Investigation on Peek and Polyurethane for Strength Used in Articulating Surface of Knee Implants

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Abstract: **Today in Medical field biomaterial's are in use for the replacement of artificial heart, skin, lever, bone etc in human body. In the advanced material engineering field, mainly mechanical parameters increase the efficiency of the system. Due to fast growing in population and more usage of automobiles leading to increase in accidents in daily life. Men/women met with such type of accidents which may cause fracture of bone.**

The largest and heaviest joint in the human body is the knee joint which includes femur, tibia, pattelar and articulating surface. Currently polyethylene is the widely used material for articulating surface of knee implants in total knee replacement. Failures of the implants after the implantation within prescribed time is mainly due to its low tensile, compressive, shear strengths, and also poor load bearing properties of Polyethylene material.

Among all available biocompatible materials PEEK and Polyurethane is selected which are biocompatible, economical, low density, easily manufacturable and readily available. Polyethylene is considered as reference for the present investigation to compare the strength of the selected materials. In the investigation basic mechanical test's viz. tension, compression, shear tests were conducted according to ASTM standards to record the mechanical properties which help to decide their strength parameter for the articulating surface.

Keywords: **Knee implants, Articulating surface, Polyethylene, PEEK, Polyurethane**

I. INTRODUCTION

The knee joint joins the thigh with the leg and consists of two articulations: one between the femur and tibia and one between the femur and patella. It is the largest joint in the human body and is very complicated. The knee is a pivotal hinge joint which permits flexion and extension as well as a slight medial and lateral rotation[1]. Since in humans the knee supports nearly the whole weight of the body, it is vulnerable to both acute injury and the development of osteoarthritis.

II. TOTAL KNEE REPLACEMENT

Total knee arthoplasty is a surgical procedure to replace the weight bearing surface of the knee joint to relieve the pain and disability of osteoarthritis. Also the other major causes of knee failure are rheumatoid arthritis, psoriatic arthritis, meniscus tears, cartillage defects and ligament tears [2].

There are four implant components to a knee total replacement: femoral component, tibial component, patellar plate and articulating pad. They are designed such that a metal component always moves against plastic or other synthetic material. This promotes smooth movement and minimal future wear. Each compartment of the diseased knee joint will be replaced with man-made implants, eliminating the damaged bearing surfaces that are causing pain.

III. MATERIAL SELECTION

For the current investigation, biocompatibility proved materials like Polyurethane and PEEK are selected among all the available materials due to their low density, low wear rate, moderate strength, and high chemical resistance to conduct basic experimental tests for articulating surface and to compare the results against existing polyethylene material[3].

IV. EXPERIMENTAL PROCEDURE

Mechanical properties are essential for successful implants, where implants are subjected to the loads like tensile, compressive and shear. In the present investigation, all specimens are subjected to tensile test, compression test and shear tests to ensure their ability to with stand the load, according to bio-material ASTM standards. After implantation, the implant should not subject to failure within prescribed period, due to human body weight. These tests are very important to decide the life of the implants as well as safe of human life after implantation.

4.1 Tensile test

It is a fundamental materials science test in which a sample is subjected to uniaxial tension until failure. The results from the test are commonly used to select a material for an application, and to predict how a material will react under other types of forces. Properties are directly measured via a tensile test are ultimate tensile strength, maximum elongation and reduction in area. From these measurements the mechanical properties can also be determined viz, Young's modulus, Poisson's ratio, yield strength, and strain-hardening characteristics.

Universal testing machine is employed for testing of selected biomaterials for investigation. In the test, movable carriage of the machine was brought on the loading bar and load was applied gradually in increments of 100N on the specimens which are prepared according to the ASTM bio-material standards E8 [4] as shown in the figure.1. The plot of load versus displacement of the crosshead is recorded, for the each specimen.

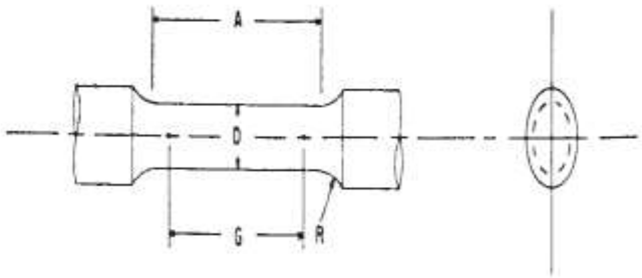


Figure.1: Tension Test Specimen

Where,

G=Gage length =50 mm

D=Gage diameter =12.5mm

A=Length of reduced section =57mm

R=Radius of fillet =13mm

4.2 Compression Test

The objective of this test is to investigate experimentally the mechanical behavior of materials subjected to compressive loading. Compressive properties are of interest in the analyses of implants subject to compressive loads. The data obtained from a compression test may include the yield strength, the yield point, Young's modulus, the stress-strain curve, and the compressive strength. The specimen is prepared according to ASTM standard E9 [4] and the compression test is carried out on UTM as shown in the figure.2.

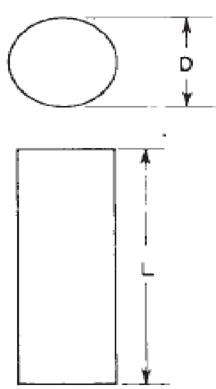


Figure.2: Compression test specimen

Where,

Length = 25mm

Diameter = 10mm

4.3 Shear Test

The objective of this test is to investigate experimentally the behavior of the material under the action of shear forces. The test specimens are subjected to double shear test. The test is performed by clamping a test sample attached to a 1-inch punch between two metal fixtures. A male punch is then forced through the hole in the metal fixture causing shear along the edge of the hole. A universal testing machine is used to push the punch until shearing of the specimen occurs. The Shear test Specimen is prepared according to ASTM standard B769 [4] as shown in the figure.3.

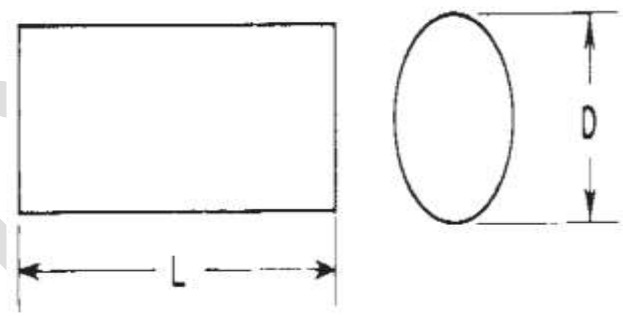


Figure.3: Shear test specimen

Where,

Length = 75mm

Diameter = 10mm

V. TEST RESULTS

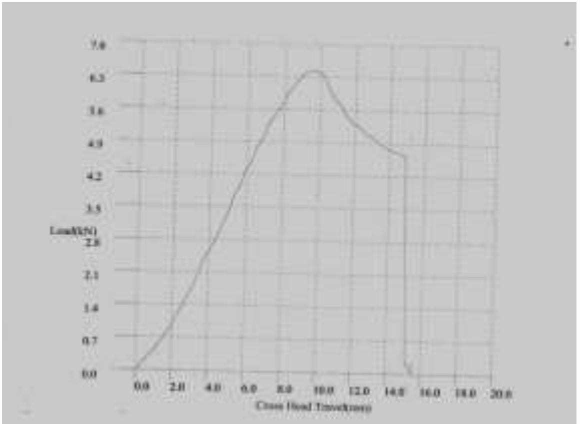
5.1 Tensile test

In tension test, for considered specimens of PEEK, Polyethylene and Polyurethane, tests were conducted using universal testing machine (UTM) and graphs were plotted against load versus displacement.

5.1.1 Tensile test of PEEK

The tensile test on PEEK showed ductile fracture. Fractured specimens exhibit the ductile properties by showing its fracture with cup and cone.

The graph.1 shows the load versus change in length of the specimen subjected to tensile test. It is clear that stress is increasing gradually with respect to strain until it reaches peak load, the corresponding value of peak load is 6.44 KN, with 9.7mm elongation and the stress at that point is 99.22N/mm^2.

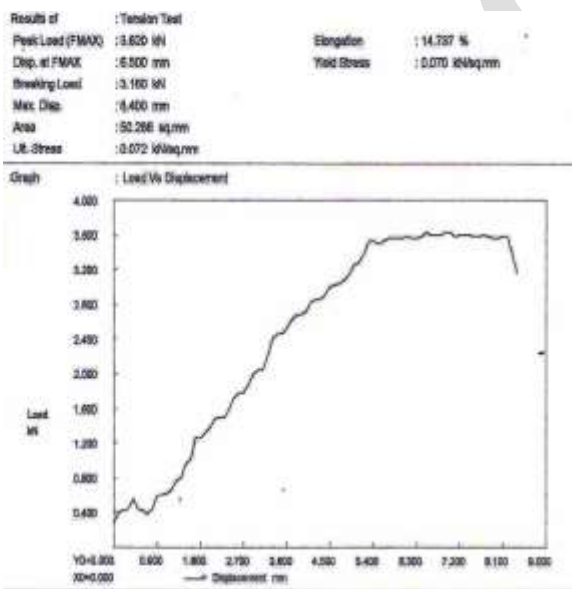


Graph.1: Load v/s Change in length in tension test of PEEK

5.1.2 Tensile test of Polyethylene

The conduction of tensile test on polyethylene showed that, material as undergone brittle fracture after absorbing the applied load.

The plotted graph.2 shows the load versus displacement of the specimen considered. It is observed that the stress is linear with strain and sudden fracture occurred after reaching peak load thus, Polyethylene material showed brittle behavior. The stress at the maximum load 3.62KN is 72N/mm^2 and the elongation at the load is 14.737%.

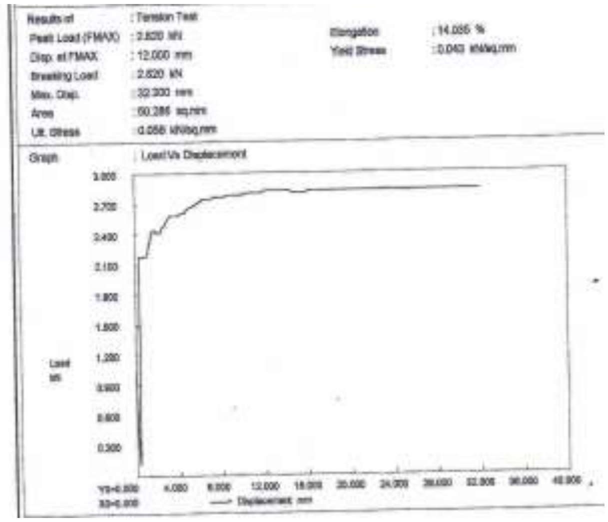


Graph.2: Load v/s Change in length in tension test of Polyethylene

5.1.3 Tensile test of Polyurethane

From the test, it is observed that Polyurethane is an elastomeric material, which is very soft and flexible.

The plotted graph.3 shows the load versus change in length of the specimen considered. It is observed that the material attains peak load at 2.82 KN with elongation of 38mm and the stress at that point equal to 56N/mm^2.



Graph.3: Load v/s Change in length in tension test of Polyurethane

5.1.4 Results comparison of tensile tests

Results obtained from tension test on all materials are tabulated in table.1 and compared their peak load withstanding ability as in graphs. It is clear that PEEK material posses more tensile strength as compared to all other materials with 99.22 N/mm^2.

Table.1: Results of tension test

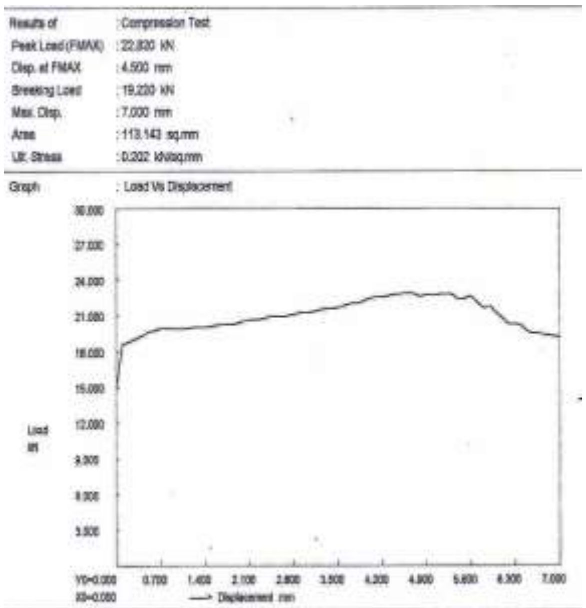
Test	Experimental data	Materials		
		PEEK	Polyethylene	Polyurethane
Tensile	Peak load (KN)	6.44	3.68	2.82
	Max elongation (mm)	9.7	8.1	38
	Tensile strength (MPa)	99.22	72	56

5.2 Compression test

In compression test, for considered specimens of PEEK, Polyethylene and Polyurethane, tests were conducted using universal testing machine (UTM) and graphs were plotted against load versus displacement.

5.2.1 Compression test of PEEK

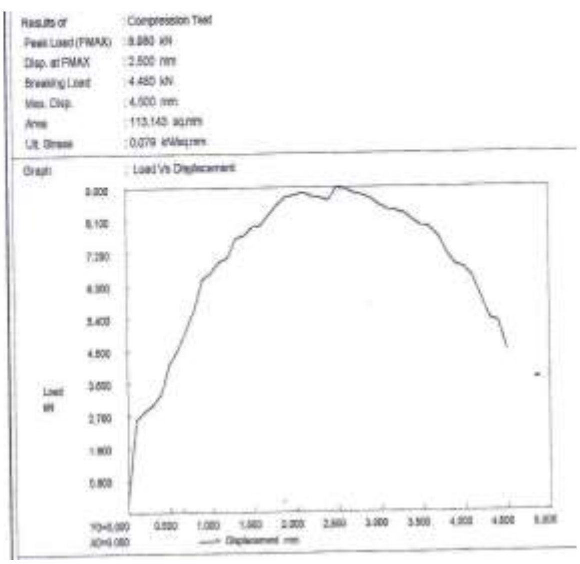
The graph.4 shows the load versus displacement of the PEEK specimen considered for compression test. It is clear that stress is increasing gradually with respect to strain until it reaches peak load, the corresponding value of peak load is 22.82KN, with 7 mm compression and the stress at that point is 202 N/mm^2.



Graph.4: Load v/s displacement in compression test of PEEK

5.2.2 Compression test of polyethylene

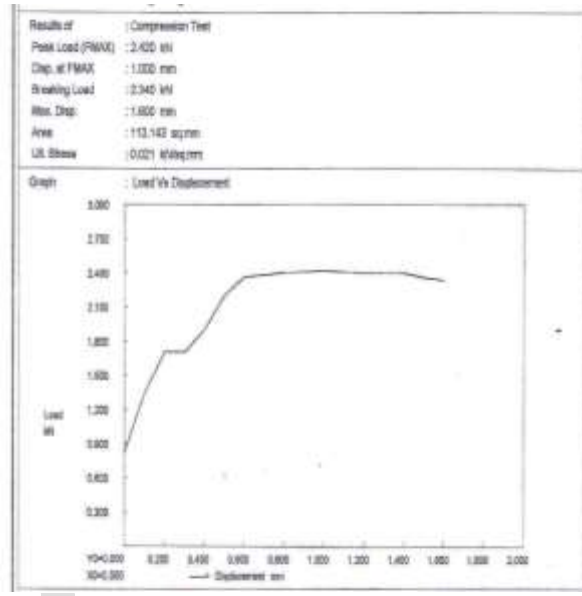
The plotted graph.5 shows the load versus displacement of the polyethylene specimen considered for compression test. It is observed that the stress is linear with strain and the stress at the maximum load 8.98 KN is 79 N/mm^2 and the compression at the load is 4.5mm. The curve is almost linear with the cross head travel and depicts the good yielding of material.



Graph.5: Load v/s displacement in compression test of polyethylene

5.2.3 Compression test of Polyurethane

The plotted graph.6 shows the load versus displacement of the polyurethane specimen considered for compression test. It is observed that the material attains peak load at 2.42 KN with compression of 1.3 mm and the stress at that point equal to 21 N/mm^2. It is clear that Polyurethane is an elastomeric material, which is very soft and flexible.



Graph.6: Load v/s displacement in compression test of polyurethane

5.2.4 Results comparison of Compression tests

Results obtained from Compression test on all materials are tabulated in table.2 and compared their peak load withstanding ability as in graphs. It is clear that PEEK material posses more Compression strength as compared to all other materials with 202N/mm^2.

Table.2: Results of compression test

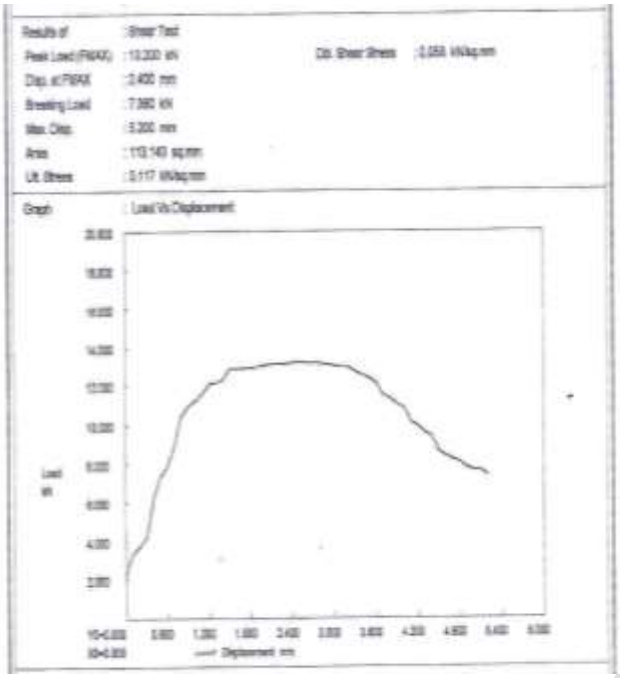
Test	Experimental data	Materials		
		PEEK	Polyethylene	Polyurethane
Compression	Peak load (KN)	22.82	8.98	2.42
	Max elongation (mm)	7	4.5	1.3
	Tensile strength (MPa)	202	79	21

5.3 Shear test

The shear test has been carried out in UTM for materials say PEEK, Polyethylene and Polyurethane to tabulate maximum shear strength of all the materials considered. Graphs were plotted against load versus displacement

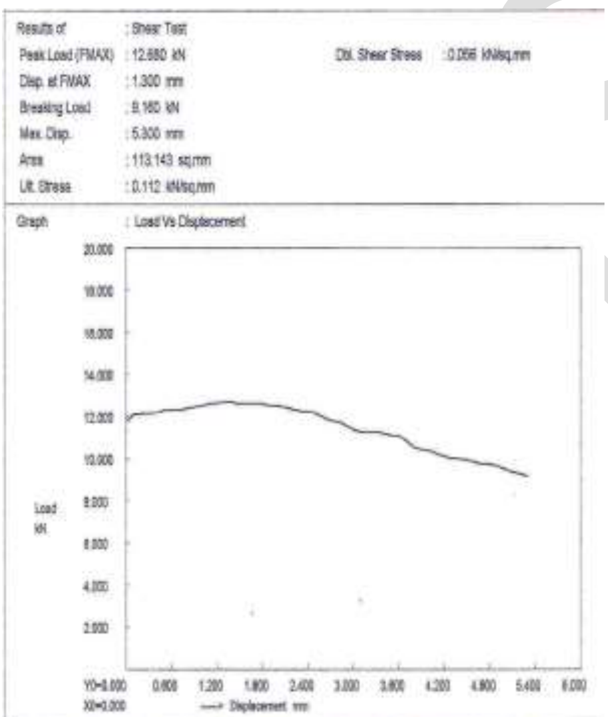
5.3.1 Shear strength of PEEK, Polyethylene and Polyurethane

The proper shearing has been taken place on all the considered specimens of different materials, which was very clear from the broken specimens.



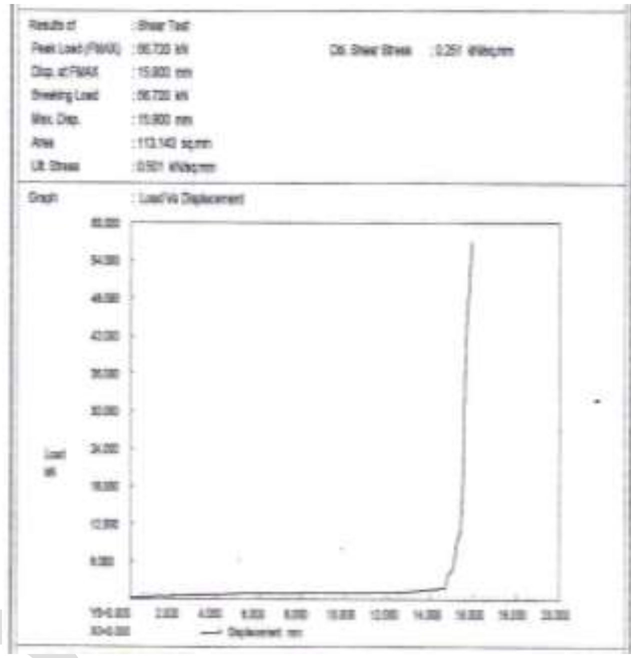
Graph.7: Load v/s displacement in shear test of PEEK

5.3.2 Shear test of Polyethylene



Graph.8: Load v/s displacement in shear test of Polyethylene

5.3.3. Shear test of Polyurethane



Graph.9: Load v/s displacement in shear test of polyurethane

5.3.4 Results comparison of shear test

After conducting double shear test, results were tabulated in the table .3and also plotted the bar chart for all the considered materials, as shown in graph .3. It is found that Polyurethane, shown better shear strength with 501 N/mm^2 at 56KN fracture load and next better material is PEEK with 117 N/mm^2 at 13.2KN fracture load, when compared to Polyethylene.

Table.3: Results of Shear test

Test	Experimental data	Materials		
		PEEK	Polyethylene	Polyurethane
Double shear test	Peak load (KN)	13.2	12.68	56
	Shear strength in (MPa)	117	112	501

VI. CONCLUSION

In most of the cases Failures of the implants after the implantation within prescribed time due to its low tensile, compressive, and shear strengths and also currently used Polyethylene material is having poor load bearing properties and even machining of the currently used material is difficult.

PEEK with 99.22 MPa of tensile strength, 202 MPa of compressive strength, 117 MPa of shear strength and density 1310 $Kg/m^{3.}$close to density of bone cartilage shows better strength compared to Polyethylene, and Polyurethane. Thus, compare to the currently used polyethylene material PEEK is very much ideal material can be used as material for articulating surfaces in total knee replacement.

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