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EFFECTS OF CARBON AND BASALT FIBRES USED AS REINFORCEMENT MATERIALS IN POLYMER MATRIX COMPOSITES ON THE COMPRESSIVE STRENGTH OF COMPOSITES

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Abstract

In this study, the effects of different amounts of carbon and basalt fibre concentrations used as reinforcement materials on the compressive strength properties of high-density polyethylene (HDPE) matrix composites were investigated. Maleic anhydride grafted polyethylene (PE-g-MA) compatibilizer was used to increase adhesion between reinforcement phases and matrix elements. Composites containing carbon and basalt short fibres in different weight ratios were produced by the melt blending method. Compression tests of polymer composite samples were made at a compression speed of 2 mm/min in accordance with ASTM D5467 standard. As a result of the tests, it was observed that the best compressive strength properties were in 20% BF reinforced composite samples.

Keywords: Basalt fibre, Carbon fibre, Compressive strength, HDPE, Mechanical properties.

1. Introduction

Technological developments and some requirements in recent years have led to the need to develop existing engineering materials, and the inadequacy of alloys has accelerated the development of composite materials [1]. A composite material generally consists of a resin main phase with low modulus/strength and a reinforcement element with a smaller secondary phase dispersed within it [2].

Composites with high-strength fibres (reinforcements) incorporated in polymeric matrices are known as fibre-reinforced polymer materials. High-strength fibres like carbon and aramid, glass, fibre-reinforced polymers, natural fibre, etc. It is a composite material made out of a coating of polymer matrix [1-3].

The current demand for lightweight and high-performance structures is leading to increasing applications of carbon fibre-reinforced polymers [4]. Carbon fibres are highly preferred in strategic areas due to the superior properties they provide. Among all reinforcement fibres, carbon fibres offer the highest specific modulus and strength. Unlike glass and other organic polymer fibres, carbon fibres do not always shatter under force [5, 6].

Carbon fibre reinforced polymer matrix composites, spacecraft, automobile, construction, biomedical and other industries are widely used. Therefore, there is a great demand for research and development of such composites [7].

Basalt fibres are one of the most important reinforcement elements that have been the subject of recent research [8]. Basalts are stones formed by the cooling of volcanic lava. However, since basalt is a natural reinforcing element, materials made from basalt are environmentally friendly and not dangerous [9].

Compared to reinforcement materials such as e-glass fibres, basalt fibres have an advantageous position due to their easy production process and cheapness. Experimental studies have shown that basalt reinforced composite materials have better mechanical properties than E-glass fibre reinforced composite materials [8-10].

Zhang et al. produced basalt fibre reinforced polymer matrix composites with different ratios by twin screw extruder and injection moulding method and investigated their mechanical properties. As a result of the experiments, it was seen that the composite samples with basalt fibre reinforcement at 15% by volume had the best mechanical properties [11].

Liu et al. prepared basalt and glass fibre reinforced polymer composite samples with different ratios by extrusion and injection moulding method. As a result of the experiments, it was observed that basalt fibre reinforced composites showed better mechanical properties than glass fibre composites [12].

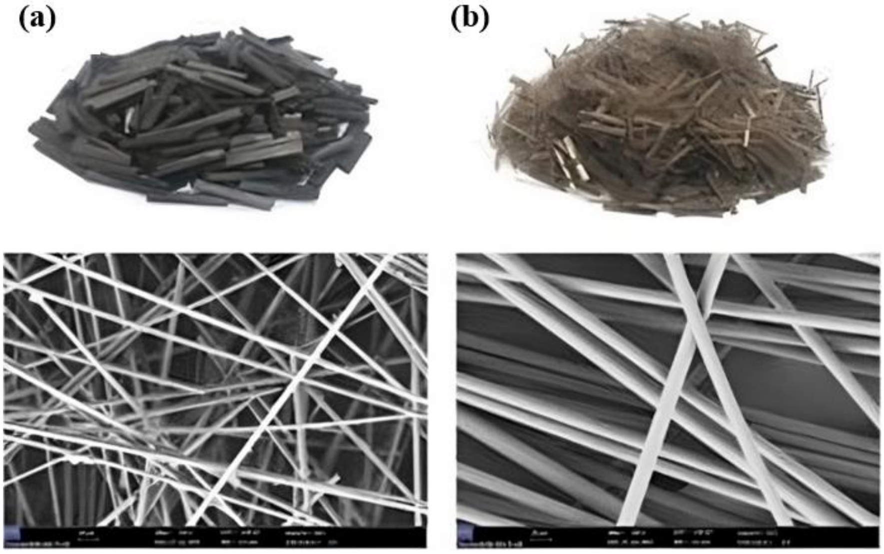
Polymer-based composite materials have advanced significantly in the industry in recent years, depending on the types of reinforcement materials employed; however, there are still certain technical challenges and concerns that need to be looked at in their applications [9-13].

The aim of this study is to experimentally investigate the effects of carbon and basalt fibres with different mechanical properties on the compressive strength values of composite samples.

2. Materials and Methods

2.1. Materials

Trademarked HDPE with a density of 0.956 g/cm^3 (SABIC® HDPE M200056) was used as the matrix material in polymer matrix composites. Carbon coated with 1.5-3% polyurethane based resin and chopped basalt fibres with a diameter of 13-20 µm were used as reinforcement materials. Maleic anhydride terpolymer (PE-g-MA) obtained from Nanocar was used as the compatibilizer material between the polymer matrix element and the reinforcement phases. SEM images of 6 mm sized carbon and basalt fibres obtained from company spintex to be used as reinforcement material are given in Fig. 1, and mechanical properties of reinforcement materials as shown in Table 1.



(a) Carbon fibre. (b) Basalt fibre.

Fig. 1. Images of fibres used as reinforcement material.

Table 1. Mechanical properties of reinforcement materials.

Reinforcement materials	Tensile strength MPa	Young modulus GPa	Elongation at break %
Basalt fibre	4150-4800	93-110	2.6-3.2
Carbon fibre	3500-6000	230-600	1.5-2

2.2. Production method of composites

To prepare the composite samples, HDPE matrix material, carbon, basalt fibres, and PE-g-MA compatibilizer were pre-dried in an oven at 80 °C for 24 h to remove moisture. Polymer matrix composite samples were prepared in accordance with the compositions given in Table 2.

Table 2. Composite compositions used in the study.

Matrix Composition (wt%)	Reinforcement Composition (wt%)	Compatibilizer Composition (wt%)
100 HDPE	-	-
90 HDPE	10 CF	-
80 HDPE	20 CF	-
70 HDPE	30 CF	-
87 HDPE	10 CF	3 PE-g-MA
74 HDPE	20 CF	6 PE-g-MA
61 HDPE	30 CF	9 PE-g-MA
90 HDPE	10 BF	-
80 HDPE	20 BF	-
70 HDPE	30 BF	-
87 HDPE	10 BF	3 PE-g-MA
74 HDPE	20 BF	6 PE-g-MA
61 HDPE	30 BF	9 PE-g-MA

The composite samples were formed by melt mixing technique using a twin-screw extruder with screw diameter D=16 mm and length/diameter (L/D) ratio of 40, rotating in the same direction. Melt mixing method is one of the simple and common methods used in the synthesis of polymer matrix composites [14]. The twin-screw extruder prevents the reaggregation of reinforcement materials in the polymer matrix and ensures a homogeneous distribution of fibres in the matrix. The production die pressure of the used machine was set as 6.7 bar and the temperature profile of the extruder bottom area during the production phase was set as 50, 200, 205, 210, 215 and 220 °C from the feeding zone to the heating zones, respectively.

The extruded material was removed from the mold in rod form, passed through a water bath at room temperature, and pelletized using a granulator. It was then dried in an oven at 80 °C for 12 hours. Pellets were then prepared using a 12 ml micro injection moulding device. Visuals of the production processes and compression test of the composite samples are given in Fig. 2.

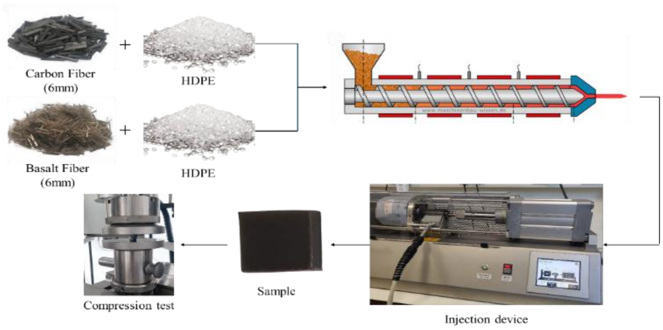


Fig. 2. Production processes and compression tests of composite samples.

2.3. Mechanical and structural characterization

To determine the compressive strength properties of polymer matrix composite samples, compression tests were carried out on a Zwick/Roell Z600 branded test device in accordance with the ASTM D5467 standard at a compression speed of 2 mm/min. Compression tests were carried out in a laboratory environment by taking 3 test samples from each composite.

Scanning electron microscope (SEM) was used to examine the changes in the structure of the composite samples after the compression tests. Before the samples were examined in SEM, their surfaces were coated with Pb in the Q150r moulding device.

3. Results and Discussion

Compression tests of composite samples were carried out at a compression speed of 2 mm/min under 20 N static force in accordance with ASTM D5467 standard. The results of the compression tests of the composite samples were calculated according to Eq. (1) and the compressive strength limits of the samples were determined.

$$\sigma_c = \frac{F_{max}}{S_0} \quad (1)$$

where σ_c is the compressive strength value of the composite sample, MPa; F_{max} is the maximum force load damaging the specimen, N; S_o is the deformation value occurring in the sample, mm.

The compressive strength values of HDPE matrix composite samples reinforced with carbon and basalt fibre at different rates, calculated according to formula 1, are shown graphically in Fig. 3.

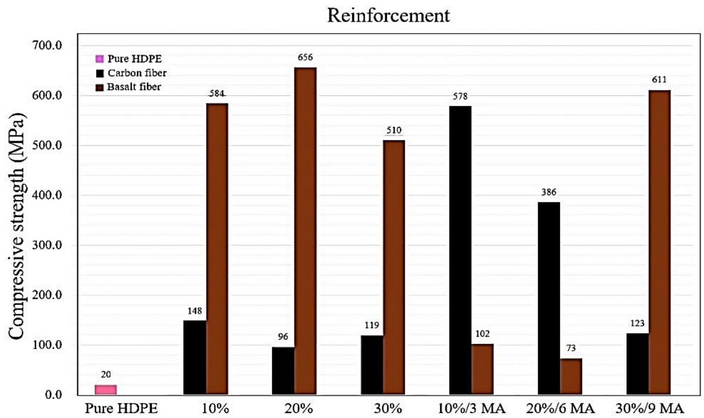


Fig. 3. Compressive strength values of HDPE matrix composite samples.

As can be seen from the graph, the compressive strength value of HDPE matrix polymer composite samples is 20 MPa. When 10% carbon and basalt fibres were used as reinforcement materials in HDPE matrix polymer composites, it was observed that the compressive strength values of the samples were 148 MPa and 584 MPa. As a result of the experiments, it was seen that the high strength value of carbon and basalt fibres used as reinforcement materials in composites significantly improved the compressive strength of the composite samples.

It was observed that when 20% carbon and basalt fibres were used at medium concentration as reinforcement materials in HDPE matrix polymer composites, the compressive strength of the samples was 96 MPa and 656 MPa. It was determined that basalt fibres had the highest compressive strength value among composite sample groups with the same concentration. Basalt fibres may be lighter than carbon fibres but still offer high strength [15, 16]. This allows HDPE matrix composites to be lighter while also achieving high performance compressive strength [17].

When high concentration 30% carbon and basalt fibres were used as reinforcement materials in HDPE matrix polymer composites, the compressive strength values of these samples were found to be 119 MPa and 510 MPa. Similar studies in the literature have reported that as the proportion of carbon fibres used as reinforcement materials in polymer composites increases, the production and processability of composite samples generally become more complex [18]. As the fibre ratio increases, it becomes more difficult to distribute carbon fibres homogeneously and integrate them into the matrix. This negatively affects the compressive strength of polymer matrix composite samples [19].

It has been observed that basalt fibres used in different proportions as reinforcement material with HDPE matrix increase the general compressive strength values of composite samples. The high strength properties of basalt fibres allow the composite samples to increase their compressive strength and allow the material to carry more load. As a result of the experiments, it was observed that the compressive strength properties of carbon and basalt fibre reinforced polymer composites vary depending on various factors such as the type and processing of fibres, the type of polymer matrix used, and the volume ratio.

Different chemical methods and substances are used to develop and optimize the weak interface between fibre-matrix in natural and synthetic fibre reinforced polymer composites [20]. Within the scope of our study, 3%, 6% and 9% PE-g-MA compatibilizers were used to improve the weak interface between fibre/matrix. Compression tests were carried out in accordance with the ASTM D5467 standard to determine the effects of the compatibilizer material on the fibre-matrix of HDPE matrix composite samples.

As a result of the experiments, it was shown that the experimental temperature values of 3% PE-g-MA moisture content as a compatibilizer between 10% carbon and basalt fibres used as reinforcement material in HDPE matrix composites were 112 MPa and 38 MPa. When 6% PE-g-MA compatibilizer was used to improve the interfaces between 20% carbon and basalt fibres used as reinforcement materials in composites and the HDPE matrix element, it was observed that the compressive strength values of the samples were 386 MPa and 73 MPa.

When 6% PE-g-MA compatibilizer was used to improve the weak interface between 30% carbon and basalt fibres used as reinforcement materials in polymer composites and the HDPE matrix element, it was observed that the compressive strength values of the samples were 123 MPa and 611 MPa.

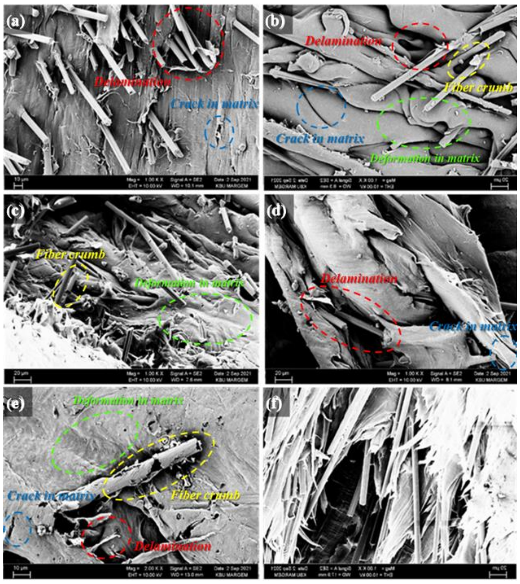
In fibre-reinforced composite materials, the load applied during mechanical tests is transmitted to the fibre through the fibre-matrix interface. Therefore, the interface structure and properties play a particularly important role on the mechanical and physical properties of the composite material. In particular, interfacial shear strength is an important parameter in controlling the strength and hardness of the composite material. In order to obtain a composite with good mechanical properties and to make maximum use of fibre properties, optimum adhesion along the interface must be ensured.

It has been observed in experiments that the maleic anhydride grafted polyethylene adapter, which is used to expand the connections in polymer matrix composites and change the fibre surfaces as used in the matrix, is more effective on carbon fibre reinforced composite samples.

Figures 4 and 5 show SEM images of HDPE matrix composite samples reinforced with different amounts of carbon and basal fibres. These images were taken from deformed surfaces after compression tests. Examining SEM pictures reveals that the fibres are dispersed uniformly throughout the HDPE matrix. The response of polymer matrix composite materials to external loading is overly complex. Impact damages occurring in composite samples due to the effect of static loads; deformation in the matrix (Figs. 4(b), 4(c), 4(d) and 5(a)), matrix cracks (Figs. 4(b), 4(d), 5(d), 5(c), and 5(e)), delamination (Figs. 4(b) 5(b), 5(c) and 5(d)) and fibre damage (Figs. 4(c), 4(e), 5(a), and 5(c)).

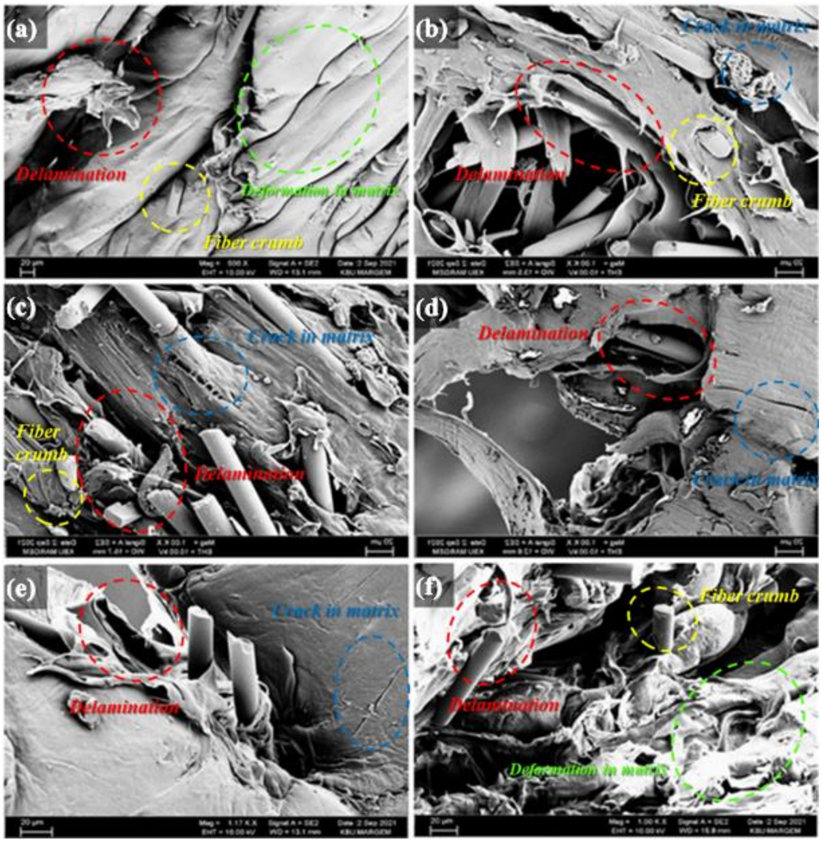
The fluctuations of composite materials over time during compression tests, depending on their fibre concentrations, explain the damage occurring in the microstructures. In low-speed pressure testing on composites, it was shown that impact energy given to the composite caused fibre damage (brittle fracture in fibres) to develop and to worsen. The damage began with matrix cracking and resulted in delamination. Upon examination, the stripped fibbers' surface revealed some places that were free of polymeric matrix (Figs. 3 and 4) and that they were clean. This suggests that the fibre and matrix have low interfacial adhesion. The dark rings surrounding the fibres signify the localized deformation of the surrounding matrix.

Simultaneously, the microstructure (Figs. 4(d), 4(e), 4(f), 5(d), 5(e), and 5(f)) exhibits traces of PE-g-MA, a compatibilizer material employed to improve adhesion between the polymer matrix element and the reinforcing phases.



(a) 10% CF, (b) 20% CF, (c) 30% CF, (d)10% CF/3% MA, (e) 20% CF/6% MA, (f) 30% CF/9% MA.

Fig. 4. SEM images of reinforced HDPE matrix composite samples.



(a) 10% BF, (b) 20% BF, (c) 30% BF, (d)10% BF/3% MA,
(e) 20% BF/6% MA, (f) 30% BF/9% MA.

Fig. 5. SEM images of a reinforced HDPE matrix composite samples.

4. Conclusions

Compression tests of HDPE matrix composite samples reinforced with different amounts of carbon and basalt fibre were carried out according to the ASTM D5467 standard.

- During the tests, it was observed that the best compressive strength properties of carbon fibre reinforced composites were in 10% CF/3% MA samples. This indicates that the compatibilizer in the composite samples provided an optimum balance between the fibre reinforcement and the matrix.
- Basalt fibres used as natural fibres generally have a better surface for bonding compared to carbon fibres. As a result of the experiments, it was observed that the compressive strength was significantly improved when used as a reinforcement material up to 20% BF. However, as the fibre ratio increased, a decrease in the compressive strength values was determined due to the agglomeration of the fibres in the matrix.
- As a result, it can be said that basalt fibres, which are natural fibres, are a more mechanically advantageous material.

Nomenclatures

F_{max}	Maximum force load damaging the specimen
S_o	Deformation value
σ_c	Compressive strength limits

Abbreviations

ASTM	American society for testing and materials
BF	Basalt fibre
CF	Carbon fibre
HDPE	High-density polyethylene
PE-g-MA	Maleic anhydride grafted polyethylene
SEM	Scanning electron microscope

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