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Tribological and Mechanical Properties of UHMWPE Polymer Composite filled with TiO_2 and Al_2O_3 Particles used as TKR Implant

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Abstract: ***This study focused on the development of a polyethylene biomaterial for replacement of the joints like knee joints, etc. Through forming aluminum oxide and titanium oxide particles into ultra-high molecular polyethylene, commonly known as high modulus polyethylene, this substance has strengthened its mechanical and wear properties. The composite is made using the injection molding machine by reinforcement materials like bio-inert aluminum oxide (Al_2O_3) and titanium di oxide (TiO_2) with UHMWPE. Mechanical properties like Tensile, Bending, impact strength and hardness and wear rate of the synthesized polymer composite is tested according to ASTM standards.C3 composite shows enhancement in mechanical and tribological properties, only decrease in the impact strength is seen comparing to other two compositions. So C3 composite can be used as implant.***

Keywords: UHMWPE, aluminum oxide (Al2O3), titanium di oxide (TiO2), TKR.

I. INTRODUCTION

One of the main challenges of medicine is the issue of articular cartilage repair. Bone and cartilage disorders are very common and are a major cause of reduced quality of life. Knee joint is a type of hinge joint with the same flexion and contraction motions, except for the slight rotation. The perfect, folding skin around the joint enables such motions to easily match every flap. Cartilages are broad, thick tissue bands that bind together the bones and provide the joints and underlying tissues with strength and stabilization. A tear in cartilage is separate from a break in cartilage. The over-spreading of the joint induces damage to the cartilage bands causing a cartilage tear. Such damage can be fixed by procedures of minimal invasive techniques. Cartilage deficiencies occur when the functionality of the damaged joint becomes impaired by a void or gap in the cartilage. During all athletic or sports activities, the main cause of cartilage defects in the knee happens in numerous ways.

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A cartilage can literally rip the end of the bone in the joint of the knee due to many injuries. whenever there is need of the replacement of the injured part in knee joint, knee spacer is used in between the femoral and tibia joint. This knee implant material should possess certain mechanical and wear properties. These implants are made of polymeric materials. The UHMWPE has various remarkable belongings, among which bio-similarity, resistance to chemicals, effective damping of the effect burden and low grating coefficient, permitting it the orthopedic supporting operator in the general joint substitution over 30 years. In any case, the UHMWPE wear and the wear trash that bring about osteolysis and aseptic relaxing have now gotten perceived as one of the significant factors in joint substitution omission, particularly when there is a long haul omission of the total joint substitution the wear and tissue reaction [1],[2]. After literature survey we chosen the UHMWPE as a matrix and aluminum oxide (Al_2O_3) and titanium di oxide (TiO_2) has reinforces [3]. All through this study, we use Titanium dioxide and Aluminium di oxide has fillers to improve the mechanical and fundamentally tribological character of UHMWPE composite. As alumina is strong and there are no changes in its property at elevating degree Celsius. As a result of their phenomenal bio-similarity, titanium and its combinations are especially significant for biomedical applications and don't respond with the tissue around the embed especially as hard tissue substitutions. The research described here's the investigation of the UHMWPE reinforced composite Al_2O_3 & TiO_2 which is moulded in a die-form designed using an injection molding machine to follow the ASTM standard. Specific mechanical and wear properties was evaluated for the prepared specimens.

II. MATERIALS AND METHODS

UHMWPE is an ethylene polymer that can carry up to 400000 units of carbon in its chain of molecules. Atomic mass (MW) of UHMWPE is the Molecular Weight of ethylene, which can extend from 2 to 6 million gm/per mole by replicating a quantity of ethylene bunches [4]-[8].

There are numerous polyethylene structures, for example, polyethylene low-density and high density along with UHMWPE. The terminology depends on the molecular weight. UHMWPE is clinically more resistant to abrasion and also to wear than HDPE or LDPE. The toughness is more than HDPE and is proportion to the molecular weight.

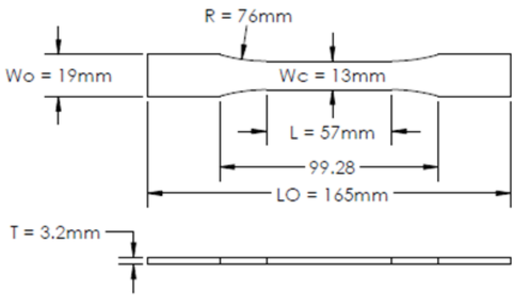
Due to this UHMWPE was currently used in total joint arthroplasty (TJA), among other PE's. The ultra-molecular weight is associated to the very high entangled densities; entangled function as a physical interlocking mechanism, that affects the crystalline morphology of the polymer when it is melted.

To enrich its properties, it is reinforced with alumina and titanium di oxide which are in powder form with mesh size of 300. Fabrication of the specimens is done in accordance with ASTM standards varying percentage of reinforcements and matrix. weight percentage of the both Matrix and reinforcements are done based on literature survey. Polymer matrix composites which are fabricated by varying percentage of matrix and reinforcements are revealed in table I.

Table I. percentage of matrix and reinforcements

Sl.No.	UHMWPE (%)	TiO2 (%)	Al2O3 (%)
1	100	0	0
2	90	5	5
3	85	5	10

Specimens for testing are fabricated using the injection moulding machine and all the test specimens meet the requirements of ASTM standard. Tensile investigation standard D638, D790 flexural investigation standard and D256 impact investigation specimens, D-scale shore hardness as per ASTM D2240, and wear test conducted according to ASTM G-99. Figures 1a, 1b, and 1c show specimen sizes.



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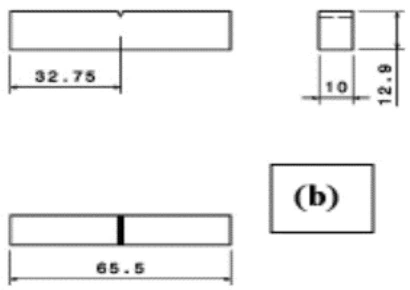
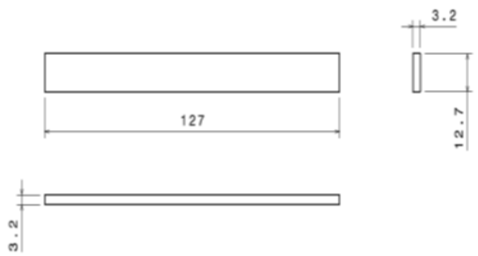


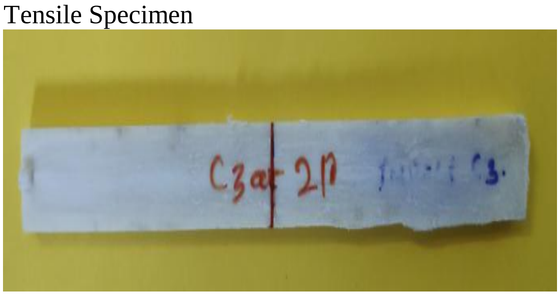


(c)

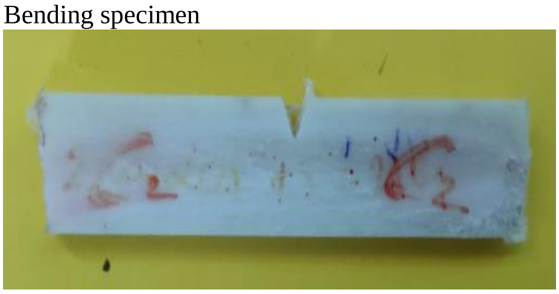
Fig. 1 (a), (b) and (c) Tensile, impact and bending strength test specimen dimensions (mm)

The extruder is used for fabrication of the composition, and the injection moulding is used for preparation of the samples according to the required standard. Initially in 1st configuration the only UHMWPE with no reinforcements, specimens for all mentioned test are prepared and composition (UHMWPE, alumina and TiO_2) fabricated with variation in UHMWPE, alumina vol. % and TiO2 % remains steady in all fabricated samples. Granule form UHMWPE and TiO_2 and alumina in precipitate are mixed with the predetermined quantity and moved to the extruder container. A mixture of UHMWPE and reinforcements are dissolved by the power-driven energy created by the screws and through the radiators placed sideways of the screws. The melted composition at that point streams into the passage die, which offers structure to the mixed material and solidifies during cooling. The obtained composition from the extruder is rendered into little pieces utilizing a pelletizer and move all the pieces to an injection moulding container. The obtained small pieces of composition are crashed into a warmed barrel by a ram. At this point the pieces gradually stirred along by a plunger, the parts are stirred into a heated zone (132-140°C) in which they are melted. As the plunger thrusts ahead, the molten portion of the composition is pushed through the nozzle into the cavity of the mold where takes the required size and shape according to the ASTM standard. Figure 2,3 and 4 shows the fabricated specimens as per ASTM standard, Extruder and injection moulding with mould.

Tensile Specimen



Bending specimen



Impact specimen

Fig. 2 Samples prepared as per ASTM standard

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Fig. 3 composite Mixture-Extruder

Fig. 4 Injection molding along with ASTM standard mold cavity

All mentioned mechanical properties tests were conducted at PST department laboratory, SJCE, Mysore, Karnataka, India and wear test are carried at SDMCET, Dharwad, Karnataka, India. Tensile test is carried at speed of 50 mm/min. Flexural test at 17.63-millimeter min^{-1}. Impact test velocity impact of 3.630 m/s. wear test is carried by considering two loads 2kg and 4kg, Rpm of 400 and duration 15mins.

III. RESULTS AND DISCUSSIONS

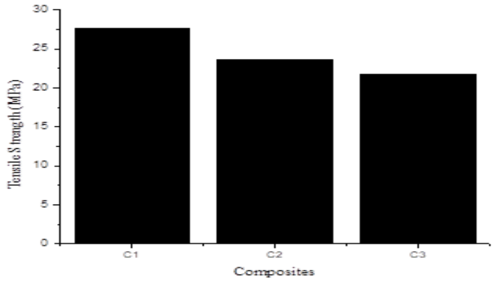
This examination shows the mechanical and tribological character of UHMWPE+ Alumina+ TiO2. Table II indicates the composite to be utilized for the test.

Table II Composites in detail and their designation

Composition	*Designation*
UHMWPE + Al_2O_3 0% + TiO_2 0%	C1
UHMWPE + Al_2O_3 5% + TiO_2 5%	C2
UHMWPE + Al_2O_3 10% + TiO_2 5%	C3

A. Tensile Strength

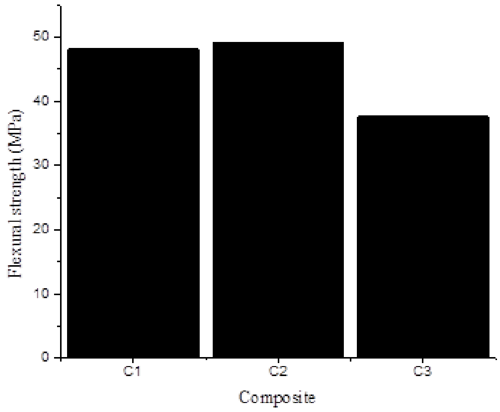
Tensile strength of fabricated samples was carried out and the outcomes are indicated in the graph 1. In this study Al_2O_3 content is varied i.e., 0% in C1,5% in C2 and 10% in C3 and TiO2 remains constant in C2 and C3. while calculating the tensile strength 2 specimens for each composition is considered and average value is considered. Composite tensile strength reduced with a rise in vol. Percent of the Al_2O_3. It indicates a weak interaction between Al_2O_3 and UHMWPE. The elongation at breaking was noted to decrease with a rise in vol. Percent of the Al_2O_3. Owing to the disruption of the UHMWPE chain of mobility by the Al_2O_3 reinforcement, the composites plastic deformation decreased. The modulus of UHMWPE composites increased with a rise in vol. percentage of Al_2O_3. This might be because of the tough particles in the matrix.



Graph 1 Tensile Strength of composites with varying % of reinforcements.

B. Flexural strength

In this study, the flexural properties of Al_2O_3 and TiO_2 reinforced UHMWPE composites with differing volume percentages were tested. According to the ASTM D790 standard, the flexural test conducted. During the test, no breakage of samples was observed. It is well known that modulus of the composite depends on the added system and matrix. In this case Al_2O_3 and TiO_2 had higher modulus value than UHMWPE. This is due to higher loads of Al_2O_3 and TiO_2 showing agglomeration. Flexural modules of reinforced Al_2O_3 and TiO_2 composites have also increased continuously due to the deposition of Al_2O_3 and TiO_2.Graph 2 indicates the flexural strength of the composites.

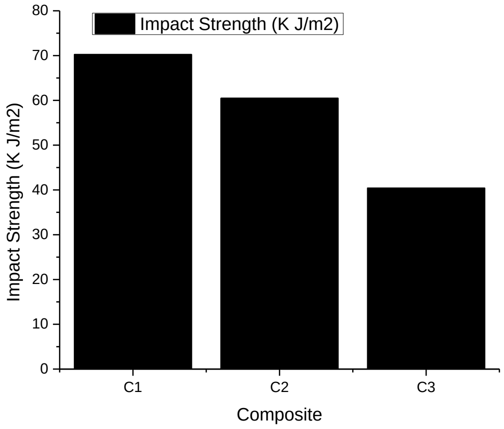


Graph 2 Flexural Strength of composites with varying % of reinforcements

C. Impact Strength

The impact behavior of the various Al2O3 and TiO2 reinforced UHMWPE composites was tested in this study. The Impact Test was carried out using an Izod Impact System of measurement as per the ASTM D256 standard. The impact strength of the composite C1 to C2 decreases as increase in % of Al2O3 and TiO2 reinforced UHMWPE. This decrease in the impact strength of the composite is due the continuity of the UHMWPE matrix failed to generate interface defaults. The toughness was found to be large. Enhanced toughness can be due to the inhomogeneous form and scale of the micro particles.

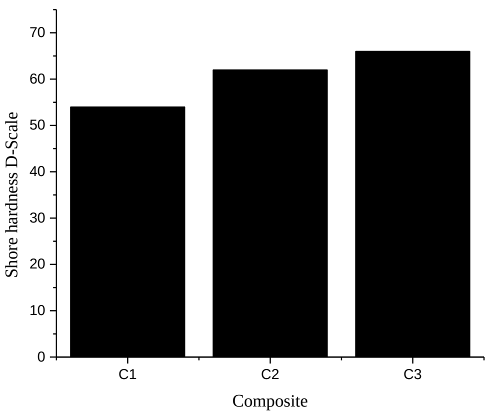
As the edges of micro-particles have different angularities, they promote loss under impact conditions due to spatial stress concentration. Reinforcements leads to fast crack induction and brings a more brittle character to the composites. Graph 3 shows the impact values of each composite.



Graph 3 Impact Strength of composites with varying % of reinforcements

D. Hardness (Shore hardness D-Scale)

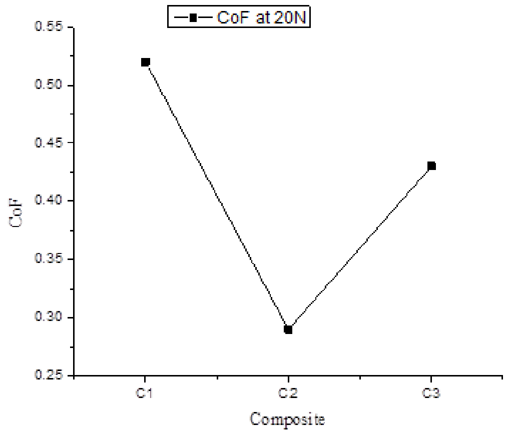
The hardness of the fabricated composite is measured using shore hardness D-scale. The hardness of UHMWPE composites improved significantly as the amount of reinforcements continued to increase. The primary indication is that the strength and stiffness of the reinforcements are significantly higher than that of the UHMWPE. When the UHMWPE composites is compressed, the load would initially be assisted by reinforcements. Therefore, the hardness of the UHMWPE composites has enhanced. Although if the contents of the additive were raised too much, the molecular consistency of the UHMWPE matrix was interrupted and the defaults, such as microfractures, increased. Therefore, the hardness of the UHMWPE composites no longer improved with a rise in the reinforcements. Graph 4 shows the hardness D-scale values of each composites.



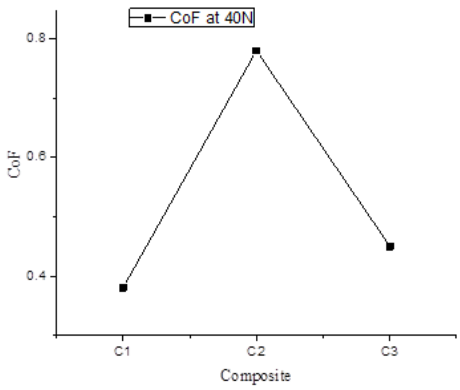
Graph 4 Hardness value of composites with varying % of reinforcements

E. Wear

Tribological experiment conducted in a dry state using a pin-on-disc machine. The parameters considered for the during test are: loads of 20N and 40N, track diameters of 50-millimeter, 400 rpm sliding speed and the complete duration of the test carried for 15 minutes. In UHMWPE + Al2O3 + TIO2 composite it is observed that wear rate is very low and test is carried in dry condition. Low wear rate is due to hard nature of the Alumina and TiO2 which are uniformly embedded in the matrix of the UHMWPE and also due to association with a high entanglement density; entanglements behave as a physical cross-link, impacting their crystalline shape as the polymer is melted. Also, UHMWPE has associated with several interlamellar molecules that bind adjacent lamellae. UHMWPE has a capacity of suppression of the development of spherulites which lead to toughness and high wear resistance. Graph 5 and graph 6 shows the CoF and Frictional force of composites with 20N and 40N load.

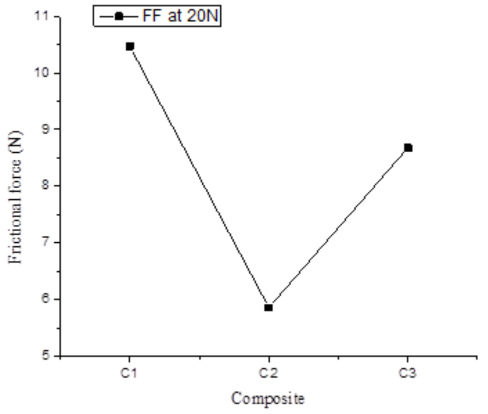


(a)



(b)

Graph 5 (a) & (b) CoF at 20N and 40N of composites with varying % of reinforcements



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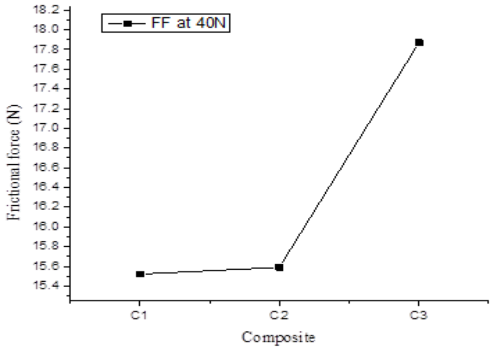

(b)

Graph 6 (a) & (b) Frictional force at 20N and 40N of composites with varying % of reinforcements

IV. CONCLUSION

Experimental analysis of tensile, flexural, impact nature and wear of Al_2O_3 and TiO_2 bonded UHMWPE composites with differing volume percentages of Al_2O_3 and TiO_2 was conducted in the present study. The appropriate conclusions have been drawn:

1. The tensile strength of the Al_2O_3 and TiO_2 fused UHMWPE composites and elongation at the break was found to decrease with increase in the amount of reinforcements and in a mean while it is found that young's modulus is increased.
2. The flexural strength of the Al_2O_3 and TiO_2 fused UHMWPE composites increases with along with flexural modulus with increase in the amount of reinforcements.
3. The hardness of the composites increases only when certain amount of the Al_2O_3 and TiO_2 are present in the composite. If the amount of reinforcement increases beyond certain %, then there is drastic decrease in hardness can observe.
4. The impact strength of the composite is very good, when there is less % of the reinforcements in composites.
5. The wear and CoF is very minimum with the presence of reinforcements in the composites.

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