Mechanical And Physical Properties Of Polyurethane Composites Reinforced With Carbon Black N990 Particles

Ismail Ibrahim Marhoon

Abstract: The effects of carbon black N990 on polyurethane properties with different weight fraction (2, 4, 6, 8, and 10 wt%) of the former were investigated in terms of tensile strength, hardness, impact strength, flexural strength, and density. The tensile strength increased when 4 wt% carbon black was added. The impact strength also improved by 33% at the same percentage of carbon black. Flexural strength improved by 12% at 6% wt., in comparison with the neat samples. Moreover, the hardness and density increased with increasing carbon black fraction for all samples. Thus, carbon black N990 acts as a particulate reinforcement that improves the mechanical properties of polyurethane.

Keywords: Polyurethane, Carbon Black, N990, Mechanical Properties, Physical properties, Composite-reinforced Particulate, Tensile, Impact, Density.

1. INTRODUCTION

High-performance polymer composites are increasingly useful in engineering applications under hard working conditions. The materials must provide unique mechanical and physical properties when combined with low specific weights [1]. Polyurethane resin systems are progressively applicable as matrices of composite materials and serve as casting resins, electrical potting compounds, automotive suspension bushings, high performance adhesives, surface sealants, surface coatings, and synthetic fibers. However, polyurethane resin systems usually contain fillers because the polymer matrix must withstand high mechanical loads. These fillers can be chosen as fibers or spherical particles [2]. A new approach that aims to overcome the basic problem of composite materials uses fillers in the nanometer scale, which is an aspect of nanotechnology [3]. The new approach demonstrates the potential to fundamentally change thermosetting characteristics and thermoplastic polymers, improving their general performance [4, 5]. Carbon black is one of the nanoparticles commercially produced in tons. Therefore, the three main properties of carbon black are particle size, structure (aggregate), and surface chemistry. Carbon black is basically carbon element in the form of very fine particles having an amorphous molecular structure. Depending on the production method, the average diameters of primary particle in several commercial carbon blacks range at 10–500 nm, while the average diameters of primary aggregates span 100–800 nm [6-8]. Carbon black is one of the nanomaterials used in modifying the mechanical, electrical, and other physical properties of polymers. Carbon conductive fillers in polymer matrices have recently emerged as another promising material because of high aspect ratio, low cost, easy production, low resistance, low density, and high conductivity [9,10].

Many studies have been conducted to improve polymers by adding carbon black, which enhances the mechanical and physical properties. Dehghani et al. improved the electrical conductivity of epoxy resins by adding carbon black (4%-33 w%) [11]. Abdul Khalil et al. enhanced the flexural and impact properties and the thermal stability of epoxy by filling with three types of carbon black [12]. Kim et al., Etika et al., and Wei et al. improved the electrical conductivity of epoxy by using carbon black as a hybrid nanofiller [13-15]. Asrar et al. studied the effect of carbon black on the electrical conductivity of unsaturated polyester and found that addition of carbon black changed the volume resistivity of the polyester. [16], Salman enhanced the tensile, flexural, impact, and hardness properties of unsaturated polyester with carbon black fi lling [17]. The objective of this research is to improve the mechanical properties of polyurethane resin by adding carbon black nanofillers (CB-N990) at different weight fractions and to optimize the effect of CB-N990 loading as well as the economic efficiency by using low-cost nanoparticles.

2. EXPERIMENTAL

2.1 Materials

A polyurethane system made from solvent-free low-viscosity polyurethane resin (Fosroc Nitofill UR63) was prepared. When mixed in desired amounts, the polyurethane reacted to form a tough and slightly flexible resin with good adhesion, viscosity of 1.0 poise at 35 °C, and specific gravity of 1.067 at 25 °C. CB-N990 filler was purchased from Alexandria Carbon Black, Egypt. Table (1) lists the carbon black properties according to the information provided by the supplier.

<table>
<thead>
<tr>
<th>Property</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade</td>
<td>N-990</td>
</tr>
<tr>
<td>Iodine No., mg/g</td>
<td>5–15</td>
</tr>
<tr>
<td>pH of water suspension</td>
<td>7–11</td>
</tr>
<tr>
<td>Dust content, max%</td>
<td>8</td>
</tr>
<tr>
<td>Bulk density, kg/m3, min</td>
<td>330</td>
</tr>
<tr>
<td>Specific surface, mg/g</td>
<td>12–16</td>
</tr>
<tr>
<td>Average size of particles, nm</td>
<td>&gt;200</td>
</tr>
<tr>
<td>Ash content, max%</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Table 1: Properties of CB-N990 used in this research according to the information provided by the supplier.

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2.2 Composite preparation
CB-N990 is added as a reinforcement material to the polyurethane resin system under different weight fractions (2%, 4%, 6%, 8%, and 10%). CB-N990 was added carefully and gradually to avoid loss. The matrix was stirred for 15 min to ensure that the carbon black was well-mixed until a homogenous mixture was obtained within the polyurethane matrix. The mixture was sonicated in an ultrasonic wave bath machine (Kawa 9050) at 40KHz operating frequency and 60W for 15 min to avoid generation of heat, which affects polyurethane resin properties, and to disperse the nanoparticles homogeneously. Afterwards, a hardener was added to the mixture at a ratio of 1:3 by weight under gentle mixing, and the mixture was poured into the mold from one corner to avoid the formation of bubbles that cause cast damage. Pouring was continued until the mold filled the required level. The mixture left in the mold for 24 hr at room temperature to allow solidification.

2.3 Tests methods of Composites
Three samples were prepared for each test, except for hardness, where five readings were taken from different places of the cast to get high accuracy. Tensile and flexural strength tests were applied using a Tinius Olsen universal testing machine (H100KU). A tensile test at cross head speed of 5 mm/min in accordance with ASTM D638M-87b [18] and a flexural test in accordance with ASTM D790 and three-point bending was used with a recommended testing span to depth ratio of 16:1 [19]. Sample hardness, in terms of Shore hardness, was measured using a hardness tester and according to ASTM D4812 [21]. The density of the composite was determined by a buoyancy test according to ASTM D792, where a sinker and wire keeps the specimen in water; and during immersion in distilled water at 23°C where a sinker and wire keeps the specimen weighed in air according to ASTM D792, where the specimen is separately weighed in air and during immersion in distilled water at 23°C where a sinker and wire keeps the specimen weighed in air according to ASTM D792, where the specimen is separately weighed in air and during immersion in distilled water at 23°C. The density of the composite was determined by a buoyancy test according to ASTM D792, where the specimen is separately weighed in air and during immersion in distilled water at 23°C where a sinker and wire keeps the specimen completely submerged as density and specific gravity are calculated by the equation 1 and 2 below [22]:

\[ \text{SG} = \frac{m_d}{(m_a - m_w)} \]

\[ \rho = \frac{\text{SG} \times \rho_w}{1 + \frac{\rho_w - \rho}{\rho}} \]

where \(\rho\) is the density (gr/cm³); \(\text{SG}\) is the specific gravity; \(m_a\) is the mass of specimen in air; \(m_w\) is the mass of specimen in water; and \(\rho_w\) is the water density at 23°C and equal to 0.9975 gr/cm³.

3. RESULTS AND DISCUSSION
The results of mechanical and physical properties of the polyurethane system under different weight fraction percentages of CB-N990 are presents in Table 2

<table>
<thead>
<tr>
<th>Carbon Black wt%</th>
<th>Tensile Strength MPa</th>
<th>Flexural Strength MPa</th>
<th>Impact Strength KJ/m²</th>
<th>Shore D Hardness</th>
<th>Density gr/cm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>PU</td>
<td>14.51</td>
<td>24.96</td>
<td>3.9</td>
<td>70.1</td>
<td>1.1705</td>
</tr>
<tr>
<td>PU+CB2%</td>
<td>16.5</td>
<td>25.85</td>
<td>4.6</td>
<td>74.9</td>
<td>1.2019</td>
</tr>
<tr>
<td>PU+CB4%</td>
<td>17.85</td>
<td>26.98</td>
<td>5.2</td>
<td>77.8</td>
<td>1.2305</td>
</tr>
<tr>
<td>PU+CB6%</td>
<td>16.9</td>
<td>27.58</td>
<td>4.2</td>
<td>80.3</td>
<td>1.2805</td>
</tr>
<tr>
<td>PU+CB8%</td>
<td>15.92</td>
<td>26.66</td>
<td>3.8</td>
<td>84.35</td>
<td>1.3015</td>
</tr>
<tr>
<td>PU+CB10%</td>
<td>15.59</td>
<td>25.89</td>
<td>2.6</td>
<td>86</td>
<td>1.3205</td>
</tr>
</tbody>
</table>

3.1 Tensile Test
Figure 1 and Table 2 shows the graph of tensile strength at different CB-N990 percentages. The tensile strength increased as the CB-N990 weight percentage rose from 2% to 4%. The higher tensile strength might be related to better dispersion of the carbon black in the polyurethane matrix, the enhanced wettability, and the improved interfacial bond. The tensile strength also decreased as the weight percentage of carbon black increased from 6% to 10% wt. The decrease in tensile strength could result from several reasons such as weak interfacial bonding at the interface of the carbon black and the polyurethane matrix and large agglomerates that may form from the high surface energy of CB-N990, which decreases the total interfacial surface area of the composite material between reinforcement and matrix material [23,24].

![Fig.1](image)

**Fig.1**: Effect of weight fraction of carbon black N990 on the tensile strength of polyurethane

3.2 Flexural Test
Figure 2 and Table 2 shows the relationship between flexural strength and CB-N990 added to the polyurethane resin at different weight fractions. A maximum flexural strength of 27.58 MPa was obtained at 6% CB-N990 in comparison with the bending strength of neat polyurethane at 24.96 MPa. The same reasons behind increasing and decreasing tensile strength explain the effects of CB-N990 on flexural strength. The adhesion between the polyurethane matrix and the CB-N990 plays an important role in the surface interaction of polymers.
3.3 Impact Test
Figure 3 and Table 2 shows the relation between impact strength of polyurethane under different CB-N990 fractions. Increasing the CB-N990 weight fraction to 4% wt. enhances the impact strength. When carbon black percentage increases, and the internal particle distance reaches a suitable range, the impact strength improves. However, if the carbon black percentage is too high, then the internal particle distance becomes too small and may lead to larger agglomerates, which suitably provides brittle behavior [25, 26].

3.4 Hardness
Figure 4 and Table 2 shows the relationship between percentage of carbon black and the Shore hardness of polyurethane. Minimum hardness is observable at 2% wt. CB-N990 and increases gradually, reaching a maximum value at 10% wt. CB-N990. This trend may be a result of CB-N990 particles becoming stressed inside the polyurethane matrix, leading to a decrease in hardness [17,27].

4. CONCLUSIONS
Addition of carbon black to the polyurethane improved the following properties of the composite. The maximum tensile strength was achieved at 4% wt. CB-N990. Also, Impact strength improved at the same percentage as tensile strength. The optimal hardness was obtained at 10% wt. CB-N990. The maximum flexural strength was achieved at 6% wt. CB-N990. The density increased with increasing CB-N990 content for all fabricated samples. A higher weight
percentage of carbon black showed more agglomerate particles in the surface.

REFERENCES


