبة الوزن لالياف البولي ستايرين النانوية أدت إلى تحسين جميع الخواص الميكانيكية. زاد معامل المرونة من 30 كيكا باسكال مع نسبة تقوية 2 في المئة إلى 90 كيكا باسكال مع نسبة تقوية 8 في المئة ، ثم انخفض إلى 75 كيكا باسكال مع 10٪ وزن. من الألياف ، بينما انخفضت الكثافة من 0.9 إلى 0.85 غم / سم ^{3} بزيادة نسبة الياف التقوية النانوية من 2٪ إلى 10٪. عندما زادت النسبة المئوية من 2٪ إلى 8٪ ، زادت قوة التأثير إلى 3. 5 كيلوجول / سم ^{2} ، ولكن عندما كانت النسبة المئوية لألياف البوليسترين النانوية 10٪ ، قلت مقاومة الصدمة إلى 3 كيلوجول / سم ^{2}. علاوة على ذلك ، بزيادة جزء الوزن لألياف البوليسترين من 2٪ إلى 10٪ بالوزن ، تمت زيادة صلادة شور من 30 إلى 50. كما تم تحسين مقاومة الشد للمادة. عندما زادت نسبة وزن الالياف النانوية من 2٪ إلى 8٪ بالوزن ، انخفضت قوة الشد بالمثل من 32 ميكا باسكال إلى 26.5 ميكا باسكال. نتج عن استخدام التشتيت خصائص ميكانيكية أفضل مثل زيادة قوة الشد ، وقوة الصدم ، وصلادة شور ومعامل يونك ، وانخفضت كثافة نماذج المادة المتراكبة بزيادة النسبة الوزنية من الياف البوليسترين النانوية.