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ORIGINAL CONTRIBUTION

Development and Behavior Analysis of CNT Fibers Reinforced High-Density Polyethylene Composite via Compression Mold Route

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Abstract High-density polyethylene (HDPE) composites are widespread in applications such as root barriers and corrosion production pipelines due to their better chemical strength, durability, and fatigue resistance. This investigation will prepare the HDPE composite embedded with 0, 5, 10, 15, and 20 volume percentages (vol%) of carbon nanotubes via compression mold technique with the applied compressive force 100 MPa. The fabricated composite's tensile and impact strength and elongation percentage are investigated based on ASTM standards. Thus, the HDPE with 20 vol% of CNT fiber indicates the maximum tensile and impact strength of 56.3 ± 0.3 MPa and 14.8 ± 0.1 J/mm^2 and elongation behavior of 148%. It is higher than the other composite prepared by compression molding. The optimum behavior of composite containing various compositions of polypropylene CNT fiber reinforced with 20% volume is recommended for lightweight and automobile applications.

Keywords CNT fiber · Compression mold · HDPE · Properties

Introduction

The trend for polymer composite with synthetic fiber facilitates as an alternative material for conventionally used material, and these composites are offered good elastic modulus, improved strength, better elongation, and enriched thermal and mechanical qualities [1]. The past reviews mostly studied CNT fiber with a polymer matrix to evaluate mechanical properties, better chemical resistance, good strength, and better wear resistance of the composite [2]. However, adding graphene and carbon fiber to an HDPE matrix improves extreme mechanical and thermal behavior. Using the fused filament technique has improved the quality of composite fabrication and is costly compared to other techniques [3]. The thermoplastic technique used in polyethylene to improve impact strength and mechanical properties using HDPE matrix [4]. MWCNT fiber blended HDPE composite is developed by the conventional route, and the polymer matrix composite is used with MWCNT to improve chemical resistance and exhibited better improvement of stiffness & strength using injection molding composites [5]. The past reviews of polymer matrix composite made with nanofiller of CNT fiber are summarized, and superior mechanical and thermal properties on the modified surface of the HDPE matrix are found. However, the properties of the composite may vary due to the dispersing of CNT and its physical characteristics, including size and orientation [6].

The CNT fiber-reinforced matrix used in multilayer natural fiber-reinforced composite spray coating has better strength and mechanical and adhesive properties [7]. The polymer matrix does not depend on the filler of the composite. If it is selected suitable for the composite, it improves the mechanical and thermal properties only concentrate on size and orientation [8]. HDPE and PPE with CNT fiber blended with various proportionate blended high viscosity if polyolefin is chosen to reduce dispersion and improve chemical properties [9]. The proper molding technique is used in ceramic matrix composite with CNT to achieve flexibility and stiffness. CNT blended some percentage of volume [10]. Carbon fiber-reinforced polymers are used for automobile and aircraft application multilayer coating to

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achieve impact resistance and compression strength [11]. The main drawbacks of conventional matrix dispersion are impact damage due to poor processing and melting. So, instead of PMC, reinforced CNT fiber should be replaced to avoid impact damage and strengthen [12] PMC with synthetic fiber epoxy material to influence compression molding to better mechanical corrosion resistance [13]. The past research conventionally improves their properties, such as metal ceramics; however, altered solutions such as polymer, Epoxy, and HDPE use CNT fiber to increase their mechanical & thermal properties [14]. However, the composite's tensile strength depends on adhesive joint strength [15] and relates to fabrication techniques [16, 17].

Composite is cited with the relevant present HDPE, and the compression mold technique suits CNT composite fabrication. The present study was executed with short CNT fiber as 0–20 vol% with 5 vol% interval blended with HDPE matrix via compression molding. ASTM standards D3039 and D256 evaluate its tensile strength, elongation percentage, and flexural strength. Evaluated results for fabricated composites showed better tensile strength and improved elongation percentage with good flexural strength.

Materials and Methods

Material

This HDPE is chosen based on improved impact strength, chemical resistance, good strength, and durability [18]. Similarly, the CNT fiber offered specific behavior, including high strength, good stiffness, durability, and better thermal stability reasons [19] as chosen by reinforcement fiber for this investigation. It is considered a 4–6-mm long chopped form during fabrication. The chopped form helps to distribute along the matrix and creates effective bonding with the matrix phase, resulting in enriched composite behavior [20]. The physical behavior of HDPE and CNT fiber is exposed in Table 1.

The combination composite details are given in Table 2. The composites are prepared by compression mold machine, and its setup is shown in Fig. 1.

This setup is operated with a hydraulic system for maximum compressive action, and the control panel controls its operating parameters. According to Table 2, the HDPE and CNT fiber is mixed with a blender machine with a low stirrer speed of 100 rpm for 10 min. After the process, thermal compression with an applied temperature of 300 °C gradually increases from the ambient temperature. The marginal improvement in temperature helps to increase the adhesive quality between the matrix and fiber [21]. After heating, its temperature is reduced to 150 °C to increase the bonding capabilities. It is compacted by the compression action of 100 MPa force for 10 min, which supports the increase in adhesive strength and removal of thermal stress. Finally, this composite is cooled by the die itself at an ambient temperature for a 3-h curing span. The fabricated composite of 150 mm × 150 mm × 10 mm is involved in mechanical behavior studies to understand the developed composite behavior and is applied in real-time applications.

Table 1 Physical properties of HDPE/CNT fiber

Characteristics	HDPE	CNT fiber
Tensile strength (MPa)	25	62
Density (g/cc)	0.92	1.85
Moisture absorption (%)	0.01	0.7

Table 2 Compositions of composite

HDPE composite samples	Volume percentages	
	HDPE	CNT fiber
C1	100	0
C2	95	5
C3	90	10
C4	85	15
C5	80	20

HDPE Composite's Behavior Study

Fabricated HDPE composite's tensile strength/elongation behavior is investigated via an ISTRON-made universal

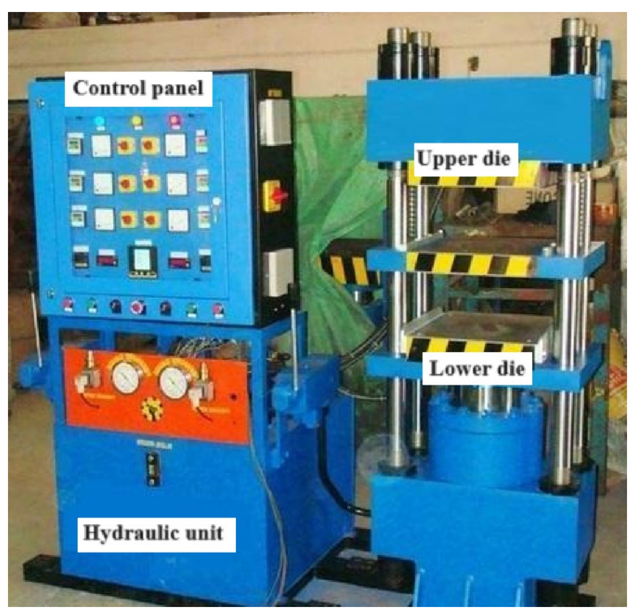

Fig. 1 Hydraulic-assisted compression molding setup

testing machine configured with electronic plots followed by a 3-mm/min speed of the cross slide. During the evaluation, this test was preferred by the ASTM D3039 standard. Based on the ASTM D256 standards, the composite's impact strength is evaluated through the ELMACH IT30 model impact toughness measuring machine. Three trials were executed with a 5% allowable error to find test significance.

Results and Discussion

Tensile Strength of HDPE

Based on Fig. 2, the HDPE matrix of the test specimen on tensile strength C1, C2, C3, C4, and C5 contained 0–20% volume of CNT fiber-reinforced composites. Thus, HDPE matrix C1 is noted at 38.5 ± 0.5 MPa, and C2, in addition to 5% volume of CNT fiber to improved mechanical properties, and adhesive behavior between matrix and CNT fiber indicate a better tensile strength of 41.4 ± 0.3 MPa, and C3 indicates HDPE matrix sample shows 44.5 ± 0.6 MPa on 10% volume added with CNT fiber.

Then, the HDPE composite C4 specimen indicated a value of 51.6 ± 0.5 MPa. Maximum tensile strength is observed at C5 specimen 56.3 ± 0.4 MPa. They are influencing the smooth distribution of fiber. HDPE sustainable with CNT fiber shows better tensile strength, and the composite sample C5 is improved by 46.2%, related to the unreinforced HDPE matrix. The surface-treated natural fiber is the reason for the improved mechanical behavior of the composite [22].

Impact Strength of HDPE

The impact strength of the HDPE matrix (C1) and its composite specimens, such as C2, C3, C4, and C5, are shown in Fig. 3. HDPE matrix C1 specimen, the impact strength CNT fiber samples show better impact strength. The impact

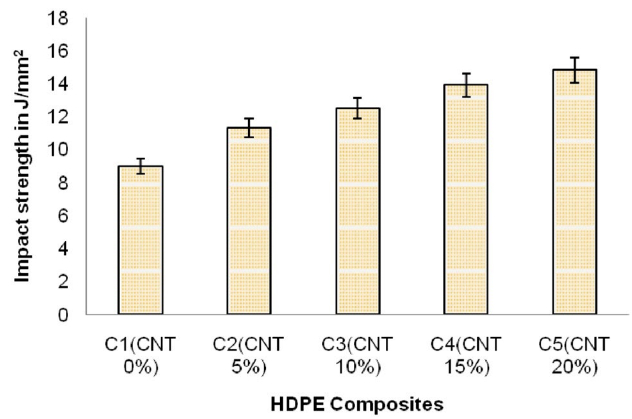

Fig. 3 HDPE composite's impact strength

strength of the polypropylene matrix without CNT fiber is 9 J/mm^2, and in addition, 5% volume of CNT fiber composite is identified by 11.3 J/mm^2. Hence, the impact strength of composite specimens C3, C4, & C5 comprises 10, 15, & 20% of volume CNT fiber by 12.5, 13.9, and 14.8 J/mm^2, respectively.

The composite sample C5 contained a maximum loading of CNT fiber specimen enhanced by 64% related to HDPE matrix C1. The surface treatment results in enriched mechanical and adhesive action and improved composite impact strength [12]. Moreover, the effective pinning action mechanism between the CNT and HDPE matrix facilitates better energy absorption capacity. It resists the fiber movement during the high-impact load, causing improved impact strength performance.

Composite Specimen on Elongation

The elongation of HDPE composite CNT fiber reinforced with 0, 5, 10, 15, and 20% volume, respectively, is shown in Fig. 4. The elongation of composite sample C1 is observed

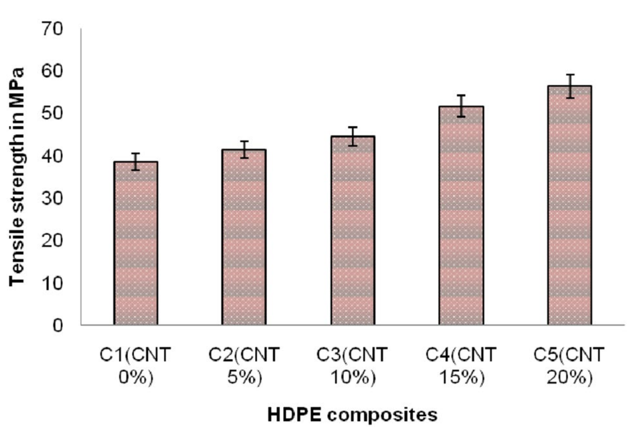

Fig. 2 HDPE composite's tensile strength

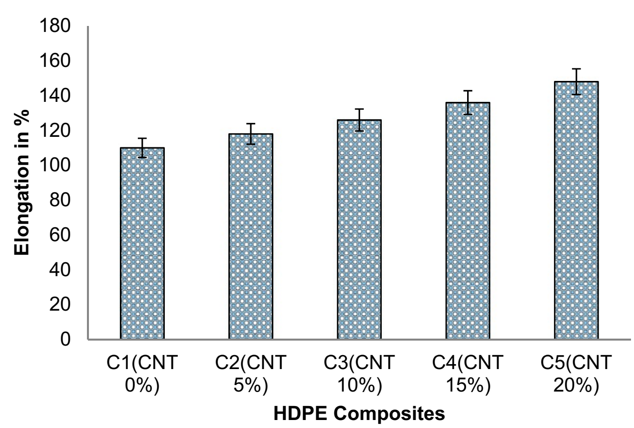

Fig. 4 HDPE composite's elongation percentage

by 110%. If adding 5% of volume, CNT fiber added to composite sample C2 is noted as 118%, higher than the C1 composite specimen. With 10% of the volume of CNT fiber added to the composite specimen, the C3 sample increased by 126% on 20% of CNT fiber. Surface-treated reinforced fiber mixed with HDPE matrix resists the indentation against the load. It has better elongation [2]. In addition, the composite sample C4 contained 15 and 20% of the CNT fiber HDPE composite volume, located at 136 and 148%.

Hence, the composite sample C5 prepared with a 20% volume of CNT fiber indicated a better elongation value of 148%, hiked by 34.5% related to the C1 HDPE matrix. The enhancement of elongation is due to the appearance of hard ceramic particles exploiting superior elongation [12]. Besides, the elongation percentage of synthetic fiber (CNT) own superior value and incorporated with HDPE polymer matrix is better to adhere behavior leads to withstand the maximum tensile load and restrict the CNT fiber dislocation [5, 6].

Conclusions

The CNT fiber incorporated HDPE composite samples were developed successfully and involved tensile strength, elongation percentage, and impact strength via ASTM standard. The main conclusions are summarized in the key lists below.

- Hence, the HDPE composite specimen prepared with various compositions and specimen C5 comprised of 20% volume of CNT fiber showed superior tensile strength, which is improved by 46.2% compared to the tensile strength of composite specimen C1 (HDPE matrix).
- The impact strength of composite specimen C5 is exposed to 64% enhancement compared to the C1 composite specimen prepared without fiber/filler materials.
- The elongation of composite specimen C5 is to improve by 34.5%, related to the C1 composite specimen without fiber and filler material.
- The impact & elongation of the C5 composite specimen are recommended for lightweight automobile applications to increase tensile and micromachining plans for future studies.

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Data Availability All the data required are available within the manuscript.

Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose. The authors have no competing interests to declare relevant to this article's content. All authors certify that they have no affiliations with or involvement in any organization or entity with any financial or non-financial interest in the subject matter or materials discussed in this manuscript. The authors have no financial or proprietary interests in any material discussed in this article.

Ethical Approval This is an observational study. Development and behavior analysis of CNT fibers reinforced high-density polyethylene composite via compression mold route: The Research Ethics Committee has confirmed that no ethical approval is required.

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