Wear performance of UHMWPE reinforced with basalt fibre for total disc replacement

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Abstract. For total disc replacement (TDR), wear of the Ultra High Molecular Weight Polyethylene (UHMWPE) bearing surface is the common cause for failure. Wear of UHMWPE plays an important role in determining the life span of TDR implants. In order to obtain materials with improved wear resistance and improved mechanical characteristics basalt fibre of 5wt. %, 10 wt. %, 15 wt. % and 20 wt. % is added with UHMWPE. The wear tests were conducted on a pin-on-disk tribometer. The specimens thus prepared were subjected to hardness tests, tensile testing and wear testing. The results indicated that the hardness increased with increasing percentages of basalt fibre content, and the tensile strength of the specimens increased until 15% of additive content and post that it decreased thereafter, Wear tests indicated a decrease in wear with increase in additive content as the coefficient of friction decreased considerably.

1. Introduction
The intervertebral disc (IVD) forms a joint between two vertebral bodies and serving as a shock absorbing member and prevents the friction between two vertebral bodies. Failure of the IVD are mainly due to disc diseases and injury due to accidents. The effect of this can be observed from the severe pain in the region of spine.[1] Total disc replacement (TDR) and interbody fusion are considered as the surgical solution for the disc injuries.[2] TDR is carried out mostly in the lumbar and cervical spine region to replace the damaged disc with the artificial disc, so as to allow slight movement in the vertebral column.[2][3]

Artificial discs mainly consist of three parts, upper endplate, inner core and lower endplate. These endplates are anchored into the vertebral bodies.[3][4] Depending upon the type of contact between endplate and the inner core, artificial discs are categorised into metal on metal, metal on polymer and polymer on polymer.[4][5] In recent years, metal on polymer contact type has been widely used for artificial disc.[6] Since artificial disc allows movement between vertebral column, friction between the endplate and the core is unavoidable. Wear debris arising due to friction will cause inflammation and possibly disc degeneration with osteolysis formation.[5]

In metal on polymer devices, cobalt-chromium, Titanium and stainless steel are widely used as metal end plates and UHMWPE, Polycarbonate urethane (PCU), Polyurethane and Polyurethane – Polycarbonate (PU-PC) graduated modulus are widely used as polymer inner core materials.[5][7] UHMWPE is considered as the core material in many implants since it has less wear debris compared to other polymer materials used in TDR.[8][9] UHMWPE is thermoplastic derivative, which is a high modulus polymer compound. It consists of very long shackles and a molecular weight of about 3.5 to
7.5 amu. The presence of extremely long shackles provides effective load transfer to the polymer spine thus, possessing excellent endurance and toughness in comparison to other existing thermoplastic derivatives. The moisture absorption rate is quite good and it has a very low coefficient of friction. This material is almost self-lubricated and therefore resistant to abrasion.

There are two different manufacturing processes used for manufacturing implants, namely ram extrusion and compression moulding.[9] UHMWPE powder is efficiently processed by compression moulding owing to its high melt viscosity. Basalt fibre is the natural fibre of volcanic origin and they are harmless to humans.[10][11][12] Basalt fibre being used as a reinforcement fibre in engineering applications and scaffold development. It is also used for hard tissue replacement by reinforced with PLA. [13]

In this work mechanical and tribological characteristics of UHMWPE-based composites with biocompatible basalt fibre were studied. Comparative analysis of UHMWPE with basalt fibre filled UHMWPE composites on their wear resistance was also carried out.

2. Materials and methods
For this study, silane-treated basalt fiber of about 4–6 mm with diameter 13 μm is obtained from Muktagiri Industrial Corporation, Borivali West, Mumbai, India. UHMWPE powder with an average molecular weight of 4 million g/mol was procured from Fairdeal Polymers Pvt Limited, Bengaluru, India was used in this study. UHMWPE powder was used as a base material and basalt fibre is used as a filler material. Basalt fibre of 5wt. %, 10 wt. %, 15 wt. % and 20 wt. % is added with UHMWPE and mixed evenly.

Separate moulds were prepared to make the specimens for tensile test and pin-on-disk wear test in order to measure the tensile strength and friction coefficient of the pure UHMWPE and basalt fibre reinforced UHMWPE. The tensile test was carried out as per the ASTM D638 (Type IV) standard. The gauge length of the specimen is 200mm. The specimens were prepared by compression moulding process with the temperature of the top plate was 21°C and that of bottom plate is 225 °C and the compression timing is set for 900 seconds under a pressure of 14Mpa. Three samples of each configuration were made, and the same has been tested in universal testing machine with constant loading conditions to find the elongation.

The wear tests were carried out against a cobalt chromium alloy disc using a pin-on-disk tribometer (Ducom TR20) with the loading condition as 20N normal load with the speed of 200rpm and the run time as 20minutes. The pins were made of pure UHMWPE and basalt fibre reinforced UHMWPE. Compression moulding process was used to prepare specimens of 10mm in diameter and 25mm in length with constant surface roughness values. The microstructures of the wear samples were studied using optical microscope. The scanning electron microscope (SEM) images were captured in the fractured specimen.

3. Results and discussion
Figure 1(a) to (c) shows the mechanical properties of pure UHMWPE and basalt fibre reinforced composites. From figure 1(a) and (c) it is evident that the 20 wt % of basalt fibre with UHMWPE shows the better result of ultimate tensile strength (UTS) and hardness, and there is an increase in that value of hardness and UTS with the increase in the percentage of basalt fibre.

There is not much change in the hardness and UTS values after 15 wt % of basalt fibre. From figure 1(b) it is clearly seen that the percentage of elongation has significantly reduced by half with an addition of 5 wt % of basalt fibre and there is not much reduction after that. It clearly shows that the addition of basalt fibre into UHMWPE will reduce the percentage of elongation significantly.
Figure 1. Mechanical properties of composites (a) UTS (b) percentage of elongation (c) hardness.

From figure 2, it is clearly seen that the coefficient of friction (COF) was decreased with the increase in the percentage of basalt fibre and there is not much change after the 15 wt % of basalt fibre with UHMWPE.

Figure 2. Wear property of composite.

Figure 3 (a) to (d) shows the SEM images of the fracture surface of the samples after performing tensile test. Cleavage fracture surface are clearly visible in pure UHMWPE (Figure 3(a)). In figure 3(b) to (d), fibre fractured had occurred. Figure 4 shows the SEM image of the fractured surface of 20wt % basalt fibre with UHMWPE. Fibre pull-out can be seen in this figure along with fibre fracture. It is also noted in figure 3(c) that the group of fibres are localised in one place. It is due to the short
fibres used as a reinforcement and uniform orientation of the fibre within the matrix is not possible due to the nature of the fibre.

![Figure 3](image1)

**Figure 3.** SEM images of tensile specimens. (a) Pure UHMWPE, (b) 5wt % of basalt, (c) 10wt % of basalt and (d) 15wt % of basalt.

![Figure 4](image2)

**Figure 4.** SEM images of tensile specimen with 20wt % of basalt.

Figure 5 (a to c) shows the microstructure images of the wear surfaces of the pin of UHMWPE composites after performing pin on disc simulation. Figure 5(a) shows the wear surface of pure
UHMWPE which shows progressive wear with deep grooves and wear debris occurring due to the plastic deformation of the pure UHMWPE.

Figure 5 (b) and (c) shows less wear track and the thickness of the wear track were reduced significantly and uniform ploughing lines can be seen with the increase in percentage of the basalt fibre. From the microstructure images of 15wt % basalt fibre (Figure 5 (c)), it can be observed that even without the presence of the fibre in the sliding surface, the wear tracks are reduced and the less COF value. The increase in the UTS value and decrease in the percentage of elongation with the addition of basalt fibre are the main factor for the decrease in wear track thickness and uniform ploughing lines.

![Microscopic images of Pin after wear test. (a) Pure UHMWPE, (b) 5wt % Basalt and (c) 15wt % basalt.](image)

**Figure 5.** Microscopic images of Pin after wear test. (a) Pure UHMWPE, (b) 5wt % Basalt and (c) 15wt % basalt.

4. **Conclusion**

From the experimental study it is concluded that,

- The addition of basalt fibre to UHMWPE will increase the tribological performance without much deviation in the mechanical properties.
- The UTS value was increased up to 10 percentage and the hardness value was increased up to 25 percentage with the addition of basalt fibre.
- Another important parameter observed in this study is the percentage of elongation. It has come down to half with an addition of 5wt % of basalt fibre and
- Basalt fibre can be used as a reinforcement for improving the tribological performance of UHMWPE. But short fibre is not suitable for use in TDR, due to the debonding of matrix and fibre.
- Further studies are required to find the effective fibre length and uniform mixture of fibre with matrix.
5. References

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