



Research Article

Enhancement of Mechanical Properties of Polyamide Hexaglycol by Dispersion of TiO₂ Nanofiller

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Abstract

The effects of 1, 2, 3, 4, and 5wt% of TiO₂ disperse nanofiller on mechanical properties of polyamide hexaglycol (PAHG) were investigated. Specimen was prepared by the hot vibration dispersion technique to make a PMNC. Hardness, tensile strength, ultimate tensile strength, young modulus, and impact at room temperature were tested. It has been found that enhancement in these properties starts at extra low weight percent (1wt%) nTiO₂. The maximum effect of nano TiO₂ addition was on tensile strength, and the lowest was on young modulus.

Keywords: Nanofiller; PMNCs; Hot vibration dispersion

Introduction

The reinforcement of polymers using fillers, whether inorganic or organic, is common in the production of modern plastics. Polymeric nanocomposites (PNCs) represent a radical alternative to the conventional filled polymers or polymer blends. In contrast to conventional systems, where the reinforcement is of the order of microns, PNCs are exemplified by discrete constituents of the order of a few nanometers (<100 nm) in at least one dimension [1-4]. The small size of the fillers leads to an exceptionally large interfacial area in the composites. The interface controls the degree of interaction between the filler and the polymer and thus controls the properties. As

in conventional composites, the interfacial region is the region beginning at the point in the fibre at which the properties differ from those of the bulk filler and ending at the point in the matrix at which the properties become equal to those of the bulk matrix [5-8]. Nanometer-sized fillers have been made from different organic and inorganic particles, and they impart improved properties to composite materials [9]. Different fillers have been used to prepare polymer/inorganic particle nanocomposites, including metals (Al, Fe, etc.), metal oxides (ZnO, Al₂O₃, TiO₂, etc.), nonmetal oxide (SiO₂), and others (SiC) [9-14]. The selection of nanoparticle filler depends on the desired thermal, mechanical, and electrical properties of the nanocomposites [15-29]. The aim of this research

was to study the effect of the weight percent of TiO₂ anatase nanofiller particles on the hardness, tensile strength, and creep at room temperature of nano TiO₂/PAHG polymer matrix composite.

Experimental Work

Materials

Polyamide hexaglycol (PAHG) containing resin and hardener was supplied from SICOMIN, USA, and 99.9% TiO₂ purchased from HORIBA, Germany with 10-30 nm particle size range were used as a matrix and a nanofiller. Mechanical properties of both polymer matrix and ceramic nanofiller are listed in Table 1.

Table 1 Mechanical Properties of PAHG, and nTiO₂

Property	PAHG	nTiO ₂
BHN (MPa)	26	130
T.S. (MPa)	15	344
U.T.S (MPa)	107	800
E (GPa)	42	122
Impact	50	415

Specimen preparation

Weighing: Table 2 illustrates the weights of nTiO₂, PAHG resin, and PAHG hardener; weight percent of PAHG resin to hardener was 1:3.

Table 2 Weights (gm) of nTiO₂, PAHG resin/hardener

Specimen	nTiO ₂	PAHG
1	1	66 resin + 33 hardener
2	2	65.4 resin + 32.6 hardener
3	3	64.7 resin + 32.3 hadener
4	4	64 resin + 32 hardener
5	5	63.7 resin + 31.3 hardener

Mixing and solidification

After weighing powder of nTiO₂ was mixed with PAHG resin using a magnetic stirrer with a very low speed (30 rpm) for 15 min at 50°C, the hardener was dropped over the mixture with continuous stirring at the same speed for 20 min at room temperature. And then the mixture was poured in a special mold according to the different standard shapes of tests, left for 24 hrs at room temperature for solidification.

Testing

Brinell testing device type (Wilson instrument,

Hardness tester, USA) with a tungsten carbide ball (10 mm in diameter) was applied according to ASTM D730-98. The device was connected to a digital system type (Sony 210) which gave direct results.

Tensile test was conducted according to ASTM E 623-92, using a set type (Instron 1195 Tensile Test) with the load of 5KN and the strain range of 0.5 mm/min. The device was connected to a digital reading and graphing unit type PLC 1800.

Charpy impact test device type CDM, U.K results were calculated according to Equation (1).

$$E = mg(h_1 - h_2) \quad (1)$$

where m was the mass of pendulum (25 kg), g was the acceleration (9.8), and h₁, h₂ were the heights of the pendulum before and after striking the specimen, respectively.

Results

Figure 1 illustrates SEM of PAHG/nTiO₂ (PMNC). We can see the good dispersion and high interaction between the polymer matrix and nano reinforcing particles. This may lead us to concluding that there is an enhancement in mechanical properties even at low nTiO₂ filler, as we shall see.

Table 3 illustrates the tensile strength, ultimate tensile strength, and young modulus of PAHG/nTiO₂ PMNC.

Table 3 Mechanical Properties of PAHG/nTiO₂ PMNC

Mechanical Property	TiO ₂ /%				
	1	2	3	4	5
Tensile strength (MPa)	180	380	593	820	1460
Ultimate Tensile Strength (MPa)	270	512	874	1050	2600
Young Modulus (GPa)	110	317	548	927	1138
Brinell Hardness Number (MPa)	83	171	326	781	1297
Impact (J)	275	498	863	1023	2468

Discussion

The nanoscale reinforcing phase can be grouped into three categories: nano particles (0-D), nanotubes (1-D), and nanoplates (2-D). In such case of nanoparticles as in our research, the particle size and distribution

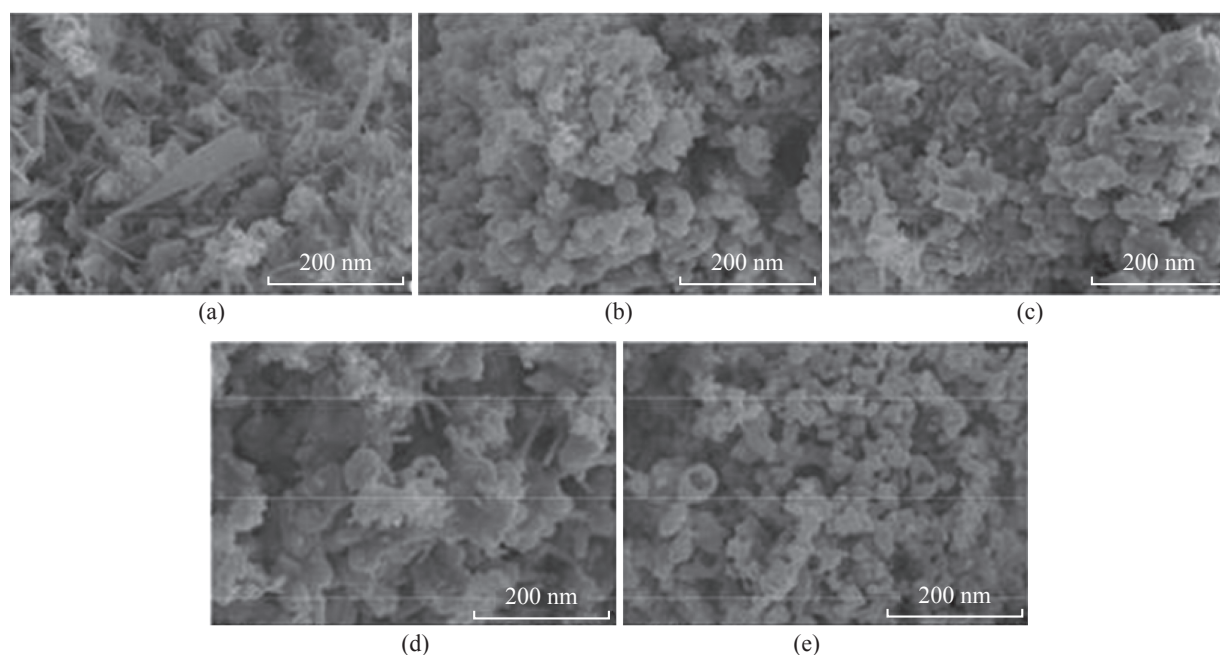


Fig. 1 SEM of PAHG/nTiO₂ PMNC (a) 1%, (b) 2%, (c) 3%, (d) 4%, (e) 5% TiO₂.

are of great importance. Depending on the types of nanoparticles added, the mechanical properties of PMNC can be altered. The changes in modulus and strength depend strongly on the degree of interaction between the nano reinforcing particles and the polymer matrix. Figure 1 illustrates SEM of PAHG/nTiO₂ (PMNC). We can see the good dispersion and high interaction between the polymer matrix and nano reinforcing particles; this may lead us to concluding that there is an enhancement in mechanical properties even at low nTiO₂ filler, as can we see from Table 3 which shows the mechanical properties of PAHG/nTiO₂ (PMNC). The tensile strength of polymer matrix nanocomposites (PMNCs) is the force required to pull the composite to the point where it breaks. Practically, the tensile strength of a PMNC is the maximum amount of tensile stress that can be subjected to before failure. That PAHG is a brittle (Table 1) material means that it does not have a yield point, and that the ultimate tensile strength (UTS) and breaking strength are the same. The advantages of using nanoparticles as the reinforcement is that their size is smaller than the critical crack length that typically initiates failure in the composite, and as a result, nano reinforcing particles provide improved strength.

When we compare the values of mechanical properties of PAHG polymer matrix, nTiO₂ particles listed in Table 1, and those of PAHG/nTiO₂ PMNC produced from them, we may conclude the following

points:

1. The effect of nTiO₂ addition starts to show on different mechanical properties even at the extra low weight percent. For example, the addition of 1% Wt nTiO₂ increases the tensile strength from 15 MPa which may be a neglected value up to 180 MPa directly, while the other properties as ultimate tensile strength, Brinell hardness number, impact, and young modulus values increase from 107, 26, 55 and 22 MPa respectively up to 270, 83, 275 and 110 GPa respectively. This increasing effect continues with the addition of weight percent till it reaches its maximum value at 5% nTiO₂ wt% for all properties (Table 3).

This large enhancement in mechanical properties makes the PAHG/nTiO₂ PMNC reach at some points to the excellent mechanical properties of metals and certain types of ceramic.

2. The increscence in mechanical properties of PAHG/nTiO₂ PMNC is irregular in spite of the regular increase in nTiO₂ weight percent. This can be explained by looking at Fig. 1 which shows the SEM images of 1, 2, 3, 4, 5) wt% of nTiO₂. From this figure we may notice the differences between the dispersion patterns of specimens, and that the concentration areas of reinforcing nTiO₂ through the PAHG polymer matrix lead to this irregularity in the increscence of mechanical properties of the produced PAHG/nTiO₂ PMNC. We must also consider that

the physical interaction between PAHG matrix and nTiO₂ reinforcement increases with the increasing of nTiO₂ weight percent due to the increase in the contact surface area between both polymer matrix (PAHG) and nTiO₂ reinforcement, leading to an increase in all the properties of polymer matrix nano composite, and hence enhances mechanical properties.

3. Despite the fact that the addition of nTiO₂ particles leads to a huge enhancement in mechanical properties (in our research), but this enhancement is not equal all over the studied properties. In a simple frame, nTiO₂ addition effects on some properties greater than the others. At the weight percent of 5% nTiO₂ as an example, we may arrange the properties according to their changes with the nTiO₂ addition as follows (Tables 1 and 3):

i. Tensile strength increased from 15 MPa for PAHG matrix up to 1460 or 1.460 GPa, while the ultimate tensile strength increased from 22 up to 2600 or 2.6 GPa.

ii. The effect on Brinell hardness number came in the second stage, increasing from 26 to 1297 or 1.297 GPa.

iii. Impact value was only 55 J for PAHG and increased to 2468 J for PAHG/nTiO₂ PMNC.

iv. The lowest effect for nTiO₂ addition was on young modulus which increased from 40 MPa for PAHG up to 1138 or 1.138 GPa for PAHG/nTiO₂ PMNC.

The enhancement in mechanical properties of PAHG/nTiO₂ PMNC makes it useful in applications where low weight and high mechanical properties are required, such as protective body armor substrates.

Conclusions

The addition of 1-5% nTiO₂ to PAHG increased the hardness, tensile strength, ultimate tensile strength, young modulus, and impact strength. A 5 % nTiO₂ specimen gave the highest change, and the most effect was on tensile strength.

Competing Interests

The authors declare that they have no competing interests.

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