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Determination of mechanical performance of glass fiber reinforced and elastomer filled polyamide 6 composites

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ABSTRACT

In this study, the mechanical performances of neat Polyamide 6 (PA6) polymer, 20wt.% glass fiber reinforced PA6, and 8% SEBS elastomer with 20% glass fiber reinforced PA6 composite were investigated. Composite materials were first produced in the form of granules by using a twin-screw extruder. Later, mechanical test samples were molded, in accordance with the American Society of Testing Materials (ASTM) standards, using an injection molding technique. Mechanical parameters such as tensile strength, tensile modulus, elongation at break, impact strength, flexural strength, and flexural modulus were determined by tensile, impact, and bending tests. With the addition of 20wt.% glass fiber reinforcement to the PA6 polymer matrix, properties such as tensile strength, tensile modulus, flexural strength, and flexural modulus increased, while properties such as elongation at break and impact strength decreased. For the 20% glass fiber reinforced PA6 composite with 8% SEBS rubber additive, while the impact strength increased by 177%, other mechanical values decreased. The fractured surface microstructure images of the samples obtained from the tensile tests were examined using a scanning electron microscope.

1. Introduction

Polymer materials have become one of the indispensable materials of our daily life and continue to replace traditional materials such as metallic materials, ceramics, and glass. Polymers have advantages such as lightness, chemical resistance, transparency, easy processability, ease of construction, colorability, and corrosion resistance, as well as disadvantages such as low strength, low-temperature resistance, scratch ability, and low resistance to UV rays. In order to reduce the disadvantages of polymers, many different additives can be used. These can be strength-enhancing additives such as glass fiber, carbon fiber, aramid fiber, and natural fibers, as well as mineral fiber-based additives such as glass beads, kaolin, talc, wollastonite, glass sphere, barium sulfate, and mica. In addition, some elastomer-based materials can be added to increase the impact toughness of polymer materials. Engineering polymers are preferred especially in industrial applications where strength, temperature, and rigidity resistance are required. Polyamide polymers are also among the most widely used plastics in the engineering plastics group. Among the most widely used polyamide varieties in the industry are PA6, PA66, PA46, and cestamide polymers. Polyamide (PA) polymers are widely used in industrial applications due to their advantageous properties such as low friction coefficient, good wear resistance, high strength, ease of processing, and high melting temperature, however, they have a high cost and show fragility in multi-axial load situations [1]. Polyamide 6 and PA66 polymers are better than all other polyamide types with regards to properties such as hardness, high strength, and heat resistance. While the density of PA6 varies between 1.12-1.14 g/cm^3, the melting point is approximately 225 ℃ and the glass transition temperature is between 50-54 ℃ [2].

In order to combine the properties of various polymer materials in a single material, polymers that are compatible

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with each other are mixed and polymer mixtures are obtained. Polymer mixes are extensively utilized in a variety of sectors for the creation of novel materials that combine the unique characteristics of each component and may be achieved by a simple physical blending process. Due to its cheap production cost, this material class is an economically viable choice for a range of applications [3, 4]. The impact resistance of plastics is vital in many industrial applications [5]. PA's impact strength must be increased before it can be utilized in some engineering or packaging applications. Reinforcing PA using glass fiber [6-9] and other polymers such as elastomers [1, 10] and thermoplastics has been attempted to enhance its impact strength. As a reactive compatibilizer, styrene-ethylene-butadiene-styrene (SEBS) rubber [11–15] has been utilized in PA6 blends. Compatibleized mixes had greater hardness values and a higher degree of crystallinity [16].

Oshinski et al. [14, 17] examined the mechanical characteristics of PA6 and PA66 polymers using varied ratios of SEBS and SEBS-g-MA compatibilizers. As a result of their research, they discovered that adding SEBS and SEBS-g-MA rubbers to PA6 polymer enhanced the izod impact strength and percent elongation at break values of the polymer combination while decreasing the elasticity modulus and yield strength values. The inclusion of 20% SEBS-g-MA elastomer resulted in the maximum impact strength. This was explained as a result of the SEBS-g-MA's low molecular weight and ability to bind effectively with the PA6 and PA66 major matrix polymers. The soft rubber phase reduced the elastic modulus and yield strength values of the polymer combination, but enhanced the percent elongation and impact strength values. Xianwei et al. [18] examined the mechanical characteristics of PA6/ABS/g-SEBS polymer blends for application in the automotive and electronics sectors, including tensile and yield strength, modulus of elasticity, notched impact strength, and percent elongation at break. In their study, they investigated the effect of a g-SEBS compatibilizer on a PA6/ABS polymer mixture. As a result of their studies, they observed that the yield strength values of the g-SEBS compatibilizer added PA6/ABS polymer mixture decreased, while the izod impact strength and % elongation at break values increased significantly. They attributed this to the high toughening properties of the g-SEBS-based elastomer phase and its ability to adhere well to the polymer blend. Carvalho et al. [19] investigated the mechanical and thermal properties of a PA6 polymer and SEBS rubber mixture using a SEBS-g-MA coupling agent. They set the ratio of the PA6/SEBS mixture (50:50) and added the SEBS-g-MA compatibility agent at rates of 5, 7.5 and 15 phr to the mixture. As a result of their studies, they observed that the tensile strength, hardness and melting temperature values and % elongation values of the mixture increased with the addition of SEBS-g-MA.

Glass fiber is typically made by mechanically pulling molten glass through a tiny aperture and is composed largely of silicon dioxide and metallic oxide modifying components. Because of their inexpensive cost and good corrosion resistance, they are frequently utilized.

This experimental study was carried out for applications that require consideration of the impact and toughness properties, as well as the strength properties, of 20% short glass fiber reinforced polyamide polymer composites [19-24], which is widely used in sectors such as automobile, electrical, electronics, textiles in the industry.

In this study, the mechanical performances of neat PA6 polymer, 20% glass fiber reinforced PA6, and 8% SEBS elastomer with 20% glass fiber reinforced PA6 composite were investigated. Mechanical tests such as tensile, impact and bending tests were carried out and properties such as tensile strength, elasticity modulus in tensile, elongation at break, impact strength, bending strength, and elastic modulus in bending were determined. The broken surface microstructure images of the samples obtained from the tensile test were examined using scanning electron microscopy.

2. Experimental Study

2.1 Materials

Polyamide 6 polymer, which is the main matrix material used in the experiments, was obtained from DomoPolimer with the trade code Domamid. The glass fiber used as the strength enhancer, was a PA2 coded obtained in compliance with polyamide from the Cam Elyaf Sanayi company. The average diameter of the glass fiber was 11 μm and its length was 4.5 mm. Styrene-ethylene-butylene-styrene rubber triblock copolymer grafted with 1.84% maleic anhydride acid coded Kraton FG 1901 from Kraton Polymers Company was used as the thermoplastic elastomer to act as the toughening material.

2.1 Composite preparation

The PA6-CE-SEBS composite was produced in granule form in a model MC75 Japanese-made industrial twin-screw compound machine. Extruder barrel heater temperatures were adjusted between 210-250 ℃. The produced PA6-GFR-SEBS composite granules were first kept at room temperature for 24 hours and then dried in a tray at 80 ℃ for 4 hours. Then, the test specimens were molded using the injection molding technique. Injection barrel heater temperatures were adjusted between 220-245 ℃. Mechanical test specimens were printed in an injection mold manufactured in accordance with standards. The injection pressure was set to 180 bar.

Tensile test specimens were prepared according to ASTM D638 standard, impact test specimens according to ASTM D256, and flexure test specimens according to

ASTM D790 standard. Tensile and flexure experiments were carried out in Zwick Z020 tensile tester at a tensile speed of 10 mm/min. Impact tests were also carried out with the Zwick brand Izod impact device. The experiments were carried out in a conditioned laboratory environment at room temperature and 50% humidity. Each test sample was repeated at least 3 times and the mean values were used in the graphs.

The working plan for the production of PA6-GFR-SEBS composite is given schematically in Figure 1.

The compositions of the produced PA6-GFR-SEBS polymer composite and the injection and extrusion process conditions are given in Table 1. The image of the tensile, impact and bending test specimens produced by injection according to the standards, used in the experiments is given in Figure 2.

3. Results and Discussion

Figure 3 shows the change of tensile strength of injection molded neat PA6 polymer, 20% glass fiber reinforced PA6, and 8% SEBS elastomer added with 20% glass fiber PA6 composites.

As shown in Figure 3, the tensile strength of the neat PA6 polymer was determined to be 74.36 MPa, while the tensile strength of the 20% glass fiber reinforced PA6 composite was 133.28 MPa and the tensile strength of 8%SEBS elastomer and 20% glass fiber added to the PA6 composite was 119.11 MPa. When 20% glass fiber was added to the PA6 polymer, its tensile strength increased by 79.2% compared to the neat PA6 polymer.

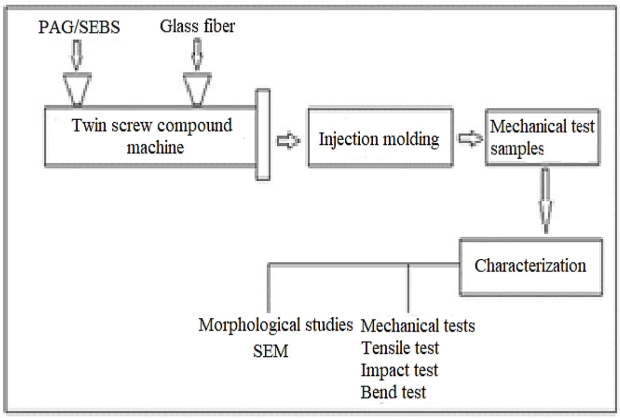


Figure 1. Schematic representation of the working plan for PA6-GFR-SEBS composite production

Table 1. Compositions and process conditions of PA6-GFR-SEBS polymer composite

No	PA6 (by weight)	Glass fiber (by weight)	SEBS elastomer (by weight)	Process conditions
1	100	-	-	Twin-screw extruder heater temperature range: 210-250 ℃ Injection heater temperature range: 220-245 ℃
2	80	20	-	
3	72	20	8	

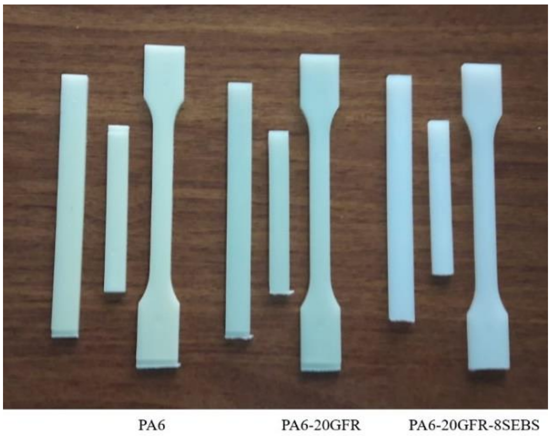


Figure 2. Image of tensile, impact and bending test samples produced by injection molding method

Its tensile strength increased by 60.1% compared to the neat PA6 polymer. However, with the addition of SEBS elastomer, a decrease of 14.17% was observed in tensile strength compared to 20% glass fiber PA6 composite.

The change in the elongation values at break of the neat PA6 and the PA6 composites, the 20% glass fiber reinforced PA6 and the 8%SEBS elastomer and 20% glass fiber reinforced PA6, are given in Figure 4.

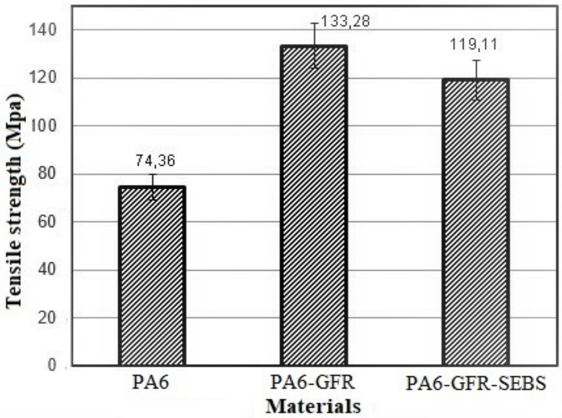


Figure 3. Tensile strength of PA6 polymer, 20% glass fiber PA6, 20% glass fiber reinforced PA6 with 8% SEBS elastomer composites

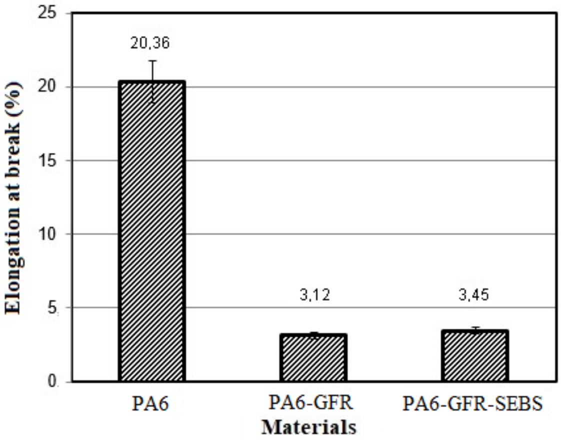


Figure 4. The change in the % elongation values at break of the PA6 polymer and the PA6-20%GFR and PA6-20%GFR-8%SEBS composites

As it is clearly seen in Figure 4, the % elongation value of the neat PA6 polymer at break was determined as 20.36%. When the main matrix material was reinforced with 20% glass fiber by weight, the elongation value at break of the PA6 composite was 3.12%, and similarly, the elongation value at break was 3.45% for the 8% SEBS elastomer and 20% glass fiber added PA6. For the 20% glass fiber reinforced PA6 composite, the elongation value at break was 84.6% lower compared to the neat PA6 polymer. It was also determined that when the PA6 main matrix material was reinforced with 8% SEBS elastomer and 20% glass fiber, the elongation value of the composite at break was 83% lower compared to the neat PA6 polymer.

Figure 5 shows the variation of the modulus of elasticity in the tensile strength tests for the polyamide 6 polymer and the PA6-20%GFR and PA6-20%GFR-8%SEBS composites according to the materials produced. As indicated in the figure, the elastic modulus obtained in the tensile test for the non-additive polyamide 6 polymer main matrix was determined as 2792 MPa. When 20% glass fiber was added to the PA6 polymer, the elastic modulus of the composite was determined to be 7237 MPa and the elastic modulus of the 8% SEBS elastomer and 20% glass fiber added polyamide 6 composite was determined to be 5492 MPa. With 20% glass fiber reinforcement to the polymer main matrix, the elastic modulus of the composite was observed to increase by 159% compared to the neat polyamide 6 polymer.

Similarly, when the polyamide 6 polymer was reinforced with 8% SEBS elastomer and 20% glass fiber, the elastic modulus of the composite was observed to increase by 96.7% compared to the neat PA6 polymer. However, with the addition of 8% SEBS rubber, the elastic modulus value of PA6-20%GFR-8%SEBS composite decreased by 24% compared to the 20% glass fiber PA6 composite. The reason for the increase in the elastic modulus of the composite is because the glass fibers were used as a strength enhancer. Glass fibers added to the polymer generally play a role in increasing the rigidity, mechanical properties, and hardness of the polymer. Styrene-ethylene-butylene-styrene elastomer is in the rubber phase and is added to thermoplastic polymers to increase the toughness of the hard polymers. SEBS elastomer was added to the composite to reduce hard, brittle, and rigid structure of the PA6 polymer composite with 20% glass fiber, and to reduce its brittleness by increasing its toughness in the area of use. SEBS disperses homogeneously in the polymer matrix, absorbing any impact to the material, increasing impact toughness and elongation at break (see Figures 6 and 4, respectively), but also causes a decrease in tensile strength values and stiffness (see Figures 3 and 5). SEBS-g-MA compatibilization agent has a low modulus of elasticity and causes a decrease in the stiffness of the composite material. Similar results were observed in previous studies in the literature [11, 14, 16-19].

The variation of the Izod impact strength values of PA6 polymer and the PA6-20%GFR and the PA6-20%GFR-8%SEBS composites is given in Figure 6. As seen in the figure, the izod impact strength of the neat PA6 polymer was determined to be 17 kJ/m^2 on average.

With 20% GFR reinforcement to the polyamide 6 matrix, the Izod impact strength of the PA6-20GFR composite was determined to be 10.6 kJ/m^2. In addition, with 8% SEBS rubber and 20% glass fiber reinforcement by weight, the Izod impact strength of PA6-20%GFR-8%SEBS composite was determined as 29.4 kJ/m^2. With 20% glass fiber reinforcement to the PA6 polymer main matrix, the impact strength of the PA6-20%GFR composite was reduced by approximately 37.6% compared to the neat PA6 polymer. Likewise, when 20% glass fiber and SEBS rubber reinforcement were made to the PA6 matrix, the impact strength of PA6-20%GFR-8%SEBS composite increased by approximately 73% and 177%, respectively, compared to the impact strength values of the PA6 polymer and the PA6-%GFR composite.

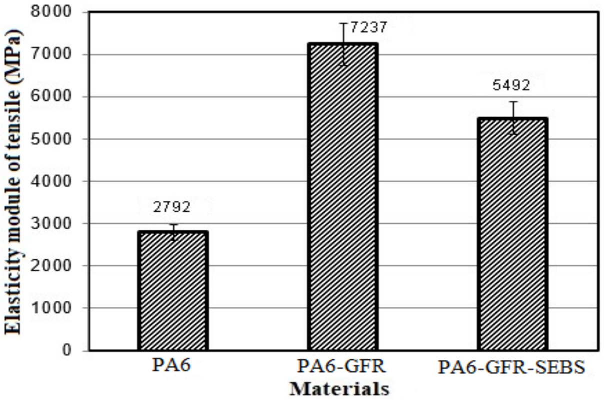


Figure 5. The change of elastic modulus of tensile strength of PA6 polymer and PA6-20%GFR and PA6-20%GFR-8%SEBS composites.

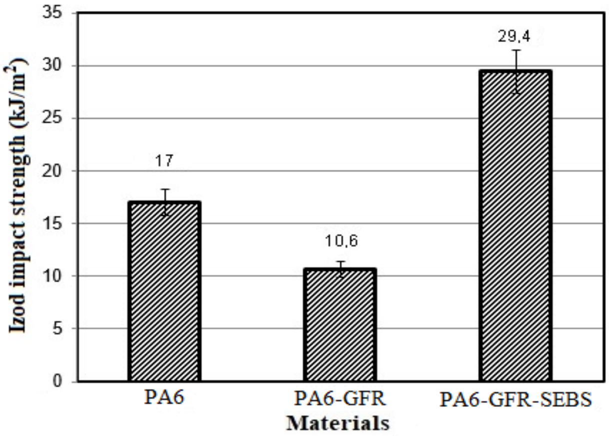


Figure 6. The variation of Izod impact strengths of neat PA6 polymer and PA6-20%GFR and PA6-20%GFR-8%SEBS composites.

Impact strength decreased with the addition of glass fiber but increased with the addition of the SEBS rubber. By adding SEBS rubber to the 20% glass fiber reinforced PA6 polymer composite, the composite became tough. Rubber phase SEBS provided the hardening factor. The results obtained are in accordance with previous studies in the literature [11, 14-18, 25, 26].

Figure 7 shows the change of flexural strength values of the PA6 polymer and the PA6-20%GFR and PA6-20%GFR-8%SEBS composites used in the experiments.

As it is clearly observed in the figure, the flexural strength of the PA6 polymer was determined as 76.62 MPa, while the flexural strength of the PA6-20%GFR composite was 137.2 MPa and the flexural strength of the PA6-20%GFR-8%SEBS composite was determined as 108.11 MPa. With 20% glass fiber reinforcement to the polymer main matrix, the flexural strength of the PA6-20%GFR composite by 79% compared to the bending strength of the neat PA6 polymer. Similarly, when 20% glass fiber and SEBS rubber reinforcement was made to the polymer main matrix, the flexural strength of the PA6-20%GFR-8%SEBS composite was found to increase by 41% compared to the neat PA6 polymer. However, with the addition of 8%SEBS rubber, the flexural strength of the PA6-20%GFR-8%SEBS composite was reduced by 37.9% compared to the flexural strength of the PA6-20%GFR composite.

The variation of the modulus of elasticity of the neat PA6 polymer, PA6-20%GFR, and PA6-20%GFR-8%SEBS composites in bending is given in Figure 8.

As it is clearly seen in the figure, the elastic modulus of the polyamide 6 main matrix in bending was determined as 1483 MPa, the elastic modulus of the composite with 20% glass fiber reinforcement in the polyamide main matrix was 3820 MPa and the elastic modulus of the 8% SEBS elastomer and 20% glass fiber reinforced PA6 composite in bending was determined as 2623.7 MPa. With 20% glass fiber reinforcement to the main matrix, the elastic modulus of the PA6-20%GFR composite in bending increased by 107.2% compared to the neat PA6 polymer. Similarly, when 20% glass fiber and SEBS rubber reinforcement was made to the polymer main matrix, the elastic modulus of the PA6-20%GFR-8%SEBS composite in bending increased by 42.3% compared to the neat PA6 polymer. However, with the addition of 8% SEBS rubber, the elastic modulus of the PA6-20%GFR-8%SEBS composite in bending decreased by 45.5% compared to the elastic modulus of PA6-20%GFR composite. The reason for the composite's elastic modulus increasing in bending is the same as the reason for the composite's elastic modulus increasing in tension. In other words, glass fibers added to the polymer increase the bending strength, rigidity, and hardness of the composite.

The addition of SEBS rubber also causes toughening of the polymer composite (see Figures 7 and 8, respectively).

The fracture surface scanning electron microscope images obtained after the tensile test of the neat PA6 polymer, and the PA6-20%GFR, and PA6-20%GFR-8%SEBS (10 µm view and 100 µm view) composites are given in Figure 9 (a, b, c, d).

It can be seen from the fractured surface microstructure images of the non-additive polyamide 6 polymer that the main matrix has elasticity and the elongated and white parts on the fracture surface are plastic deformation (See Figure 9 (a).) In Figure 9 (b), the fracture surface image of the PA6-20%GFR composite is given. It was determined that the short glass fibers are homogeneously distributed within the main matrix and the fracture surface is smooth and brittle. In Figure 9 (c), the fracture surface image of the PA6-20%GFR-8%SEBS composite is given and the microstructure images show that the glass fibers are generally homogeneously distributed in the matrix material. At the same time, the elongation of the main matrix after the applied force, despite the 20% glass fiber reinforcement, shows that the SEBS rubber in its composition makes the composite elastic.

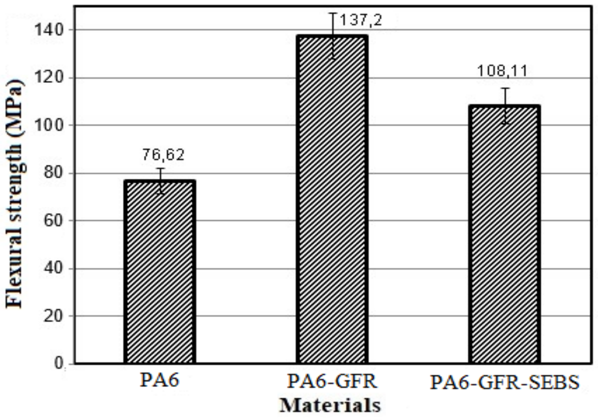


Figure 7. The variation of Izod impact strengths of the neat PA6 polymer and PA6-20%GFR and PA6-20%GFR-8%SEBS composites

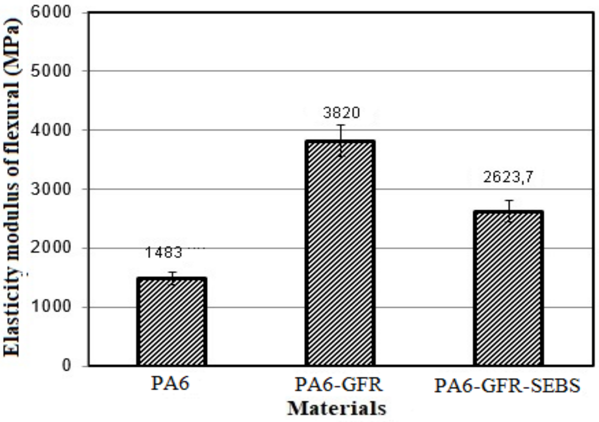
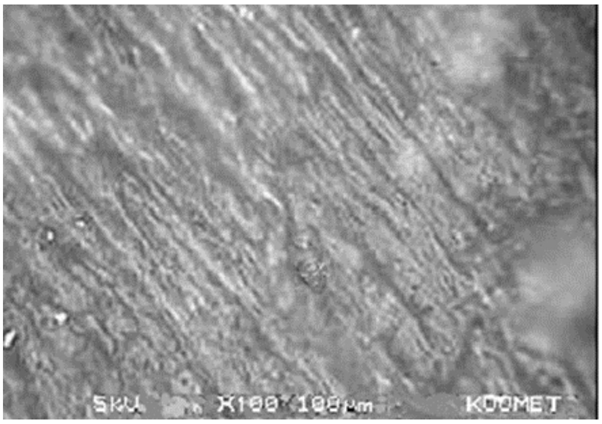
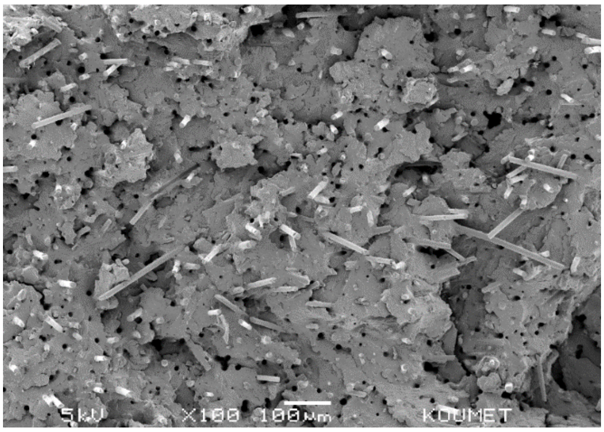


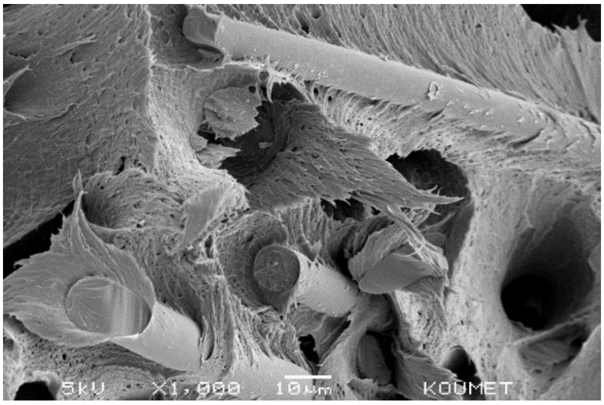
Figure 8. The variation of the modulus of elasticity in bending of the neat PA6 polymer and the PA6-20%GFR and PA6-20%GFR-8%SEBS composites



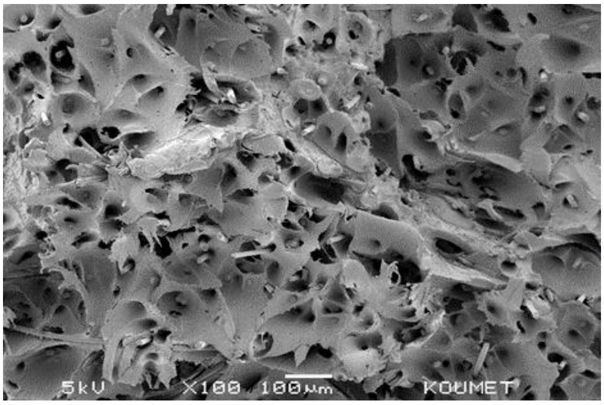
a) PA6



b) PA6-%20GFR



c) PA6-%20GFR-%8SEBS (10 μm view)



d) PA6-%20GFR-%8SEBS (100 μm view)

Figure 9. PA6, PA6-20% GFR, and PA6-20%GFR-8% SEBS SEM images

Meanwhile, it is observed that short glass fibers, which act as strength enhancers, are well bonded to the main matrix body and the fiber/matrix interface bond is good (See 9 (c and d)).

4. Conclusions

As a result of the experimental study, the following mechanical and microstructural test results were obtained.

- With the short glass fiber reinforcement added to the PA6 polymer main matrix, the tensile strength, elasticity modulus in tensile strength, flexural strength, and elastic modulus in bending of the composite material increased. It was determined that the 20% glass fiber reinforcement composite added to the main matrix increased the tensile strength, elasticity modulus in tensile, flexural strength, elastic modulus in bending by approximately 79.2%, 159%, 79%, and 107.2%, respectively.
- With the short glass fiber reinforcement added to the PA6 polymer main matrix, the % elongation at break and decrease in Izod impact strength values of the composite material were detected. Again, it was determined that 20% glass fiber reinforcement added to the polymer matrix reduced the elongation and Izod impact strength values of the composite by approximately 84.6% and 37.6%, respectively.
- The 8% SEBS rubber added to the PA6-20%GFR composite caused a significant increase in the Izod impact strength of the composite material. Compared to the PA6-20%GFR composite, the impact strength of the PA6-20%GFR-8%SEBS composite was greater by approximately 177%.
- The 8% SEBS rubber added to the PA6-20%GFR composite caused a decrease in the tensile strength, elasticity modulus in tensile, bending strength, and elasticity modulus in bending of the composite material. It was determined that the addition of 8% SEBS elastomer added to the main matrix decreased the tensile strength, elasticity modulus in tensile strength, flexural strength, and elastic modulus in bending by 14.17%, 24%, 37.9%, and 45.5%, respectively.
- In industrial applications where toughness, as well as strength, is required, it may be recommended to consider the values obtained from the PA6-20%GFR-8%SEBS composite.

Declaration

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. The authors also declared that this article is original, was prepared in accordance with the international publication, and any special permission is not required.

Author Contributions

H. Ünal developed the methodology and experimental study. K. Ermiş supervised and prepare the manuscript.

Nomenclature

ASTM : American Society of Testing Materials
GFR : Glass fiber
PA6 : Polyamide
SEBS : Styrene-ethylene-butadiene-styrene
SEM : Scanning electron microscope
P : Power

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