# Hybrid Polymer Matrix Composites for Biomedical Applications

Dr. Mohammed Haneef, [1] Dr. J. Fazlur Rahman, [2] Dr. Mohammed Yunus, [3] Mr. Syed Zameer, [4] Mr. Shanawaz patil, [5] Prof.Tajuddin Yezdani[6]

[1]Principal, Department of Mechanical Engineering Ghousia College Engineering, Ramanagara, Karnataka State, India
[2]Professor Emeritus, Department of Mechanical Engineering, H.K.B.K. C.E., Bangalore, Karnataka State, India
[3]Professor Lecturer Department of Mechanical Engineering H.K.B.K.C.E., Bangalore, Karnataka State, India
[4]Assistant Professor Department of Mechanical Engineering Ghousia College Engineering, Ramanagara, Karnataka State, India

***Abstract***: *Bones and joints in human body made of a natural composite material are fractured due to excessive loads and impact stress. The various types of bone fractures which occur in human body depend upon crack size orientation, morphology and its location. In general, the mean load on the hip joint is expected up to three to five times of the body weight during jumping, jogging etc. .These loads are fluctuating depending on the activities such as standing, sitting, jogging, climbing the staircase etc. The material of prosthesis and the durability of alternate bone material is of critical importance, because it largely determines how load is transferred through the stem. In the geometry and design of the material, the young's modulus of a material is critical design variable.*

*The polymeric biocomposites reasons, why they are becoming most common composites, include their low cost, high strength and simple in manufacturing principles by molding process. But they suffer from poor mechanical properties like higher wear rate, lower hardness and Young's modulus.*

*An attempt has been made to develop hybrid bio polymer matrix composites using high density poly ethylene as the matrix material with Titanium Oxide ($TiO_2$) particles and Alumina ( $Al_2O_3$) particles as the reinforcement material with varying parcentage using extrudal injection moulding machine. The different testing namely, tensile, hardness, flexural strength, density, fractography, corrosion and wear test were conducted on the standard samples prepared. It is found an appreciable improvements in the mechanical and tribological properties of the hybrid polymer matrix composite, which can be used for variety of applications in thehuman body bone replacement. In this case, their application in orthopaedic as implantable material in the bone surgery has been considered and studied. These composite materials have found wide use in orthopaedic applications, particularly in bone fixation plates, hip joint replacement, bone cement and bone graft.*

***Keywords:*** *A Polymer Matrix Composite, polyeuthylene+ Titanium Oxide ($TiO_2$) particles + Alumina ($Al_2O_3$), Orthopaedic applications.*

## I. INTRODUCTION

Bone, which is a natural composite material, consists mainly of collagen fibers and an inorganic bone mineral matrix in the form of small crystal called apatite. Collagen is the main fibrous protein, the composite of mineral component in the body. Cartiligen is a collagen based tissue which contains large protein saccharit molecules that form a gel in which collagen fibrous are bonded [1]. Articular cartillery forms the baring surfaces of the moveable joints of the body which behaves linear visco elastic. It has also very low coefficient of friction (μ) largely attributed to the presence of senovial fluid that can be squeezed upon compressive loading [5].

Bone replacement materials are required for variety of reasons [11]. They may require when section of bone is missing and the gap needs to be filled. There are several options for the types of bone replacement.

1) Allograft: means material from another patient.
2) Autograft: It means using material of a person from different site.

Synthetic materials are gradually becoming more popular. Hydroxy apatite is prepared easily, but it is ceramic, which is too brittle to be used on its own for large scale applications. Copmosites of a hydroxy apatite with degradable polymers can also be used which allows bone to regrow and fill the same. Bio materials both natural and synthetic materials are used to replace part of a living system. This group of materials include metals (such as stainless steel, titanium alloy) and ceramics (such as alumina and toughened Zirconia) known for high strength, ductility and resistance to wear, but metals exhibit low bio compatibility, corrosion and high stiffnees compared to tissues and also metal ions which cause allergic reactions. Ceramics are known for their good bio compatibilty, corrosion resistance but main drawback is brittleness, low fracture strength, difficult to fabricate and low mechanical properties and high density. But polymer composite bio-materials provide better alternative choice for replacing because of bio-compatibility, corrosion resistant and easy to fabricate etc. Composite materials are having the advantages of high specific modulus and strength to weight ratio besides, they have superior toughness to prevent crack propagation.

Metal matrix and Fiber reinforced composite materials have been used these days due to their durability, less weight and better compatibility. The basic requirements for human joints include mechanical property (yield stress, plasticity, Young's Modulus, Fatigue strength), Physical properties (density, magnetic properties etc.), chemical properties (resistance to different forms of corrosion and wear degradation), biological property (bio –compatibility) and lesser cost [1]. The following polymer composite bio- materials are used for various bio medical applications.

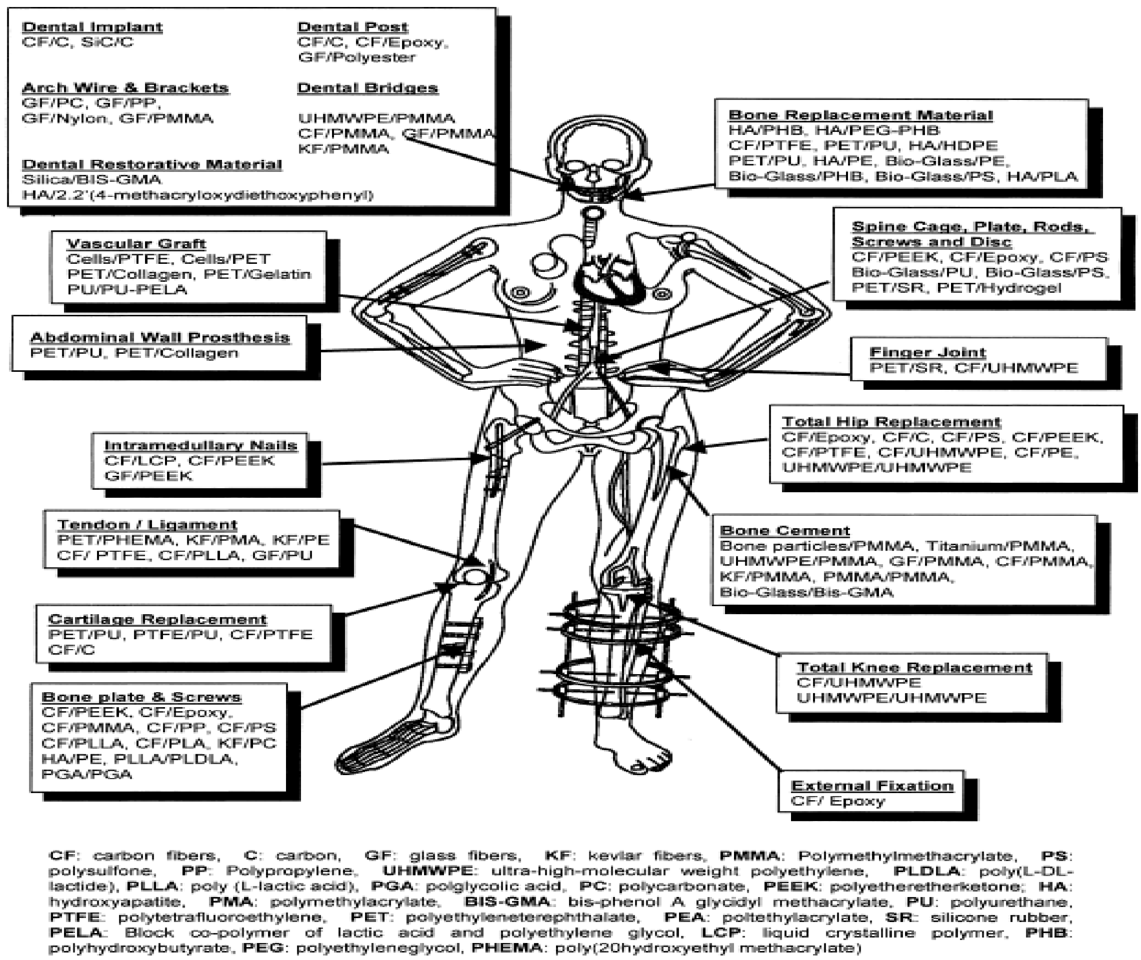


Fig.1. Application of different composites in different parts of body

1) Total knee replacement: polyethylene, carbon fibers and ultra molecular weight polyethylene.
2) Total hip replacement: carbon fibres-Epoxy carbon fiber- Polysulphone, polyeyhylene carbon fibers etc.
3) Finger joint: ultra high molecular weight polyethylene, poly sulphone etc.,
4) Bone cement: Titanium, carbon fibers- ultra high molecular weight polyethylene, Kevlar fibers/ poly tetra fluoroethylene (PTFE) etc.,
5) Dental implant: Carbon fibers/ carbon, Silicon carbide (SiC)/ Carbon.
6) Bone plates and screws: Polyethylene/ hydroxy apatite, carbon fiber/ epoxy, Kevlar fiber/ poly carbonate etc.
7) Cartilage replacement: Carbon fibers/ PTFE, Polyeurethane.

At present steel, titanium and titanium based alloys are being widely used for the bone replacement of materials and also different ceramic materials like hydroxyl apatite, Alumina, Zirconia are widely researched materials for implant applications and they are commercially produced despite of their high cost. Different bio-compatible polyethylene (PE) and poly ehterther ketone (PEEK) based materials are being used as low loading bearing application for bone and other bio medical applications for having good bio-compatibility.

From the literature survey, it is found that, most of the research was carried out with respect to bio-compatible materials using stainless steel 316L, Ti-6AL-4V alloy, Co-Cr alloy, hydroxyl apatite (HAP), ultra high molecular weight polyethylene (UHMWPE), Alumina ($Al_2O_3$), Titanium oxide ($TiO_2$), Silicon carbide (Sic) etc. as the replacement material for various types of bone fractures like knee joint, hip joint, ankle joint and also for dental applications[18].

## II. METHODOLOGY

This paper highlights about the study of basic properties required to replace bone materials for various types of bones and joints fractured by the synthesis of bio-compatible, hybrid polymer matrix composites.

Polymer matrix composite is the material consisting of polymer (resin) as matrix combined with a fibrous reinforcing dispersed phase. Polymers make ideal matrix material, they can be processed i.e. fabricated more easily, with light weight and offer desirable mechanical properties. The reasons for the selection of these composites are low cost, high strength and simple manufacturing principles.

The various mechanical properties of typical polymeric bio-materials are shown in the table.1.

Table1. Material Properties

| Material | Modulus (GPa) | Tensile Strength (MPa) |
|---|---|---|
| **Metal alloys** | | |
| Stainless steel | 190 | 586 |
| Co-Cr alloy | 210 | 1085 |
| Ti alloy | 116 | 965 |
| Amalgam | 30 | 58 |

The some of the commonly used areas of these biomaterials are joint replacements, total hip replacements, bone plate and bone cement, dental implants for tooth fixation, heart valves, contact lenses, vascular grafts, dialysis membrane, catherters, pace makers, leads, blood vessel prosthesis and opthalmagic devices. Although an organic material bone can often be considered in the same way as manmade engineering materials due to the nature of its synthesis, it is likely to show more variations in measured properties than with typical engineering materials, which are due to the following factors.

1) Age
2) Gender
3) Location in the body
4) Mineral content
5) Amount of water present
6) Diseases

With the increase in the age of human beings, the bones becomes less dense and the strength of these bone also decreases, thereby more susceptible to fracture. The various mechanical properties of bio materials studied are 1) Tensile strength 2) Young's modulus 3) Hardness 4) Fracture strength 5) Bending flexural strength and 6) Factography.

Based on geometry, design and material of prosthesis the young's modulus of material becomes a critical design variable as it largely determines how load is transformed through the stem. In order to study the durability of alternate material which is of critical importance, an attempt has been made to develop a hybrid bio polymer matrix composites using HDPE as the matrix, with titanium oxide particles and $Al_2O_3$ Particles as the reinforcement material with varying percentage. Using rule of mixture of composites, namely, with 10% weight titanium oxide and 5%, 10%, 15% and 20% of $Al_2O_3$ and the reinforcing HDPE as matrix material, hybrid biopolymer composites were fabricated using injection molding machine.

Using extruder injection type molding, all the samples prepared as per ASTM Standard D3039. They were subjected to various tests, mechanical and tribological properties to investigate and study the various properties like Tensile strength, young's modulus, flexural strength, hardness tests.

Factography test using SEM and salt sprayed corrosion test were also conducted to study wear behavior of bio polymer composites. This is being done to assess the suitability of bio polymer composites (i.e. HDPE + Titanium oxide+ Aluminium oxide) in bio medical applications.

The schematic work plan of this research work is shown below.

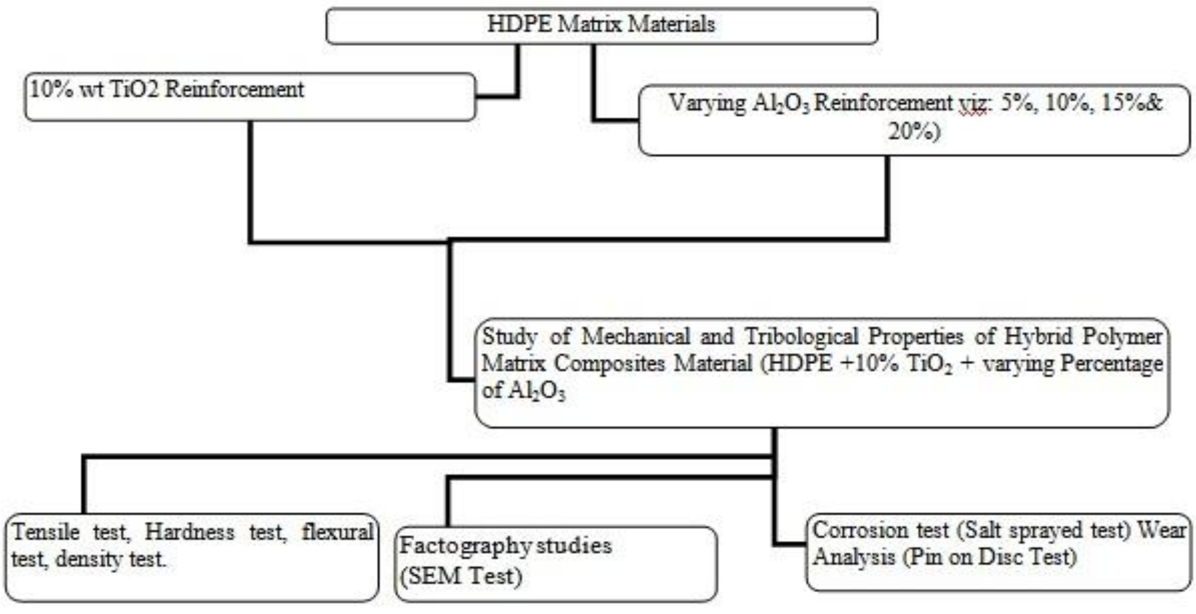


Fig.2. Organization Chart

List of samples prepared with different composition are shown in Table 1.

Table1.

| SAMPLE | HDPE | $TiO_2$ | $Al_2O_3$ |
|---|---|---|---|
| 1 | 85 wt % | 10 wt % | 05 wt % |
| 2 | 80 wt % | 10 wt % | 10 wt % |
| 3 | 75 wt % | 10 wt % | 15 wt % |
| 4 | 70 wt % | 10 wt % | 20 wt % |

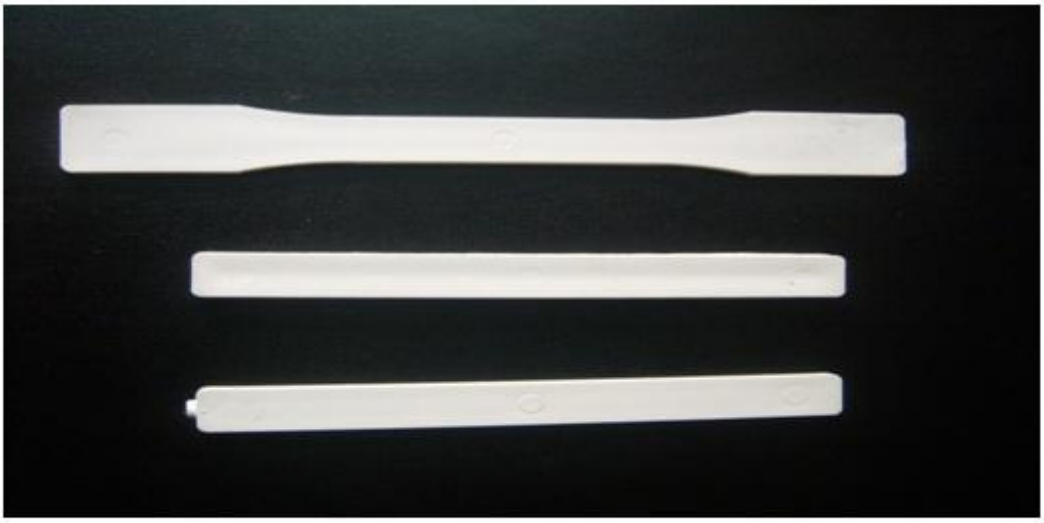

**Fig.3. Photographs of specimens of HDPE matrix +$TiO_2$/$Al_2O_3$ as varying reinforcement**

## III. Results and Discussions

1) T It is inferred from the test results that, the tensile strength of composite material increases with increasing percentage of filler contents namely, 5%, 10%, 15% and 20% of $Al_2O_3$ keeping 10% of Titanium Oxide constant. This results in the increase of the load carrying capacity of composite material. The maximum peak tensile stress achieved is 16.1 MPa and young's modulus of 500 MPa (for HDPE +10% $TiO_2$ + 20% $Al_2O_3$ of the composite specimens) as shown in figure 4 and figure 5.

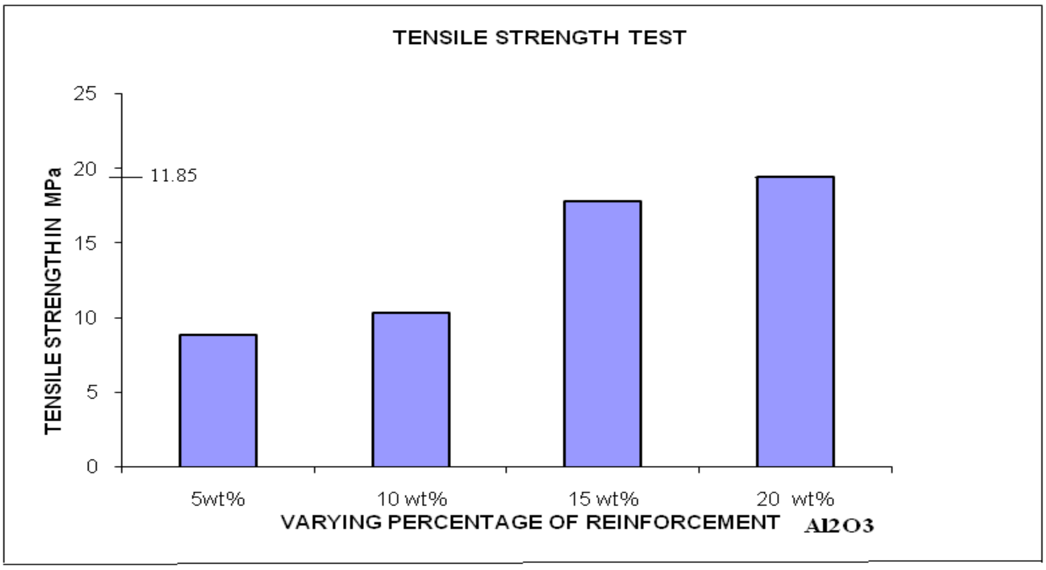


**Fig.4. Variation of Tensile Strength for varying percentage of Reinforcement**

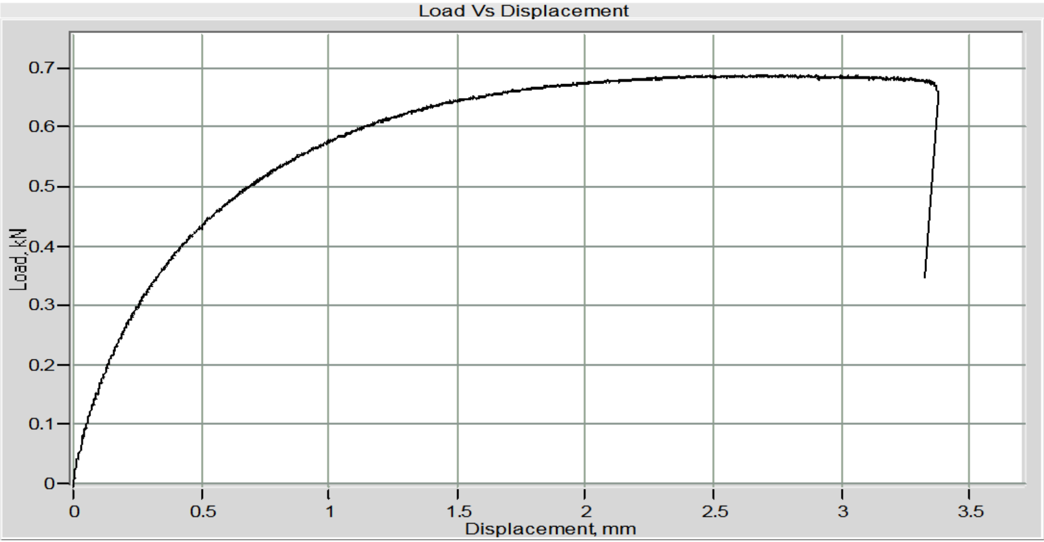


**Fig.5. Load Vs Displacement curve for HDPE/10wt% $TiO_2$ -20wt% $Al_2O_3$**

2) Flexural strength: The figure 6 shows the variation in the flexural strength of composite specimen with varying percentage of reinforcement material $Al_2O_3$. Flexural strength of composite material increases with increasing percentage of filler contents (from 5% to 20% of $Al_2O_3$). The maximum Flexural strength achieved is 11.85 MPa for HDPE+10% TiO2 + 20% Al2O3 of the composite specimen shown in figure 6.

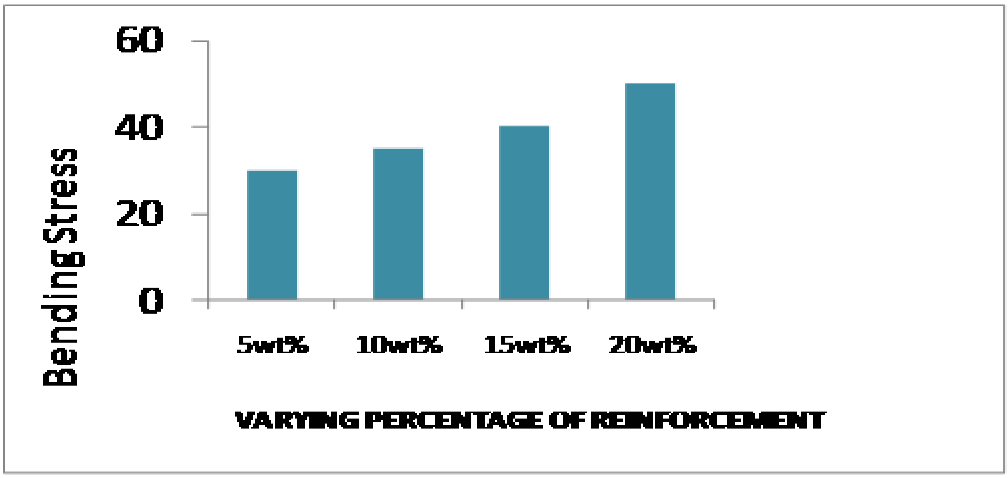


**Fig.6. Variation of Bending Stress for varying percentage of Reinforcement**

3) Hardness: Figure 7 shows the variation in the hardness of specimen with varying percentage of reinforcement. The maximum hardness shore D hardness number is found to be 55.

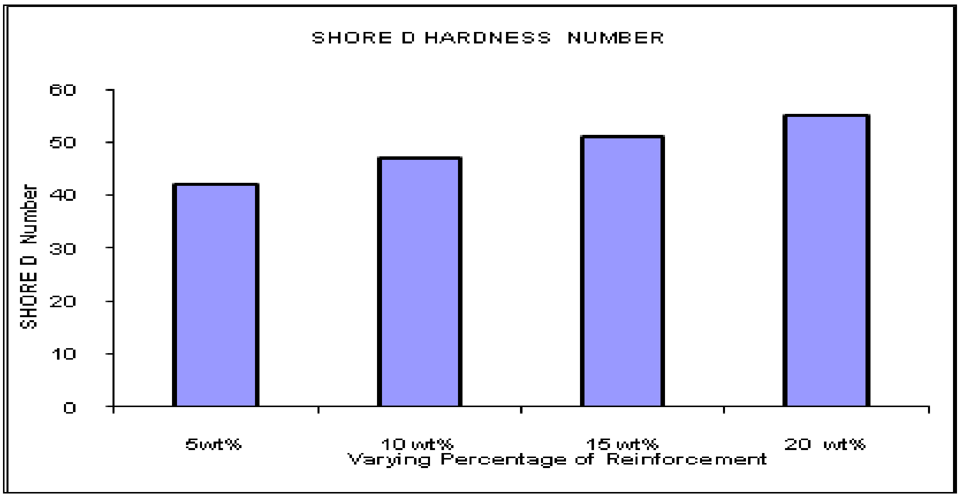


**Fig.7. Variation of Hardness for HDPE/10wt% $TiO_2$ -5 wt% to 20wt% $Al_2O_3$**

4) Density Test: figure 8 shows the variation of density with percentage of reinforcement. The increased density of composites are attributed to good bonding between the matrix and reinforcement.

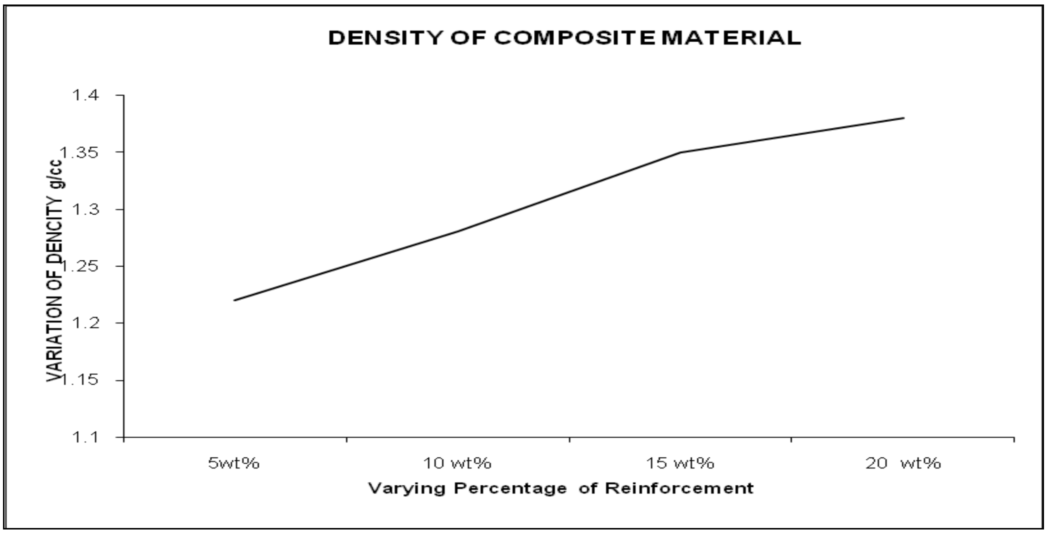


**Fig.8. Variation of Density with Persentage of Reinforcement**

5) Factography study: the fractured surface of +10% $TiO_2$ + (5%, 10%, 15% and 20%) $Al_2O_3$ indicates homogeneous mixing of HDPE+$TiO_2$ + $Al_2O_3$ particles with no casting defects resulting in enhancing the mechanical properties of composite material.

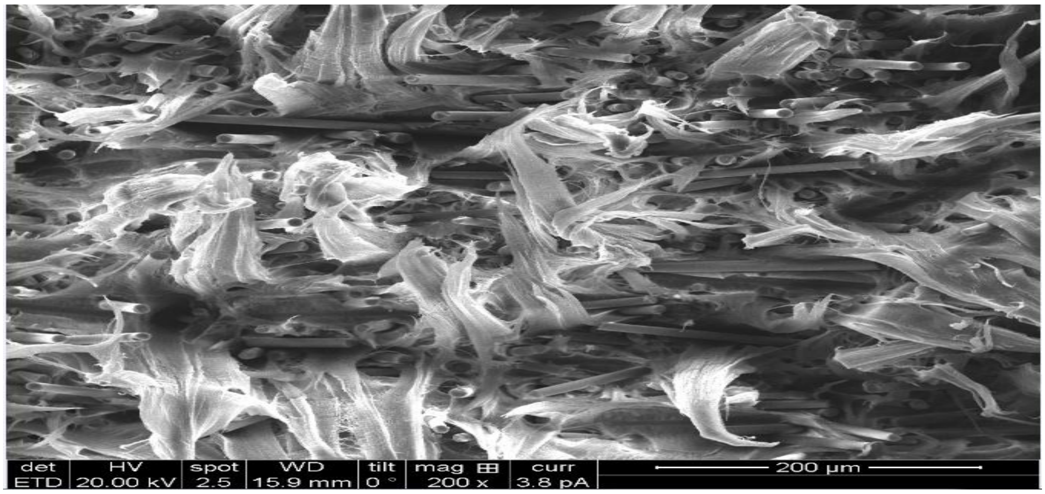


**Fig.9. Fractured surface after tensile strength test for HDPE+ 10% $TiO_2$ +15% OF $Al_2O_3$**

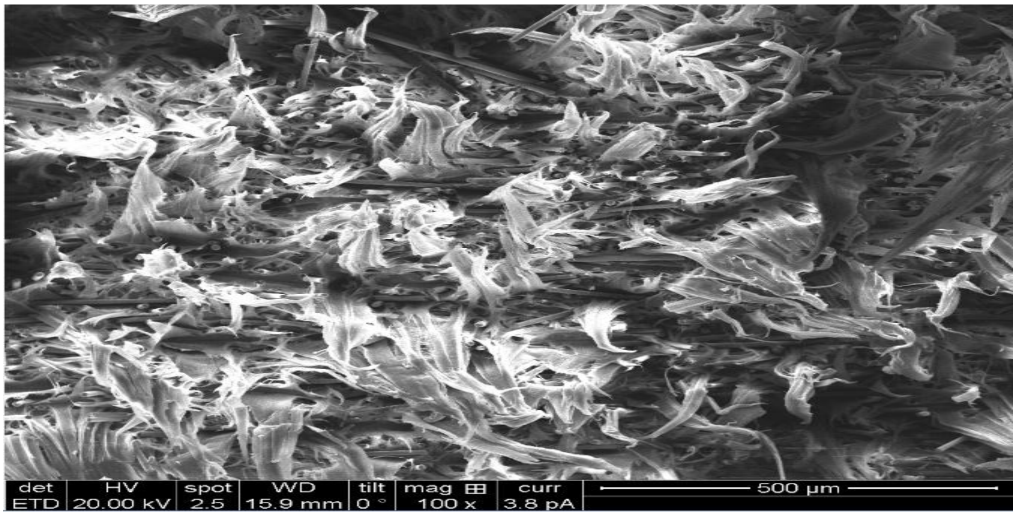


**Fig.10. Fractured surface after tensile strength test for HDPE+ 10% $TiO_2$ +20% of $Al_2O_3$**

6) Corrosion test / Salt sprayed test: It has been observed for a given time period of 24 hours, no corrosion was found on all the specimens of hybrid polymer matrix composites.

**Table 2. Corrosion Test for 5% of $Al_2O_3$ & 10% of $Al_2O_3$**

| **Methodology for corrosion test** | |
|---|---|
| After Test | Cleaned with running Water |
| Test Solution | 5% NaCl (AR Grade) Solution in distilled water |
| Test Temperature | 35°+/-2°C |
| Volume of Solution Collected/Hr/80Cm$^2$ Area | 1.41 ml |
| pH of test Solution | 7.08 |
| Required Exposure Period | Not Specified |
| Type of protection Used | Nil |

Observation:

| **PH value** | **Time in Hours** | **Observation** |
|---|---|---|
| 7 | 24 | No Corrosion was observed |

7) Wear analysis- Pin on disc wear test: The wear data i.e. wear loss in grams for different loads namely, 10 N, 20N and 30 N at constant speed of 500 rpm for different samples are shown in table 2. The following observations were made in the wear analysis test.

a. With increase in the load on the specimen, the wear loss of composite increases. Whereas, wear loss decreases with increase in the percentage of reinforcement of composite.
b. It is also noticed with increase in sliding time, wear of the component also increases.
c. The coefficient of friction as well as frictional force of composite decreases with increase in percentage of reinforcement as shown in figures.

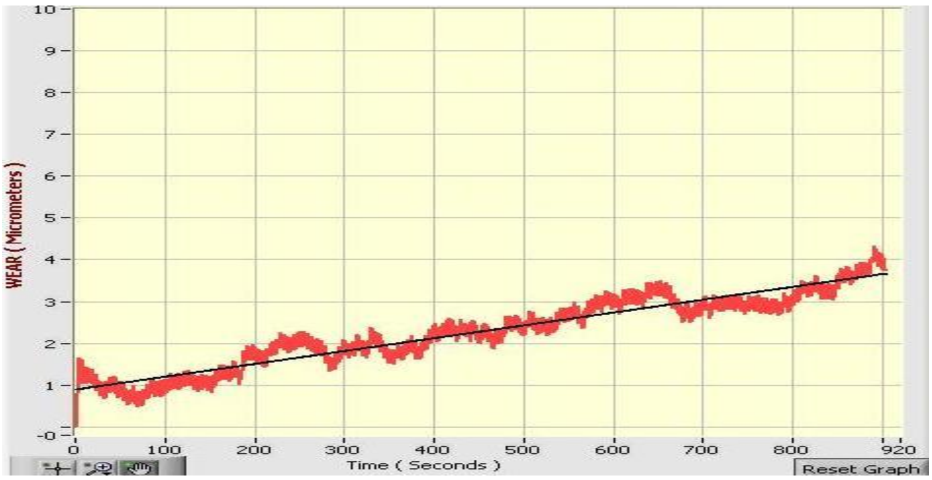


**Fig.11. Wear (Micrometers) V/s Time (Seconds) at load 10N for 20wt% $Al_2O_3$**


**Fig.12. Coefficient of Friction V/s Time (Seconds) at loads 10N for 20wt% $Al_2O_3$**

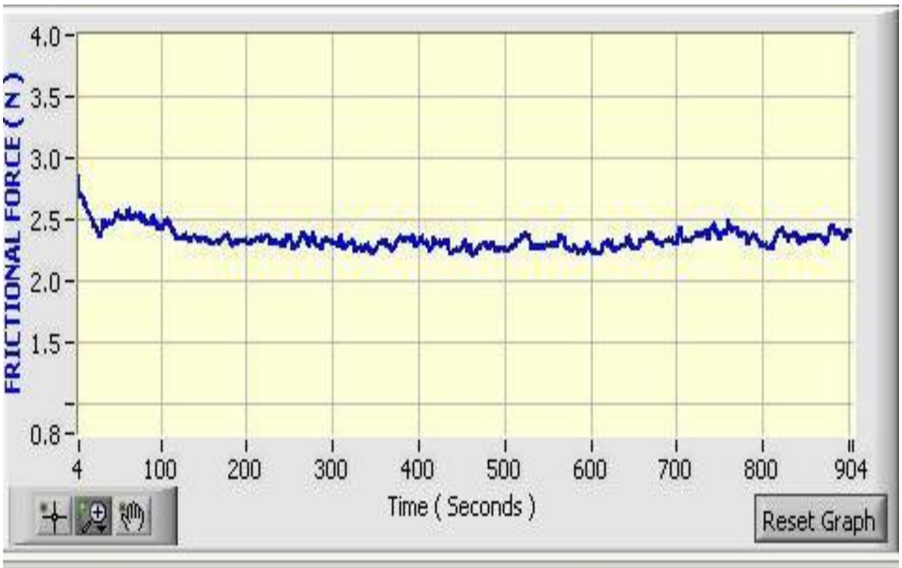


**Fig.13. Frictional Force (N) V/s Time (Seconds) at load 10N for 20wt% $Al_2O_3$**

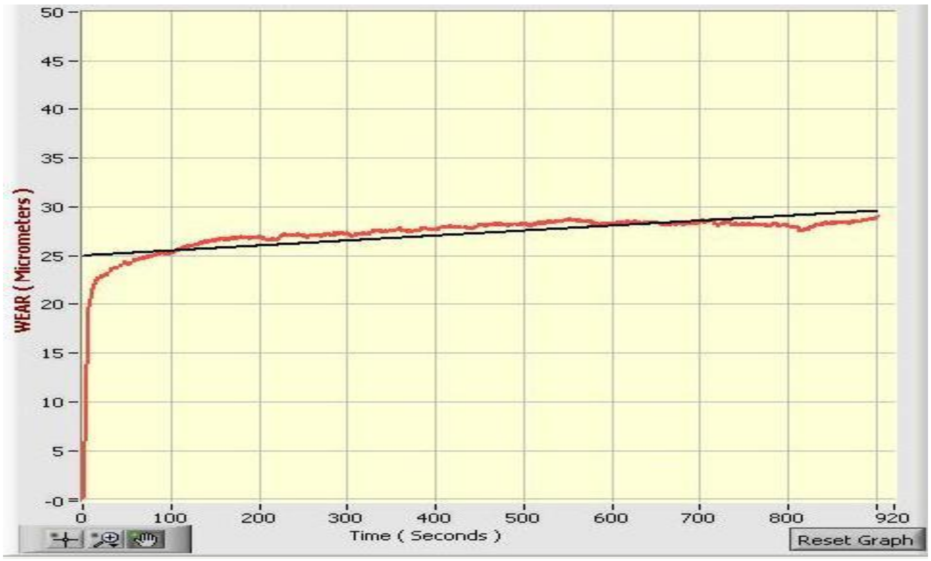


**Fig.14. Wear (Micrometers) V/s Time (Seconds) at load 20N for 20wt% $Al_2O_3$**

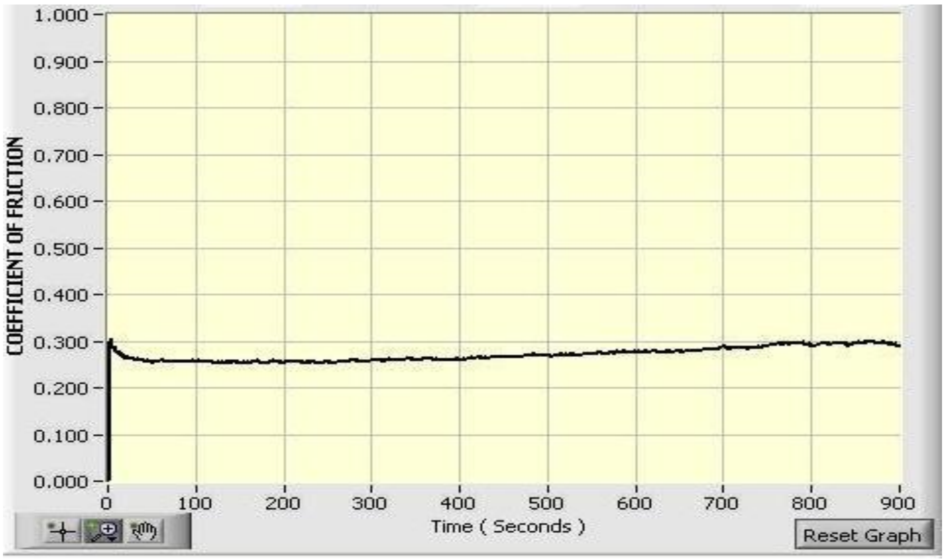


**Fig.15. Coefficient of Friction V/s Time (Seconds) at load 20N for 20wt% $Al_2O_3$**


**Fig.16. Frictional Force (N) V/s Time (Seconds) at load 20N for 20wt% $Al_2O_3$**

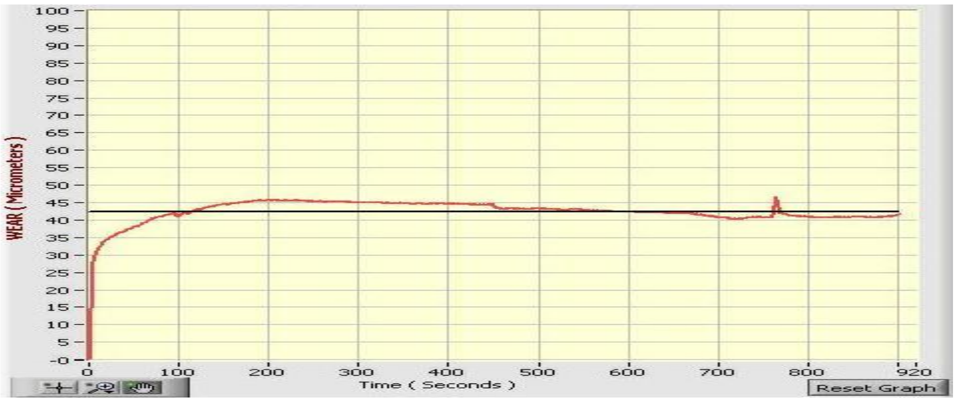


**Fig.17. Wear (Micrometers) V/s Time (Seconds) at loads 30N for 20wt% $Al_2O_3$**


**Fig.18. Coefficient of Friction V/s Time (Seconds) at load 30N for 20wt% $Al_2O_3$**


**Fig.19. Frictional Force (N) V/s Time (Seconds) at load 30N for 20wt% $Al_2O_3$**

## IV. CONCLUSION

Based on the investigations carried out on hybrid polymer matrix composites, the following conclusions were made

1. It is observed that, the tensile strength, hardness and bending strength and density of this hybrid polymer composite increases with the increase in percentage of reinforcement.
2. Maximum tensile strength of 16.7 MPa, Maximum hardness of 55 shore D number and Maximum Bending strength of 12MPa was achieved with HDPE + 10% $TiO_2$ and 20% $Al_2O_3$ reinforcement.
3. Factography of specimens indicates absence of casting defects and proper bonding behaviour matrix material and reinforcement.
4. No corrosion was observed on the specimens after the corrosion test was conducted for a time duration of 24 hours at PH value of 7.
5. Based on the observations of results of various tests, it is suggested that, HDPE+10% $TiO_2$ + 20% $Al_2O_3$ reinforcements could be used as a suitable for bone materials, in orthopedic applications.
6. This polymer matrix composite (HDPE+10% $TiO_2$ + 20% $Al_2O_3$) have variety of applications in the human body and they can be applied on hard and soft tissues of implantable materials.
7. Composite materials are extensively used in orthopaedic applications particularly in bone fixation plates, hip joint replacement, bone cement and bone graft. The investigations of all possible factors which may affect the life time, together with response of human body, body parts, tissues and muscles changing itself with increasing age, may be performed by special procedures with sophisticated approach.
8. A prototype of bone specimens made of the above composite materials needs to be analyzed in a host body conditions for compatibility of human body.

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