IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 15, Issue 6 Ver. II (Nov. - Dec. 2018), PP 39-44
www.iosrjournals.org

Study of wear behaviour on Hybrid Polymer matrix Composite Materials Used as Orthopedic Implants

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Abstract: *This paper constitutes study of wear behaviour of hybrid polymer matrix composites, Prepared of LDPE as matrix and TiO2, $CaCO_3$ and Al_2O_3 used as reinforcement material with TiO_2 constant of 10% in all compositions, were as $CaCO_3$ and Al_2O_3 will be of 8%,12% & 16% used for implant material. Due to their cost effectiveness, greater strength and ease of fabrication, polymer composites are noticeable candidate almost in all areas. However, when they are used in their original form, they possess very low wear resistance. Over the past centuries, there is lot of research works carried out in the medical field and materials science in development of biomaterials for implant applications. So, many different materials are used as implants for replacing of damaged parts. The samples were prepared according to ASTM standards by injection moulding machine with varying percentage of reinforcements in polymer matrix.*

Date of Submission: 26-11-2018 Date of acceptance: 07-12-2018

I. Introduction

Polymer composites over the decades had more attentions because of their major improvement in mechanical properties. By additions compounds such as Aluminum Oxides (Al2O3) [4], glass fibers[5], carbon nanotubes and carbon black[6], to polymers is going to produce new polymer composites with enhanced mechanical and wear resistance properties in addition to being comparatively cost-effective compared to their original corresponding item. This may result in new industrial uses. These reinforcements are going to affect the properties, surface characteristics and bonding of polymer will lead to enriched properties for industries uses[7]. These additives will help to withstand some of the applied tension to the polymer matrix leading to improved tensile properties of the finished product. Polyethylene's are polymer materials which are easily manufactured and low cost which can be handled at temperature of 140-249 ^{o}C[1]. Polyethylene's are of three types, in that low-density polyethylene (LDPE) one of the types, it as branch structure and property of cross linking. Cross interconnecting nature of polyethylene forms a linkage of high molecular weight, which increases impact strength, ecological stress, flaw and scratch resistance without affecting rigid strength and density to any considerable amount[1].

In recent days researchers are using alumina, TiO_2 has a reinforcement to enhance the wear properties of LDPE because alumina is hard material and it is unchanged at very high temperature and it exits in two form ionic bonding and covalent bonding[2]. To come up with new reinforcement researchers are using calcium carbonate ($CaCO_3$) which has been used as a cheap substitute to the Al_2O_3 for the production of flexible polyurethane composites to enhance mechanical properties of the finished product. Addition of $CaCO_3$ in thermoplastic fabrication is a common practice for reduced production cost[3]. The present work is analysis of $CaCO_3$, Al_2O_3 & TiO_2 reinforced LDPE composite, which are moulded into the shape of the die prepared according to ASTM standard using injection moulding machine on a low budget, which can be functioned with a smaller amount of effort.

II. Materials and Methods

There are three type of polyethylene's are available. In which UHMWPE is one which have poor properties like ductility and fracture toughness. But other two polyethylene, LDPE & HDPE have good cross-linking property which results in their improved molecular structures and mechanical properties. Both LDPE & HDPE have the similar properties. Therefore, in this investigation low density polyethylene (LDPE) used as polymer matrix material. LDPE have poor mechanical properties and which can be enriched by adding metallic or/and ceramic in the polymer matrix. Hence, in the present study alumina ($Al2O_3$), calcium carbonate ($CaCO_3$) and titanium oxide (TiO_2) were used as the reinforcing materials and all the reinforcing materials are in powder form with 325 mesh size. For the perfect results different compositions used for the fabrication of the samples.

Based on the literature survey weight percentage of LDPE, $Al2O_3$ and TiO_2 for one composition and weight percentage of LDPE, $CaCO_3$ and TiO_2 for other composition decided1-3. Table 1 shows the polymer and reinforcements percentage in production of polymer matrix composites. Figure 1 indicates the specimens produced by injection moulding machine.

Table 1 Compositions of Polymer matrix composites

Sr. No.	LDPE (%)	TiO2 (%)	Al2O3 (%)/CaCO3 (%)
1	82	10	8
2	78	10	12
3	74	10	16

Figure 1 Prepared specimens according to ASTM standard

Extruder is used for composition preparation and Injection moulding machine is used for specimen's preparation according to ASTM standard. For composition (LDPE, TiO2 & Al2O3) preparation with variation in LDPE, Al2O3 and TiO2 remains constant in all specimens. LDPE which is in granular form and TiO2 & Al2O3 which are in powder form are mixed with measured amount and transferred into hopper of the extruder. The material is slowly melted by the mechanical energy generated by turning screws and by heaters arranged along the screws. The molten polymer composition then passes through die, which give shape to the polymer composite and hardens during cooling. Obtained composites is made into small pieces using pelletizer and transfer all pieces into hopper. Composition pieces are fed by ram from a hopper into a heated barrel. As the granules are slowly moved forward by a screw-type plunger, the pieces are moved into a heated chamber (150-250 ^{o}C), were they get melted. As the plunger advances, the melted pieces are forced through a nozzle into the mould where it takes the shape of mould cavity as defined by ASTM standard8-10. It saves the time and composite material. The same steps are followed to prepare (LDPE, TiO2 & CaCO3) composition. Figure 2 show the Extruder and Figure 3 shows injection moulding machine with mould cavity [10].

Figure 2 Extruder

Figure 3 Injection moulding machine with mould cavity

III. Experimental Test

A specimens are obtained of desired size from injection mould technique ,2 specimens of each composite, total of 6 composites are considered for test i.e.., (LDPE+10%TiO_2+8%,12% ,16%Al_2O_3) & (LDPE+10%TiO_2+8%,12%,16%$CaCO_3$).

Figure 4 Pin-On-Disc Machine & Data Acquisition

This test method covers a laboratory procedure for determining the wear of materials during sliding using a pin on-disk apparatus. For the pin-on-disk wear test conducted in this research, the specimens were flat, which is positioned perpendicular to a circular disk.

A specimen, rigidly held, is often used as the pin. The test machine causes either the disk specimen or the pin to revolve about the disk centre. The sliding path is a circle on the sample surface. The pin is pressed against the disk at a specified load usually by means lever and attached weights.

Data Acquisition: The friction coefficient signal is displayed in real time on a PC Screen. Data can be viewed as it is logged for the entire specified test duration, which can be recalled later for detailed analysis. The software allows 4 different logged test files for on-line analysis / mapping. The software displays the test time, turn count, linear velocity, and user-defined test parameters. This data can be stored and printed along with the friction traces.

Purpose: Records friction and wear in sliding contact in dry condition.

IV. Results & Discussions

This investigation illustrates the wear behavior of LDPE + Alumina/Calcium carbonate + Titanium Dioxide polymer composites. The injection moulding machine was used for fabricating samples and ASTM standards were followed to carry out the test. Table 2 indicates the designation of each composite which will be used throughout this paper.

Table 2 Designations and detailed compositions of the composites

Composition	Designation
LDPE+10%TiO_2+8%Al_2O_3	Al1
LDPE+10%TiO_2+12%Al_2O_3	Al2
LDPE+10%TiO_2+16%Al_2O_3	Al3
LDPE+10%TiO_2+8%$CaCO_3$	Ca1
LDPE+10%TiO_2+12%$CaCO_3$	Ca2
LDPE+10%TiO_2+16%$CaCO_3$	Ca3

Tribological test

Tribological test consists of analysis of coefficient of friction and wear in terms of height loss. Triboloical test were carried out in dry condition using pin-on-disc tribometer. The test parameters considered for the study are: normal load of 50 N, track diameter of 75 mm, sliding speed of 400 rpm and the entire test were carried out for 15 mins duration. Figure 5,6 and 7,8 shows the coefficient of friction and wear of the composite materials.

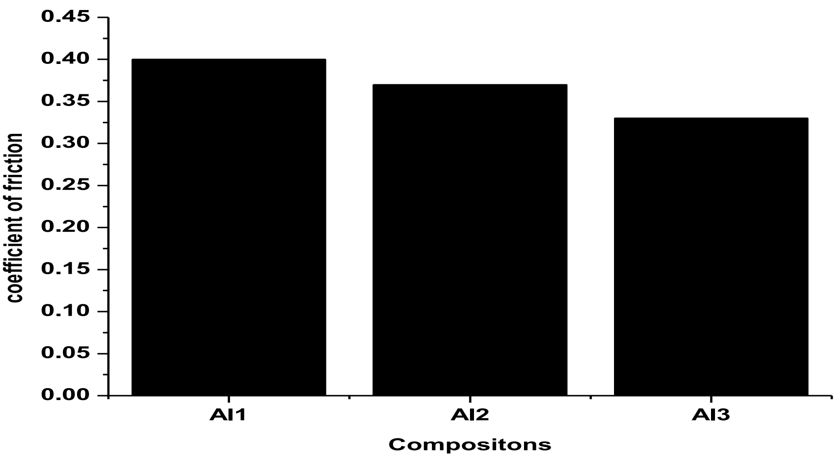

Figure 5 COF of Al1, Al2 & Al3

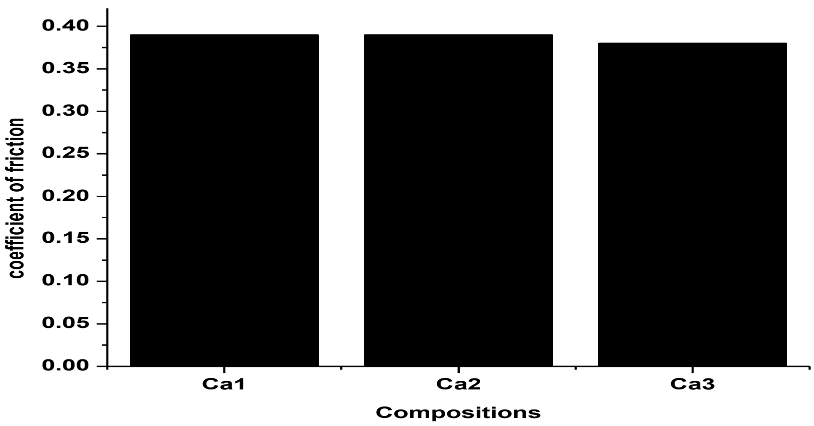

Figure 6 COF of Ca1, Ca2 & Ca3

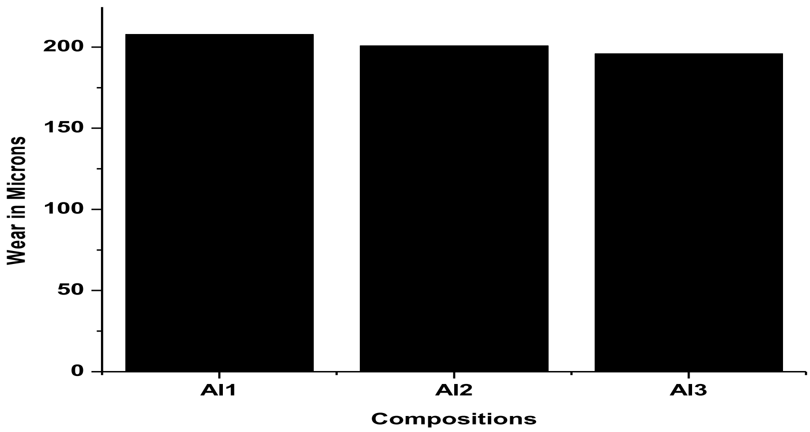

Figure 7 wear of Al1, Al2 & Al3

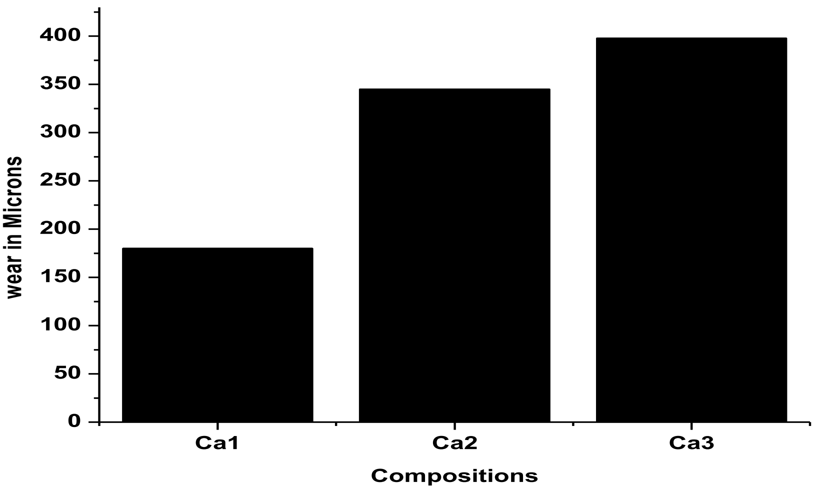

Figure 8 wear of Ca1, Ca2 & Ca3

It tends to be seen from figure 5 and 7 that the coefficient of friction and wear rate reduces with increment in the level of alumina particles in the composites. The lowest coefficient of friction (0.33) and wear (196) was gotten at Al3. Wear of the composite material is less due to the presence of alumina particles which increases the wear opposition of the composite material. Due to harder and stiffer nature of alumina particles prompts increase the protection from strip off or scratch of the composite material. The minimum of coefficient of friction might be because of quality of alumina particles which helps in moving contact as opposed to sliding friction.

Figure 6 and 8 shows the variations in coefficient of friction and wear behaviour for considered sliding distance and load. It is seen that the sliding distance and applied load had a great effect on the wear rate of composites. wear increases with considered sliding distance and load. Based on these results, it could be claimed that the level of the filler can affect the matrix hardness and bonding strength between the filler and polymer matrix. With increases in the calcium carbonate (Filler) in polymer matrix may decrease the hardness of the matrix and weaken the adhesion between the filler and polymer matrix. The weak bond led to the filler particles detaching from the matrix and the matrix pulling out more easily, which could increase the wear rate of the composites. Therefore, calcium carbonate was not suitable for the high load tribological application.

V. Conclusion

The tribological properties of LDPE composites filled with TiO_2, Al_2O_3 and $CaCO_3$ were studied at load of 50 N, track diameter of 75 mm, sliding speed of 400 rpm and the entire test were carried out for 15 mins duration. The effects of reinforcements on the wear and friction behaviour were discussed. From the above, the following conclusions could be drawn:

1. The wear loss of composites increases with increasing load and distance.
2. The coefficient of friction minimum in case of alumina filled composites and wear is also low due to harder and stiffer nature.
3. The coefficient of friction is minimum in case of calcium carbonate filled composites.
4. The sliding distance and applied load had a great effect on the wear rate of composites. The applied load is a more significant parameter than the sliding distance.
5. The bonding strengths between the polymer matrix and fillers changed with the content of the fillers, which accounted for the differences in the tribological properties of the composite filled with the varied content fillers.

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Gururaj Hatti. "Study of wear behaviour on Hybrid Polymer matrix Composite Materials Used as Orthopedic Implants." IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) , vol. 15, no. 6, 2018, pp. 39-44.