Investigation of Mechanical Properties on 10% of Al_2O_3 and 10% of ZrO_2 with polyurethane resin Polymer Composite as an Orthopedic Implant

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Abstract- *The paper deals with the study on mechanical properties ofHybridpolymer composite material for 10% of Alumina (Al_2O_3) and 10% of Zirconium Dioxide (ZrO_2) with polyurethane resin mixed with hardener for medical applications. It starts with the preparation of material by weight fraction method and fabrication of these basic materials by hand lay-up moulding technique. By this the laminates are prepared with the specific size, later it is cut into the different shapes as per ASTM standards for conducting different material testings' like tensile, compression, bending tests to study the mechanical properties of prepared composite material. These results are compared with femur bone material properties.*

Keywords- Hand lay-up moulding, tensile test, compression, bending, polyurethane resin.

I. INTRODUCTION

This paper deals with the study and preparation of composite material for orthopaedic implant i.e. for medical application. This involves the concept of study of mechanical properties of femur bone and the composite material also the comparison of results for both the material by conducting the different material property tests. There are lot of research work is going on in the medical field and also there are many research works are already done on orthopaedic implants. By taking the reference from all those research works on the orthopaedic implants we are doing a project by preparing the composite material for the replacement of femur bone. In this project we are trying to introduce the new composite material and we expected to have the better mechanical properties like high strength, low density and resistance to wear and corrosion.

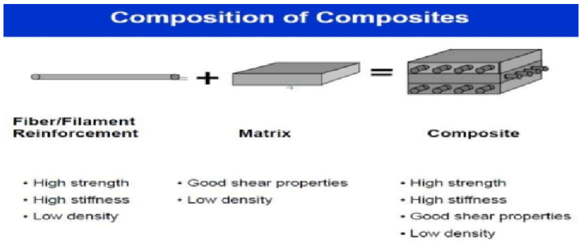


Fig.1.1 Composite structure

This we can conclude by conducting the different types of material testing like tensile, compression and bending tests to find out the material behaviour under different load. These tests are conducted in various Research and Development institutes. The composite material is prepared by adding the 2 to 3 materials having the different compositions and different chemical and physical properties. The composite is prepared by Hand Lay-Up moulding technique in the laminates form having the size 300×300×3.2 mm size. Later the laminates are cut into different shapes for different tests as per the standards. From this laminates three samples are prepared for each tests. This cut specimens are tested for three samples. The average values of results of three samples.

II. LITERATURE SURVEY

- Sundeep et.al prepared and studied the material property for 5%, 2.5%, 7.5% and 10% of SiC with combination of 5% of fly ash. [2] Mr.JenixRinoInvestigation of .composite material of Al6063 matrix material includes zircon sand and alumina by 8% was studied [4]
- K. B. Girisha et al. investigated the effect of different weight fraction of zirconium oxide nanoparticle reinforced Al356. Used for orthopedic implants. [5]
- Sliviasuner Moreno theory prepared the ultra-molecular weight polyethylene for joint replacement [6]
- jagadish S P et. Al they found mechanical properties of existing material SS316L and used for implant material. [7]
- D.Chandramohan& .K. Marimuthu. they used natural fibres for medical applications[8]

Femur bone:it is the longest bone in the human body. It is located at the right and left side leg

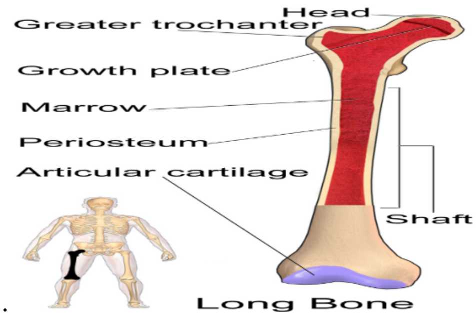


Fig. femur bone of human body

Table 3.1 mechanical propertiesof femur bone Biomed Research International Value 2015.[3]

Mechanical Tests	≤ 30 Years	31 – 50 Years	51 – 70 Years	≥ 70 Years
Tensile Strength MPa	43.44 ±3.62	39.82± 4.29	33.16± 6.43	30.16 ±7.09
Compressive strength MPa	155.8 ±9.53	142.37 ±12.12	124.44 ±15.40	115.29±12.94
Bending strength MPa	84.03 ±9.91	75.22± 11.61	61.89± 10.81	43.57 ±11.74
Shear strength MPa	55.41 ±4.56	49.54± 7.11	39.61± 8.39	32.62 ±8.35

III. PROBLEMS IDENTIFICATION

It is identified that the problems associated with the orthopaedic implants. In our present generation, peoples are facing so many problems in health because of change in environment i.e. the problems may arise from genetic factor, effect of food, living style and factor of age. The strength of human bones are going to wear day by day i.e. decrease in the bone strength. This affects the mechanical properties of the bone. The femur bone can bear the major loads in regular activities like running, jumping, lifting and dancing etc. apart from this the femur bone may fracture from several reasons. They are as follows.

1. Heavy load
2. Car accidents
3. Falling from height
4. Slip in bath room
5. Natural disaster
6. In old age
7. Defective bone.

In these situations there is a maximum chance for the fracture of femur bone. So doctors suggested that patients may undergo 2 types of surgeries. They are

a) Inserting the bio material into the bone
b) Replacement of bones by new biomaterial. Biomaterials are also referred as implants.

The main reason for the failure of this material is progressive application of stress, change in the cross section and increase in the wear rate by solid surface mechanical actions. In many cases doctors preferred stainless steel 316 materials and some other materials for the replacement of femur bone as the effective solution for the fracture of femur bone. And also in many research works the different composite materials are also tried for this replacement.

Later we found that there are so many problems that affects to the human body by using this type of material. Some of them are as follows

1. Heavy pain in body
2. Cause the infection
3. Sometimes this may undergoes deformation
4. Loosening
5. Fatigue
6. Gradual wear
7. Corrosion
8. Toxicity

IV. METHADOLOGY

In order to achieve these objectives it need to following the different methodologies for the preparation of composite material for orthopaedic implants i.e.in medical applications with required characteristics. The steps involved in our project are as follows.

1. The first step is we are making the literature survey to study and identify the problems occurred in orthopaedic implants surgery. Based on this survey, the planning is done to select the basic materials for the preparation of composites.
2. The composites material is prepared by combining the different powders like aluminium oxide and zirconium dioxide with polyurethane resin.

3. These basic materials are mixed by the weight fraction method. We have selected and studying the material for 10 % of Al2O3 and ZrO2 and 80% of polyurethane resin.
4. By this the laminates are prepared by the Hand Layup moulding technique. The laminates having the size 300×300×3.2 mm. these are later cut into different shapes for conducting the different tests.
5. As per the standards the laminates are cut into pieces for conducting the tests like tensile, compression, bending tests.
6. These results and graphs of composite material are compared with results of properties of femur bone and conclusion is given and future scope is defined.

V. EXPERIMENTAL PROCEDURES

The procedure involves the steps in fabricating the polymer composite material. The fabrication process involves the weighing, preparing the solution, testing and comparing the results. After preparing the composite material, it is cut into different shapes for conducting the various tests. These tests help to find out the material properties of the polymer composite material. The detail procedure of preparing the composite material is discussed here.

5.1 Materials used for Fabrication Composite Material

1. Aluminium Oxide (Al_2O_3), Active Neutral.
2. Zirconium dioxide (ZrO_2).
3. Polyurethane resin.

1. Aluminium Oxide (Al_2O_3), Active Neutral:-

The Aluminium Oxide (Al_2O_3), Active Neutral is used as the basic raw material for preparing the polymer composite material for medical applications. Aluminium Oxide is basically a chemical material composed of aluminum and Oxygen.

Fig.5.1 Aluminium Oxide (Al_2O_3), Active Neutral

The chemical formula is Al_2O_3 and it is the most abundantly available chemical and available in the crystalline polymorphic phase. Because of its good material characteristics, it has got wide range of applications.it is used in ceramics for fabricating the different composites materials.

2. Zirconium Dioxide (ZrO_2) :-

In our project the Zirconium dioxide (ZrO_2) is used as another basic material for preparing composite material for medical applications. The Zirconium dioxide is basically a chemical compound. It is white coloured oxide of zirconium and chemically it is not reactive. The basic nature of Zirconium dioxide is resistance to wear and resistance to the forces under the different loads in the structural materials. Because of its hardness nature it has got the wide range of applications.

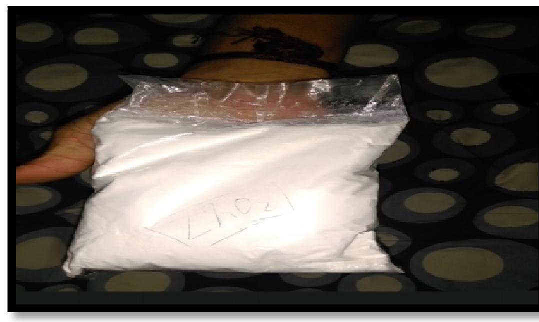


Fig.5.2 Zirconium dioxide (ZrO_2)

3. Polyurethane Resin:-

Polyurethane resin is used as a basic matrix material in this project. It is basically a polymer joined by the several urethane links. This is produced by the combinations of isocyanates and polyols. It is used as the catalyst in the chemical composition. This cannot be melt by heating because it is thermosetting polymer. The polyurethane resin has got different applications in health and industrial applications. This is mainly used in the gaskets, insulation panels, microcellular foam seals etc.

Fig.5.3 Polyurethene Resin

5.2 Requirements for composites material fabrication:-

1) Zirconium Dioxide
2) Polyurethane Resin
3) Aluminium Oxide
4) Roller
5) Stirrer
6) Furnace or Oven for heat Treatment

5.3 Steps in Fabrication of composite material:-

The fabrication of polymer composite material i.e. for 10% of both Al_2O_3 and ZrO_2 consists of following steps.

1. Cleaning the surfaces
2. Weighing
3. Preparation of solution
4. Moulding

1. Cleaning The Surfaces:-

The surface is cleaned to remove the dirt and other foreign particle from the surfaces by using acetone. Acetone is used to clean the surfaces before moulding.

Fig.5.4 cleaning the surfaces

2. Weighing:-

Rule of Mixtures:-

In many research works related to material science, the different material properties of composite materials are measured by using this Rule of mixtures. In order predict the actual weight required to measure the percentage of material is added to composite material. This is done by weight fraction method.

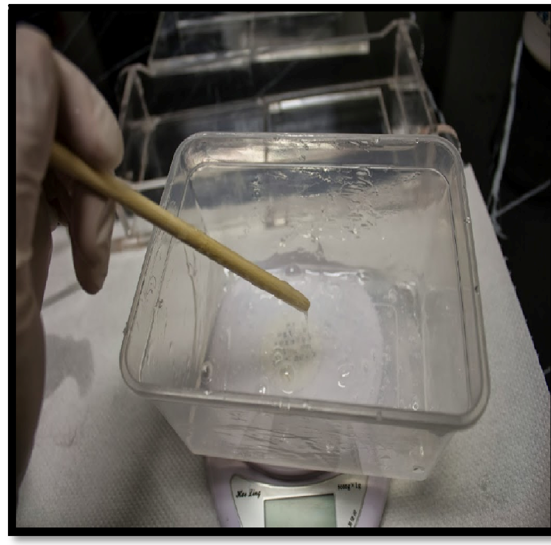


Fig.5.5Weight fraction method

Formula is,

$$M_c = \rho_c \times V_c$$

Where, M_c –Mass of composite
ρ_c –Density of composite
V_c–Volume of composite

1. Density (ρ) of the resin in g/cm^3 (Density= Mass/Volume (or) Volume=Mass/Density)

1. ZrO2 = 5.68 g/cm^3
2. Al2O3 = 3.9 g/cm^3
3. Polyurethane resin=1.2 g/cm^3

2. Volume

A) Volume of Tensile Test Specimen= (L*W*T) mm
= (300*300*2.5) mm

V=Volume for Tensile -225 cm^3

B) Volume of compression & bending specimen= (300*300*3.2) mm

V=Volume for compression & bending -288cm^3

C) Volume of wear specimen= $\pi/4 * D^2 * L$
$= \pi/4 * 10^2 * 300$

V=Volume for Wear-225 cm^3

Volume of Composite = Volume of Epoxy + Volume of Carbon Fiber

$V_c = V_{Al2O3} + V_{Poltyrethane} + V_{ZrO2}$

(Mass of Composite / Density of Composite) = (Mass of resin/ Density of resin) + (Mass of ZrO_2 / Density of ZrO_2) + (Mass of Al_2O_3 / Density of Al_2O_3)

$Mc/\rho c = m_{resin}/\rho_{resin} + m_{ZrO2}/\rho_{ZrO2} + m_{Al2O3}/\rho_{Al2O3}$

(Dividing the Mass of composite (m_c) on both sides

$1/\rho_c = 1/\rho_{Resin} (m_{Resin}/m_c) + 1/\rho_{Al2O3} (m_{Al2O3}/m_c) + 1/\rho_{ZrO2} (m_{ZrO2}/m_c)$

$1/\rho_c = (0.8 / 1.2) + (0.10 / 3.9) + (0.10/5.68)$

$1/\rho_c = 0.70\ cm^3/g$

$M_c = \rho_c \times V_c$=1.4232 X 225

m_cm

1. 319.5*10% Al_2O_3=31.95 gms
2. 319.5*10% ZrO_2=31.95 gms
3. 319.5*80% polyurethane resin=225.6 gms

Similarly we calculated for Compression Test & Bending Test and Wear test.

3. Preparation Of Solution:-

- The previously measured both Al_2O_3 and ZrO_2 for required proportion is mixed with the polyurethane resin.
- This is stirred slowly by using stirrer. Hardener is mixed with this solution having 10% of both Al_2O_3 and ZrO_2 with 10:1 proportion.
- Now the polymer matrix material is ready to pour into the mould for preparing the laminates.

Fig.5.6 Preparation of solution

4. Moulding:-

The polymer composite is prepared by Hand Layup technique. This technique involves the following steps

1. In this method the both Al_2O_3 and ZrO_2 powders are blended by weighing.
2. The polyurethane resin is mixed with hardener by proper proportion.
3. The mould with the size (300*300*3) mm and placed on the flat surface and wax is applied on the flat surface.
4. Then pour the prepared polymer matrix material into the mould.
5. The solution is rolled slowly to remove the air bubble and for each corner material is circulated.

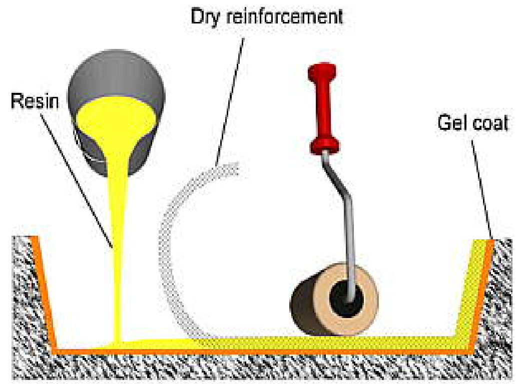


Fig.5.7 Hand Lay-Up Technique.

6. By using cylindrical mild steel rod the rolling process is carried out.
7. The coating is done for top layer for good surface finish.
8. The Teflon paper or glass cloth is added to cover the layer and the rolling is slowly carried out.
9. Allow the mould for 80 min for sufficient curing and so as it dries the hardness increases.
10. After the laminates are prepared, it is cut into required shape to carry out the different tests for determining the material properties.

VI. TESTING METHODS

6.1 TENSILE TEST:-

To determine the tensile strength and to measure different properties of material like young's Modulus, Ultimate strength etc.

Fig.6.1 specimen beforeTensile test

The main purpose of making the Tensile Test for specimen is to determine the amount of force required to elongate at the breaking point. This mainly helps to know how the material will act under load in different application.

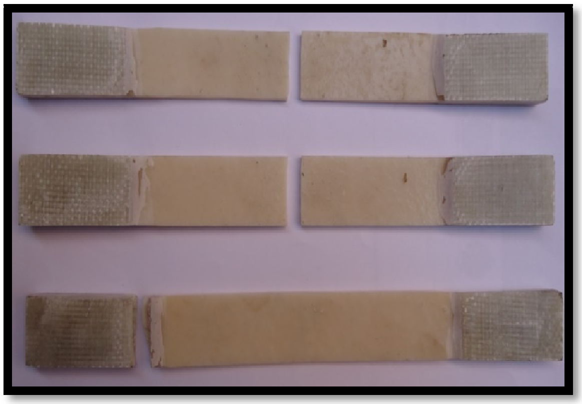


Fig.6.2 specimen after Tensile test

6.2 Compression Test:-

To study how the specimen reacts when the material is compressed and to determine the % of reduction in the area, % of contraction and modulus of elasticity.

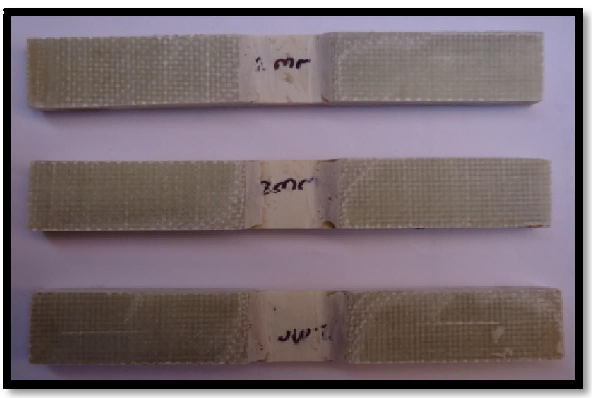


Fig.6.3 Specimens before Compression test

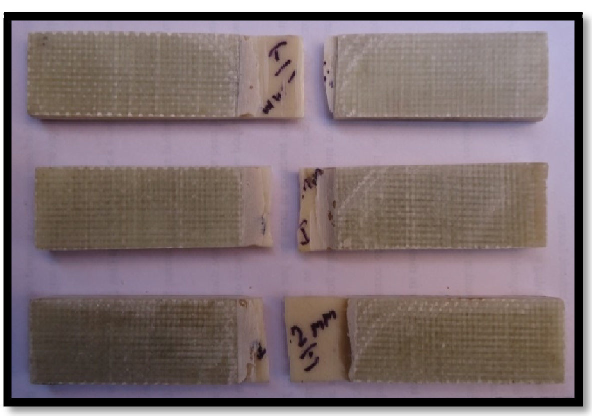


Fig.6.4specimen after compression test

6.3 Bending Test:-

To study how the material behaves under bending stress and to determine elastic strength, modulus of elasticity, modulus of rupture etc.

Fig.6.5 Specimens before Bending test

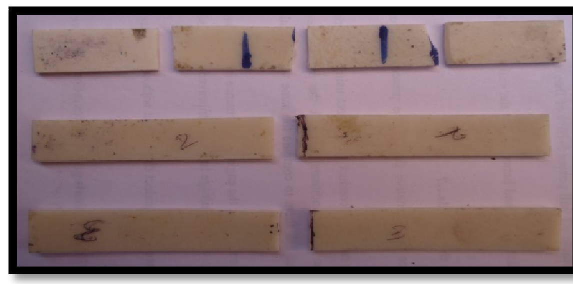
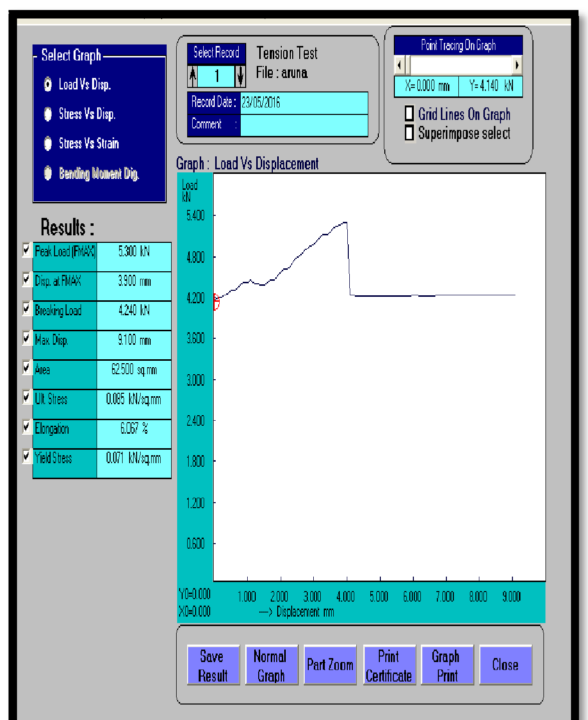


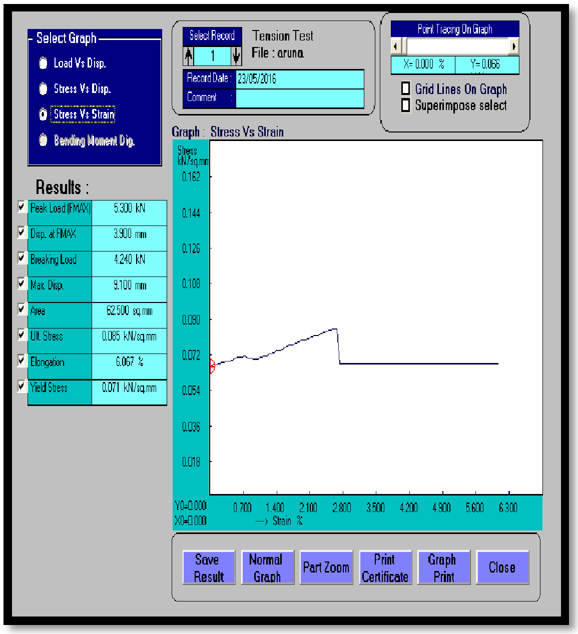
Fig.6.6 specimen after Bending test

VII. TEST RESULTS

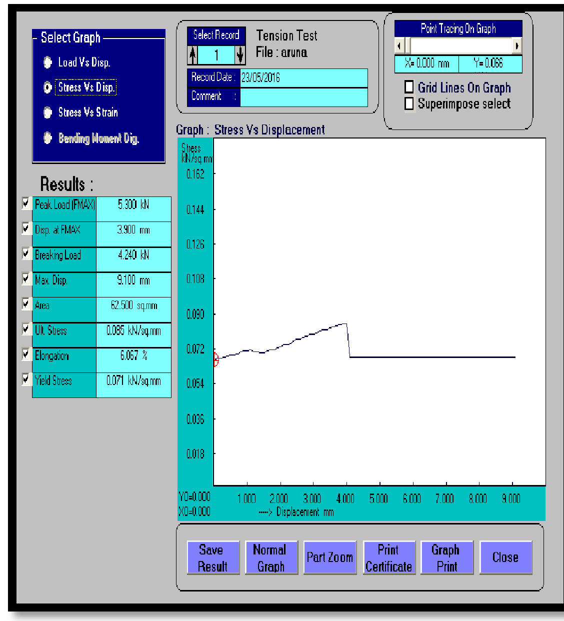
7.1 TENSILE TEST RESULTS:-



Graph.7.01 Load V/S Displacement



Graph.7.02 Stress V/S Strain

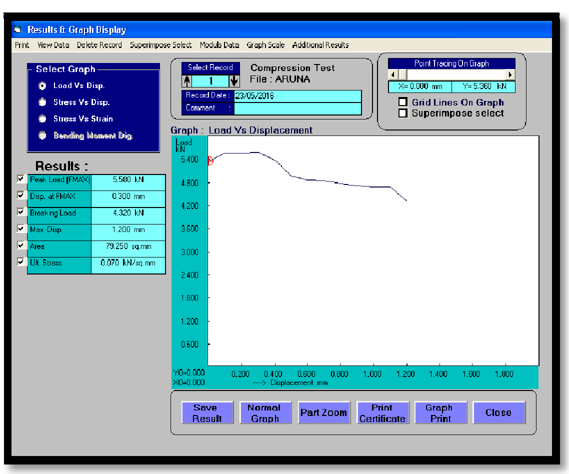


Graph.7.03 Stress V/S Displacement

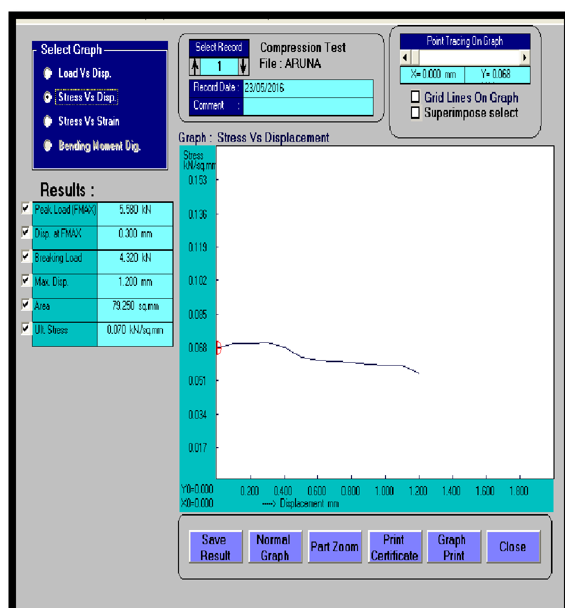
Table 7.01:-

Sp. No.	Peak Load (Fmax) kN	Displacement at Fmax (mm)	Breaking Load (kN)	Maximum Displacement (mm)	Area mm^2	Ultimate Stress (kN/mm^2)	Elongation %	Yield Stress (kN/mm^2)	Femur Bone Tensile Strength or Ultimate Stress
1	5.300	3.900	4.240	9.100	62.500	0.085	6.067	0.071	43.44±3.62 Mpa or 0.04344±0.00362 (kN/mm^2)

7.2 COMPRESSION TEST RESULTS:-

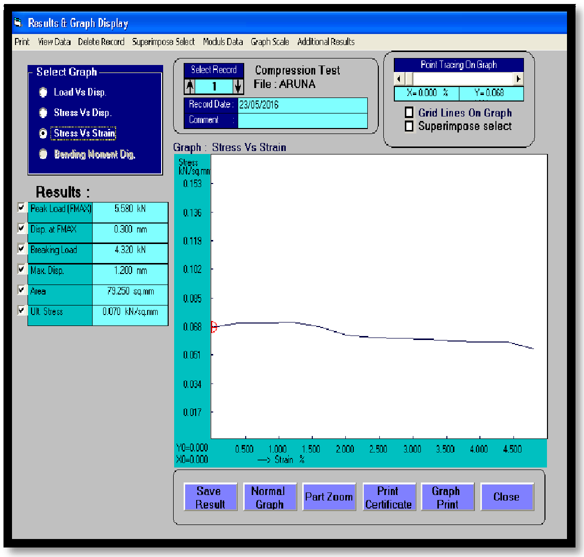


Graph.7.04 Load V/S Displacement



Graph.7.05 Stress V/S Displacement

Table 7.02



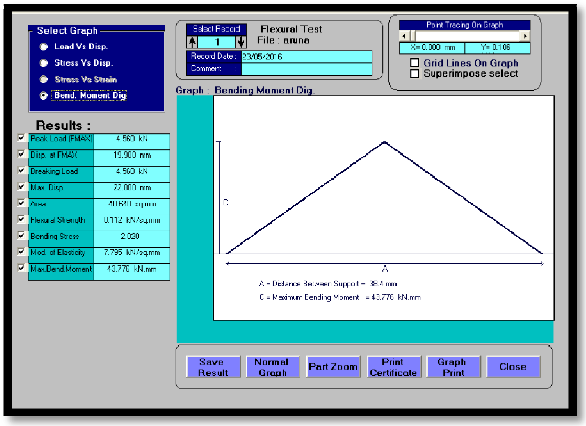
Graph.7.06 Stress V/S Strain

Sp No	Peak Load (Fmax) kN	Displacement At Fmax (mm)	Breaking Load (kN)	Maximum Displacement (mm)	C/S Area mm²	Bending Strength (kN/mm²)	Bending Stress (kN/mm²)	Modulus of Elasticity (kN/mm²)	Maximum Bending Moment kN.mm	Femur Bone Bending Strength
1	4.560	19.900	4.560	22.800	40.640	2.020	0.112	7.975	43.776	84.03±9.91 (Mpa) or 0.084± 0.00991(kN/mm²)

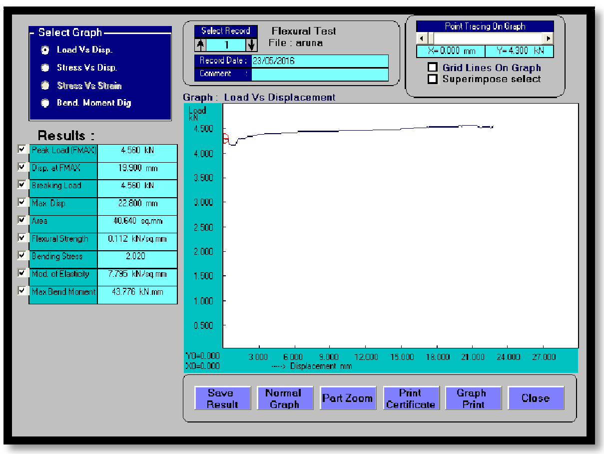
SP No.	Peak Load (FMAX) kN	Displacement at Fmax (mm)	Breaking Load (kN)	Maximum Displacement (mm)	Area mm²	Compressive strength (PKL/Area) (kN/mm²)	Femur Bone Compressive Strength
1	5.580	0.300	4.320	1.200	79.250	0.070	115.29±12.94(Mpa) or 0.11529±0.01294 (kN/mm²)

7.3 BENDING TEST RESULT:-

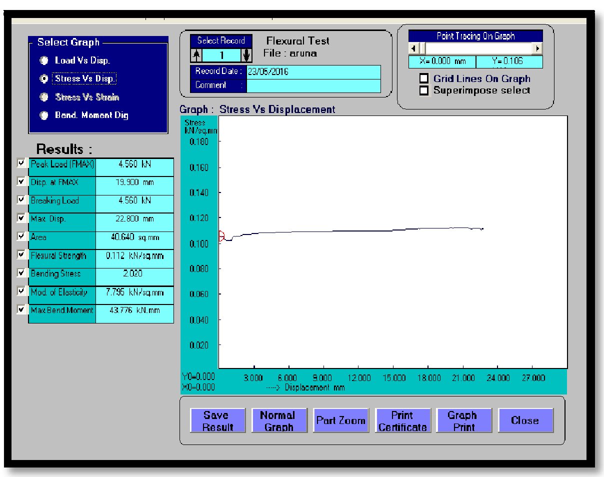
TABLE 7.03:-



GRAPH.7.07 BENDING MOVEMENT DIAGRAM



GRAPH 7.08 LOAD V/S DISPLACEMENT



GRAPH.7.09 STRESS V/S DISPLACEMENT

VIII. CONCLUSION

From these tests it is concluded that the different tests are made to check whether the properties of polymer composite material will matches with the femur bone material properties at different ages or not. So by observing these results and analyzing the graphs we conclude that the value of tensile strengths of specimen after conducting the test is 0.085 kN/mm^2. So this value matches with the femur bone tensile strength. Similarly a value of compression strength of specimen is 0.070kN/mm^2. So this result will not match with required Strength. Bending strength of specimen is 2.020 kN/mm^2. So this result will matches with required Strength of femur bone.

FUTURE SCOPE

1. It is possible to conduct DME analysis to study the damping analysis, temperature that material can withstand and stiffness of the material.
2. Fatigue test is done to measure the maximum strength that material posses. Coating test is made for better surface of implants and we can make different coatings like plasma spray coating and high velocity oxygen fuel spraying (HVOF).
3. Corrosion test can be used know whether the material will corrode or not. This test is done by keeping the material in artificial saliva for 48 hours.

REFERENCES

[1] A Review on Mechanical Properties of Natural Fiber Reinforced Hybrid Polymer Composites by K. P. Ashik, Ramesh S. SharmaJournal of Minerals and Materials Characterization and Engineering, 2015, 3, 420-426

[2] From the journal of orthopaedic sciences by Sandeep kumarreddy and s.kvenkateshguptha. International Journal of orthopaedic science

[3] Biomed Research International Value 2015. From International journal of Biomedical Research

[4] Mr.Jenix Rino et al research works the investigation of .composite material of Al6063 matrix material. IOSR-JMCE e-ISSN:2278-1684 volume-5, Issue-5

[5] K. B. Girisha et al. investigated the effect of different weight fraction of zirconium oxide nanoparticle reinforced Al356. IRJET Volume-2, Issue03. June-2015

[6] Slivia suner Moreno theory of ultra-molecular weight polyethylene for joint replacement.Doctoral Thesis ISSN 1402-1544

[7] Evaluation of mechanical properties of existing material SS316L used as femur bone implant material by Dr A

Thimmana Gouda, Jagadish S P, Dr K R Dinesh, Dr N PrashanthDr. Neeta Hatapaki.

[8] A Review on Natural Fibers D. Chandramohan& .K. Marimuthu.Malaysian Journal of Educational Technology Volume 10, Number 2, December 2010