JSRT JOURNAL
PAGES: 20-27
9/10/24
JOURNAL OF SCIENTIFIC RESEARCH AND TECHNOLOGY VOLUME-2 ISSUE-9 SEPTEMBER

A Study on the Mechanical Properties of Hybrid Polymer Composites

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ABSTRACT

For quite some time, several orthopedic treatments have made use of metallic implants. Titanium, ceramics, medical grade titanium, and many other metal alloys are often used in orthopedic implant procedures. The creation of alternatives to metal implants, such as polymer composites, was driven by concerns about ion release and corrosion. This study is concerned with the development, processing, and examination of mechanical characteristics of carbon fiber powder/high-density polyethylene (HDPE) composites using Al_2O_3 and SiC fillers. When estimating mechanical parameters, ASTM standard procedures are used. The findings, which are grounded on mechanical assessment of composite performance, demonstrate the optimal selection of composite components for potential use in orthopaedic implants in the future.

Keywords – Polymer, Hybrid Composites, HDPE, ASTM, Al_2O_3

I. INTRODUCTION

The term "composite" refers to materials that have different chemical and/or physical properties from one another. A composite consists of a matrix, reinforcement, and the interface between the two. In composites, the orientation of the reinforcements is maintained by a matrix, which is a continuous phase. Distributing a stronger ingredient throughout the matrix serves as reinforcement. Mechanical or chemical bonds are formed between the matrix and reinforcements. Classification of composites is based on the kinds of matrix and reinforcements used. Polymer matrix composites (PMCs), metal matrix composites (MMCs), and ceramic matrix composites (CMCs) are the three main categories of composites formed by the matrix. Please use this format and follow its structure according to your requirements; it is merely an example paper.[1]

Metal, polymer, and ceramic components come together in a hybrid hip prosthesis to provide optimal biocompatibility, load bearing efficiency, minimal friction, and compressive and tensile strengths. There are several different kinds of hybrid hip prosthesis, including metal on polyethylene, ceramic on metal, ceramic on polyethylene, and many more. A femoral head made of CoCr, a stem made of Ti6Al4V alloy, and an acetabular socket made of Ti alloy are the components of a THR bio implant. Patients who are less active and in their 70s are often the ones who benefit most from these types of hip implants [2].

Ceramic on polyethylene is an attractive new grouping that has just been developed to lessen the discharge of metal ions and the production of waste particles. Additionally, oxide ceramics such as alumina, zirconia, or ZTA exhibit remarkable durability. Despite their poor fracture toughness, ceramics are capable of withstanding considerable compressive stress [3]. Worryingly, periprosthetic osteolysis and aseptic loosening, brought on by wear debris from polyethylene (PE), ultimately lead to implant failure in such a coupled joint [4]. Materials with a low coefficient of friction and chemical stability include hydrophobic polytetrafluoroethylene (PTFE) and ultra-high molecular weight polyethylene (UHMWPE). On the other hand, granulomas and tissue reactions are long-term effects of the polymers used to transport high wear debris. This happened because debris formed under bearing action due to poor compressive strength and stiffness [2].Given the above, studies are being conducted on ultra-high-performance micro- and nano-fiber reinforced UHMWPE with various additives to mimic the optimal in vivo characteristics.[5].

1.0 OBJECTIVES OF RESEARCH

1. Making carbon fiber-reinforced HDPE polymer resins, both with and without fillers.
2. For the purpose of testing the manufactured composites' mechanical properties.
3. In order to analyse the results of adding filler and not adding filler.

1.1 Scope of the Present Work

The next piece of writing reveals that no one scientific group has fully shown the mechanical property of hybrid produced carbon fiber powder supported HDPE polymer by means of filler material.

The present study aims to develop bio-composite materials from commonly utilized assets for use in biomedical devices, such as bone plates and screws, and for internal and external fixation. The HDPE is reinforced with designed carbon fiber power, and the fillers are Al_2O_3 and silicon carbide. A future constructed grid will be stabilized using silicon carbide and aluminum trioxide, the polymer will bond to the ground, or living things will attack water.

1.2 METHODOLOGY

At the outset of this experiment, the materials are chosen:

- HDPE as the matrix.
- Carbon fiber powder as reinforcement
- Silicon carbide and aluminum oxide powder as filler addition.

The injection molding process is used to create composite material by mixing these elements in various amounts. The universal testing machine is used to conduct compression, flexural, and tensile tests on composite materials. The matrix material of choice is high-density polyethylene (HDPE), a thermoplastic polymer derived from petroleum.

II. SELECTION OF MATERIALS

2.1 Selection of Matrix Phase

HDPE's density ranges from 970 kg/m3 to 0.93 to 0.97 g/cm3. HDPE, in contrast, is just somewhat denser than low-density polyethylene. Not only that, it's more opaque and complicated, and it can tolerate somewhat greater temperatures (1200 C/248 F for brief intervals). Because of its low friction coefficient, resistance to wear, lack of taste and odor, and lack of moisture absorption, high-density polyethylene (HDPE) is an ideal material. One of the most popular polyolefins, HDPE has several advantages over other options, including cheap cost, good processability, chemical resistance, and high strength.

2.2 Carbon Fiber Powder Selection

Composites with reinforcement provide better mechanical qualities and stronger final products. One of the most popular reinforcing materials is carbon fiber powder. The reason for this is because a lot of the performance features that are needed require carbon/graphite fibers. The majority of a fiber's mass is carbon, and its diameter ranges from 5 to 10 micrometers. Among carbon fibers' many benefits is their impressive strength-to-weight ratio.

FIG 1: CARBON FIBER POWDER

2.3 Selection of silicon carbide filler

To enhance the qualities of some combination materials or to decrease the need of more costly binder ingredients, fillers are particles added to materials such as plastics, composites, and concrete. One of the best abrasives is silicon carbide. In addition to being chemically inert, strong, thermally conductive, hard, elastic, and thermal shock resistant, it also exhibits minimal thermal expansion and high hardness.

Fig 2: silicon carbide powder

2.4 Selection of silicon carbide filler

Rocks such as mica and felspar contain aluminum, the most common metallic element in the Earth's crust. The chemical formula for aluminum oxide, an amphoteric oxide of aluminum, is Al2O3. Alumina and aloxite are other names for it in the fields of materials science, ceramics, and mining. A hard substance, Al2O3 is resistant to both acid and moisture. Anions are arranged in a hexagonal close-packed HCP array.

Fig 3: Aluminium oxide

2.5 New data collected

The following ingredients are used to make the polymer composite samples: The composition and concentration of the composites as shown in Table 1.

Sl. No	Composition	Composites	Reinforcement (%)	Matrix (%)	Filler (%)	
					SiC	Al_2O_3
1	H1	Carbon fibre powder/HDPE	0	100	0	0
2	H2	Carbon fibre powder/HDPE	20	80	0	0
3	H3	Carbon fibre powder/HDPE	20	76	2	2
4	H4	Carbon fibre powder/HDPE	20	72	4	4
5	H5	Carbon fibre powder/HDPE	20	68	6	6

III. SPECIMEN PREPARATION

The material used in this study is a carbon fiber powder reinforced high-density polyethylene (HDPE) polymer with added silica and Al2O3. The HDPE was obtained from ACE workshop in Bangalore, India, the carbon fiber powder was from Arrow Technical Textiles Private Limited in Mumbai, India, and the fillers were from Vasa Scientific in Bangalore, India. The extruder was used to compound the materials.

The extruder is one of seven auxiliary equipments used in the composite manufacturing process using high-density polyethylene (HDPE) and carbon fiber powder. Figure 3.1 shows the many components of the process, including the extruder, feeders, cooler, pelletizer, storage silo, bagging machine, heat exchanger, and cooling bath. This compounding extruder runs at 900 revolutions per minute. As the name suggests, micro injection molding requires a small opening through which a pressurized liquid or resin is injected to achieve the desired form. To create the specimens, the pellets are fed into an injection moulding machine.

Fig 5: Micro injection moulding machine

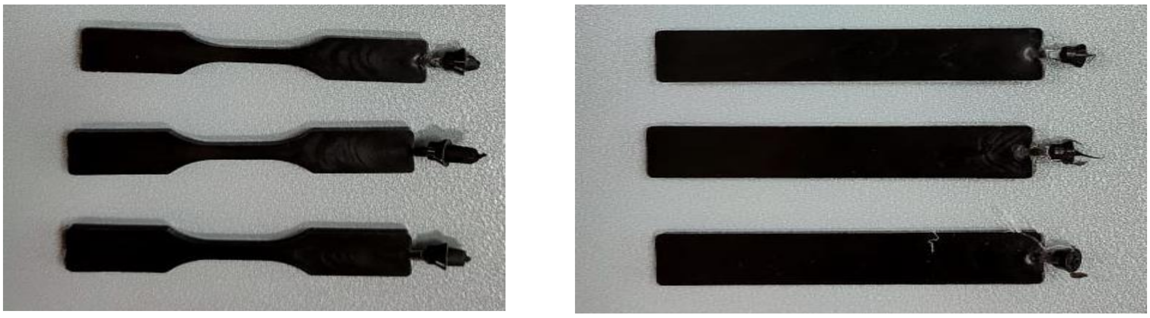


Fig 6: Tensile and impact sample prepared by micro injection moulding machine according to ASTM standard

IV. RESULTS AND DISCUSSION

a. Tensile Test

TABLE 2 Experimental Results of Tensile Properties

SL No	Specimen Composition	Matrix phase (HDPE)	Reinforcement Carbon fiber powder	Filler's addition		Tensile stress (MPa)	Tensile modulus (MPa)
				Al_2O_3	SiC		
1	H1	100	0	0	0	15.9	250
2	H2	80	20	0	0	17	275
3	H3	76	20	2	2	19.5	415
4	H4	72	20	4	4	22.5	510
5	H5	68	20	6	6	23.8	550

Figure 7 displays the hybrid composites' tensile stress and elastic modulus as a function of the quasi-static tensile load, and Table 2 summarizes the results of the tensile tests.

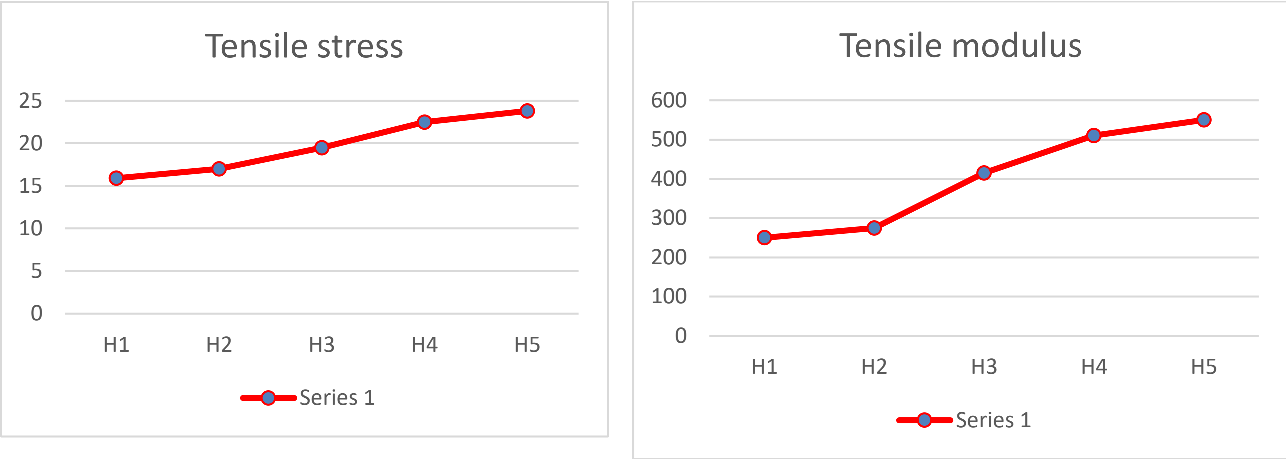


Fig 7: Tensile stress and Tensile Modulus

The specimen with the greatest tensile strength values was the hybrid polymer composite with carbon fiber powder as a 20% reinforcement and fillers that included 6% Al2O3 and SiC. This is because the composites are less likely to crack when subjected to tensile stress, a consequence of improved load transmission across the fiber/matrix interphase. Carbon fiber powder reinforced high-density polyethylene (HDPE) has an already high tensile strength, and adding fillers makes it much stronger.

b. Flexural Test

TABLE 3 Experimental Results of Flexural Properties

SL No	Specimen Composition	Matrix phase (HDPE)	Reinforcement Carbon fiber powder	Filler's addition		Flexural stress (MPa)	Flexural modulus (MPa)
				Al_2O_3	SiC		
1	H1	100	0	0	0	25.11	902
2	H2	80	20	0	0	33.2	975
3	H3	76	20	2	2	40.5	1150
4	H4	72	20	6	6	45	1390
5	H5	68	20	4	4	52	1435

Table 3 summarizes the results of the flexural tests, and Figure 9 displays the hybrid composites' flexural modulus and flexural stress under a quasi-static tensile load.

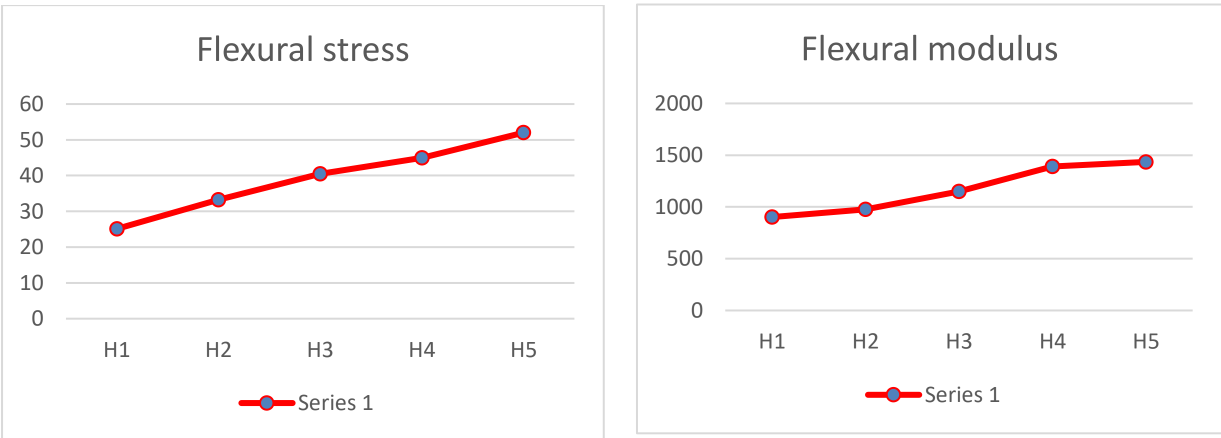


Fig 8: Flexural stress and Flexural Modulus

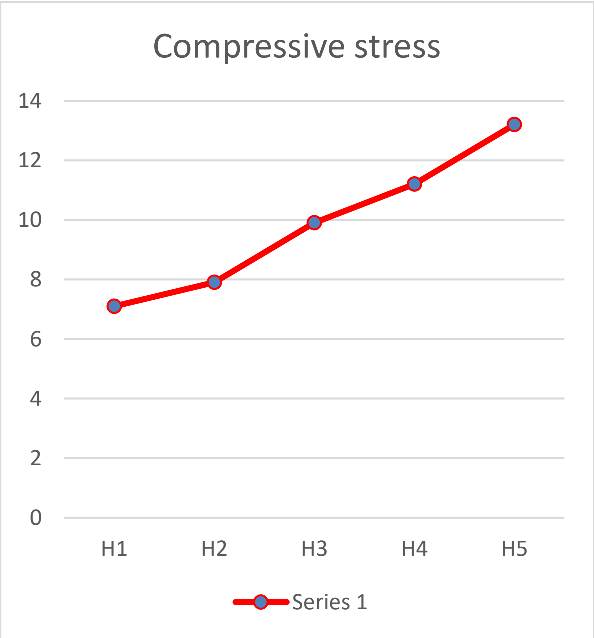
When flexural stresses are produced, they mix compressive and tensile forces. The flexural strength and modulus become more apparent as the fiber loading increases. For hybrid composites, the flexural strength and modulus reach their maximum at 20% fiber loading. As the loading increases, the tangling of the fibers and the effective wetting of the fibers by the polymer both contribute to further increases. Research has shown that flexural strength and modulus of hybrid polymer composites both rise linearly with increasing fiber loading from 0% to 20%.

c. Compression Test

TABLE 4 Experimental Results of Compression Properties

SL No	Specimen Composition	Matrix phase (HDPE)	Reinforcement Carbon fiber powder	Filler's addition		Compressive stress (MPa)	Compressive modulus (MPa)
				Al_2O_3	SiC		
1	H1	100	0	0	0	7.1	105
2	H2	80	20	0	0	7.9	132
3	H3	76	20	2	2	9.9	207
4	H4	72	20	6	6	11.2	242
5	H5	68	20	4	4	13.2	335

Figure 9 shows the compressive stress and compressive modulus of the hybrid composites under quasi-static tensile load while the summary of the compression test data is presented in Table 4



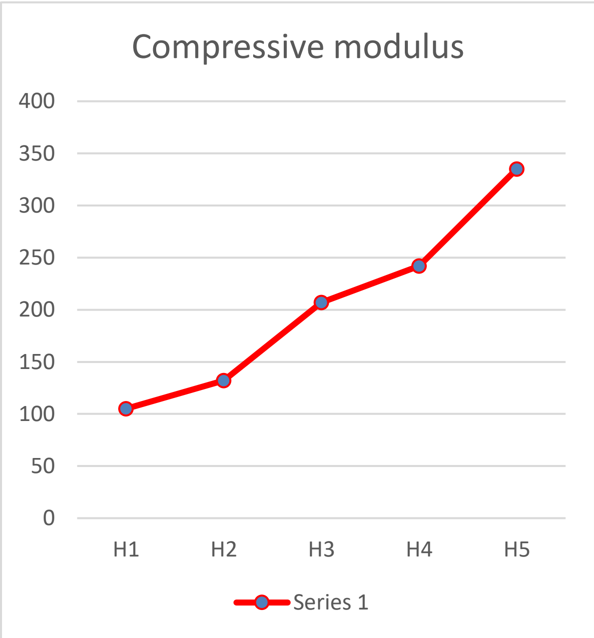


Fig 9: Compressive stress and Compressive Modulus

The compressive strengths of the composite specimens were measured using a mono axial compression test. Tables 4 show the findings for the hybrid polymer composites. Adding varying weights (percentages) of carbon fiber powder, Al2O3, and SiC to HDPE composites increases their compressive strength, which is proportional to the carbon fiber powder, Al2O3, and SiC content. Adding 20% vol% carbon fiber powder to 7.1 MPa plain HDPE polymer boosts it by almost 90% to 13.2 MPa; both versions include 6% vol% Al2O3 and SiC fillers.

d. Impact Test

TABLE 5 Experimental Results of Impact Properties

SL No	Specimen Composition	Matrix phase (HDPE)	Reinforcement Carbon fiber powder	Fillers addition		Impact energy (J/m)
				Al_2O_3	SiC	
1	H1	100	0	0	0	9.5
2	H2	80	20	0	0	11.2
3	H3	76	20	2	2	13.5
4	H4	72	20	6	6	16.4
5	H5	68	20	4	4	20.7

Table 5 summarizes the results of the impact tests, and Figure 11 displays the hybrid composites' impact energies as measured by the Izod impact test.

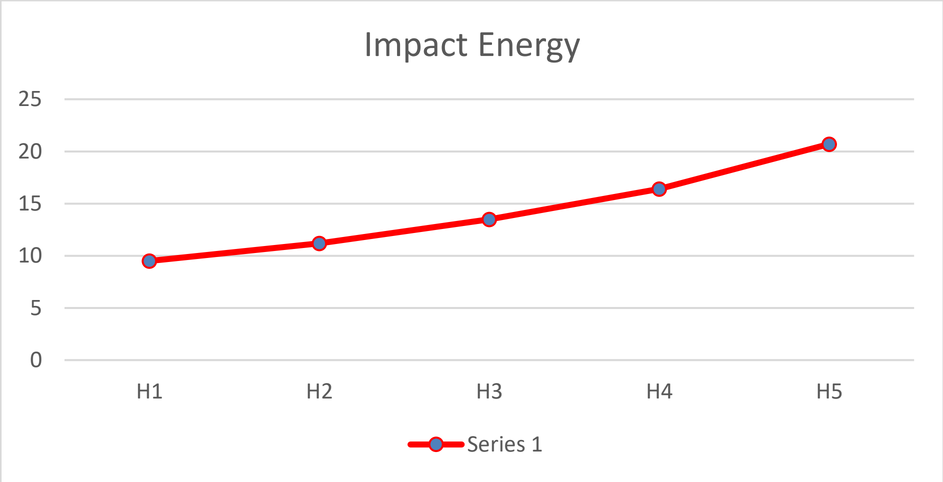


Fig 10: Impact Energy

Hybrid polymer composites have a better impact strength since they include carbon fiber powder as a 20% reinforcement and filler additives that comprise 6% Al2O3 and SiC. The impact strength is increased by a factor of 150 using hybrid polymer composites. The filler-matrix compatibility may have been enhanced because organic groups were present on the surfaces of the Al2O3 and SiC. Because of a subsequent debonding step (void formation) that would cause specimen failure in the event of excellent phase adhesion, particle size determines when the matrix really separates from the particles. When the matrix and filler have strong adherence, tiny particles are desirable. The particles clump together to create smaller ones when the filler concentration is increased due to the decreased surface energy of the SiC. Consequently, HDPE polymer composites containing 6% Al2O3 and SiC have enhanced impact strength.

V. CONCLUSIONS

The present study set out to investigate the mechanical characteristics and possible applications of treated carbon fiber powder reinforced HDPE polymer composites.

To begin, a composite's tensile strength value was found to be 20% higher with the inclusion of fiber and filler content, namely 6% Al2O3 and SiC. The highest tensile strength value was reached after that, at 20% composition with 6% Al2O3 and 2% SiC additions.

Despite this, the carbon fiber powder does initially provide a substantial amount of reinforcement to the HDPE composite. However, as the quantity of fiber used in composites grew. As a result, the interfacial connection between the fiber and the matrix is improved, and up to 20% of the fibers in the composites are evenly distributed.

Supplementing the material with 6% Al2O3 and SiC enhances its flexural characteristics. Because of this, even at greater filler concentrations, the microparticles are well dispersed. The amount of carbon fiber powder, Al2O3, and SiC added to HDPE composites determines their flexural strength. With a fiber content of 20% composite offering the maximum value, the flexural strength of the composites improved with increasing percentages across the board. Flexural modulus of composites demonstrates that flexural modulus of reinforced carbon fiber powder reinforced HDPE composites changes with increasing amounts of carbon fiber powder, Al2O3, and SiC.For composites with 20% fiber content or more, the flexural modulus rose in direct proportion to the fiber quantity.

Adding varying weights (percentages) of carbon fiber powder, Al2O3, and SiC to HDPE composites increases their compressive strength, which is proportional to the carbon fiber powder, Al2O3, and SiC content. The compressive strength of clean HDPE polymer is 7.1 MPa, but it improves by almost 90% when 20% volume percent carbon fiber powder is added. Both mixtures include 6% volume percent Al2O3 and SiC fillers. Compressive strength measurements of hybrid composites including carbon fiber powder, aluminum oxide, and silicon carbide in varying quantities reveal a linear relationship between filler concentration and compressive strength.

How loading the carbon fiber/HDPE composites affects their unnotched Izod impact strength. Impact strength improves up to 20% carbon fiber powder content, as seen below. As a result, the resistance of the fiber against cracking—mainly caused by debonding and pull-out processes—increases with increasing carbon fiber powder concentration.

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