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SEM Analysis of UHMWPE for Biomedical Application

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Abstract. The objective of this study is to investigate the wear mechanism of UHMWPE acetabular liner. There were three samples of acetabular liner with variations without crosslink, with crosslink doses of 50 kGy and 100 kGy which were subjected to a wear testing process. The wear test was carried out using a Tribometer wear testing machine with a total of 30,000 cycles and a load of 800N. Microstructure analysis was performed using scanning electron microscopy (SEM). The results show that the surface of the UHMWPE acetabular liner with the crosslink treatment is smoother than the untreated one. This shows that UHMWPE with crosslink treatment has a lower wear rate, where the greater the crosslink dose the lower the wear rate. The wear mechanism that occurs in this study is the third body abrasion which leads to adhesive wear.

Keyword: Acetabular Liner; UHMWPE; Crosslink; SEM

1. Introduction

Total hip replacement is currently the most successful standard treatment to restore quality of life and increase mobility [1] from several common joint diseases, such as traumatic disease, necrotic ischemia disease, degenerative arthritis disease, inflammation, tumor disease and hip fracture [2]. Although THR is considered to be one of the greatest achievements in orthopedic surgery since the 1960s, hip replacement has not been a complete success and needs further development. The main limitation in THR is the age of use around 15 to 20 years, which is not satisfactory for patients under 60 years where about 44% demand a usage age between 20 to 25 years [3].

The metal hip implant component on UHMWPE was the first effective pelvic implant developed in the 1950s. The pair of femoral metal heads on the UHMWPE acetabular cup continues to be the most common choice of artificial hip joint use to date [4]. It is the cheapest and most common type of pelvic implant, with a long track record of use around the world. However, UHMWPE still has limitations. The main limitation of UHMWPE is the fairly rigid nature of the material which does not mimic the viscoelastic properties of native articular cartilage found in the hip joint. Many researchers think hard to solve this problem. Several basic approaches are being taken by researchers to extend the life of the artificial hip joint, one of which is by increasing wear resistance through surface technology. In this case, the performance and service life of the bearing material are subject to changes in the level of surface engineering. This is because the failure of the UHMWPE material during contact with tougher materials both in sliding and rolling contact causes plastic deformation and wear.

Crosslinking is a method to reduce the wear rate of UHMWPE which is carried out by means of gamma ray irradiation (γ). The radiation crosslinking in UHMWPE was developed using high doses of radiation to reduce polymer ductility and increase the wear resistance of UHMWPE. James et al [5] stated that the effectiveness of crosslinking depends on the resin and the process. In addition, it is known that the in vivo wear rate of the unrelated UHMWPE implant bearing components is affected by the fabrication method. Bistolfi and coworkers [6] in his research resulted in an increase in UHMWPE wear resistance when given crosslink treatment with a moderate dose of 50 kGy. A previous study [7] also showed a decrease in the wear rate of 30% in UHMWPE that underwent the crosslink process with a dose of 40 kGy when compared to untreated ones. Another study by the same group [8] also resulted in five times lower UHMWPE wear rates when given crosslink doses of 75 kGy and 100 kGy when tested in a hip simulator for 5M cycles against CoCr femoral head.

One of the efforts to predict the wear mechanism contained in acetabular liners after the wear testing process is carried out is by conducting microstructure observations through SEM tools. Unal and Mimaroglu [9] through their observations show that the wear mechanism that occurs in UHMWPE after the testing process is wrinkled. Atkinson et al. [10] indicated that adhesive and fatigue on the surface of UHMWPE were the two main wear mechanisms. The adhesive process occurred quickly after sliding, and fatigue only appeared after long periods of sliding. Song et al. [11] obtained the wear mechanism in the form of plastic deformation and ploughing when observing the effect of machining on the tribological properties of UHMWPE. Therefore, the main purposes of this study is to observed the wear mechanism that occurs on the surface of the acetabular liner made from UHMWPE after the wear testing process using scanning electron microscope (SEM).

2. Materials and Methods

2.1 Materials Preparation and Testing

In this research, a CNC milling machine was chosen to manufacture acetabular liner made from UHMWPE. There are 3 samples produced with given parameters as shown in Table 1. Acetabular liner products that have gone through the process of measuring the accuracy dimensions and surface roughness, then tested for wear using a Tribometer machine. The wear test is carried out for 30,000 cycles on gait walking conditions. The research method in this study is shown through the flow diagram in Figure 1.

Table 1. Acetabular Liner Specimen Parameter

***Acetabular Liner* Spesimen**	**Load**	***Dose Crosslink***
Spesimen 1	800 N	*Non crosslink*
Spesimen 4	800 N	50 kGy
Spesimen 5	800 N	100 kGy

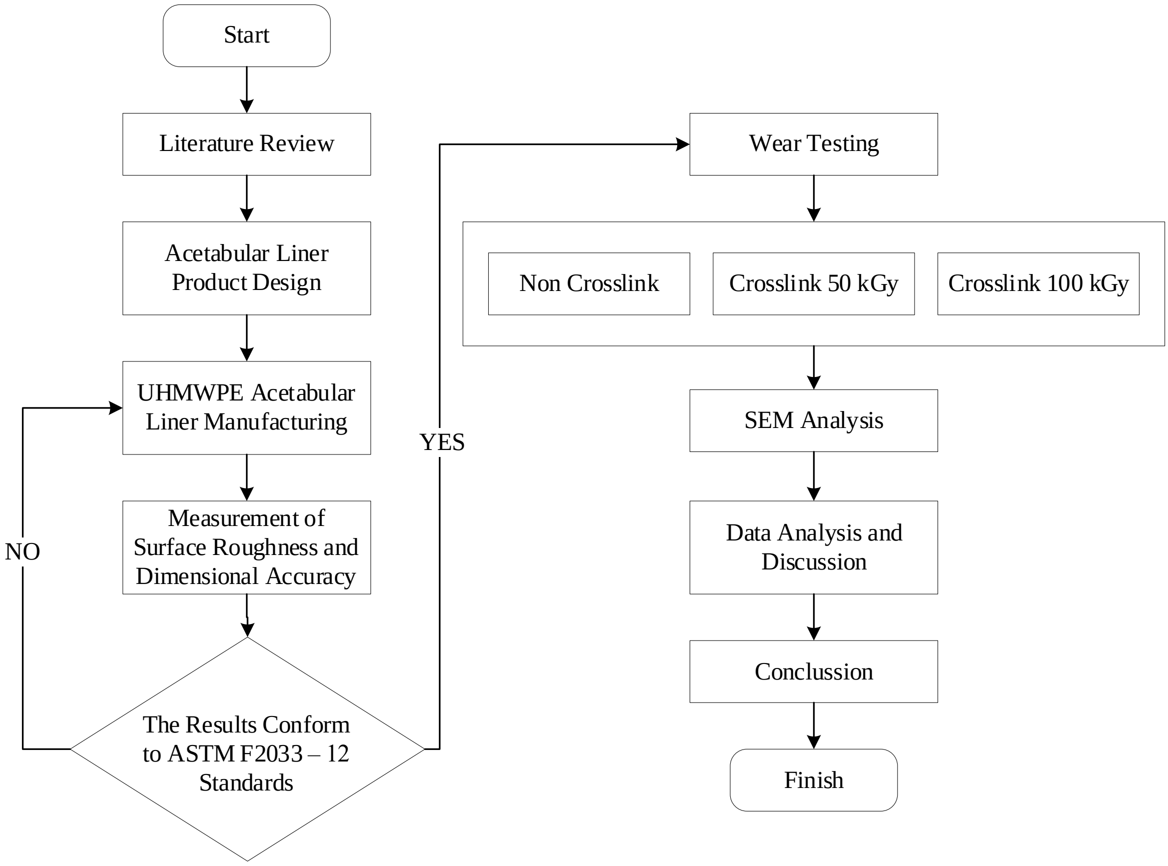


Figure 1. Research Flow Chart

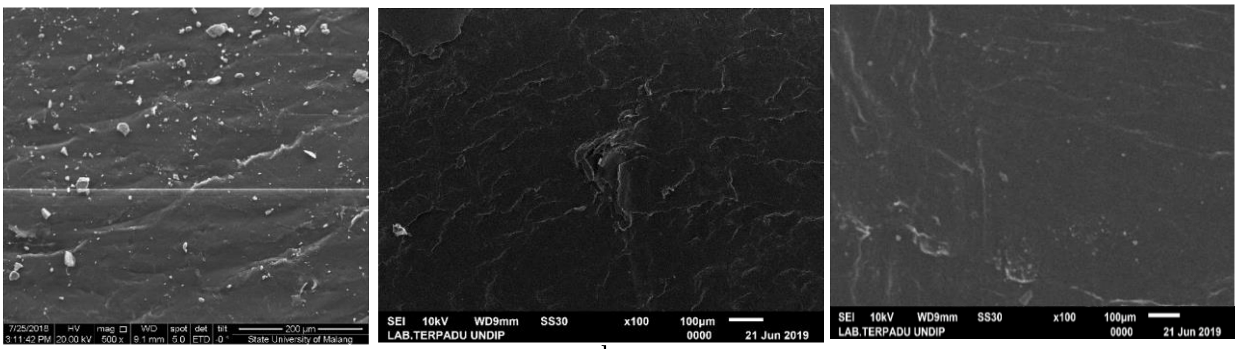
2.2 Microstructural Test using SEM

Acetabular liner products that have been tested for wear are then subjected to surface analysis using scanning electron microscopy (SEM). SEM analysis in this study was used to examine the wear mechanism that occurs on the surface of the UHMWPE acetabular liner after wear testing. Samples to be tested are prepared in small and flat sizes and then numbered. The initial step of the test is to apply a coating using gold.

3. Results and Discussion

Observations of the acetabular liner specimens made from UHMWPE after testing for 30,000 cycles showed that there were wear areas such as polish due to continuous loading. The results of SEM images of acetabular liner surfaces that have undergone wear testing are shown in Figure 2, where each sample is without crosslink, with crosslink 50 kGy, and with crosslink 100 kGy. Based on the figure, it can be seen that the surface of the acetabular liner made from UHMWPE without crosslink has very small surface defects. This phenomenon can maintain a low wear rate. The SEM image of the surface of the contact area shows the scratches received as a result of the simulated run cycle. This scratch may occur due to the friction of the metallic counterface which is forced to move against the acetabular liner surface. As in the research conducted by Trommer et al [12], it is stated that scratches in random directions occur on the acetabular liner indicating a third body abrasion.

In addition, scratching is an important characteristic noted in worn acetabular liners due to particles generated from fibrils starting from a bumpy ripple [13]. The presence of ripple in the wear area of acetabular liner due to the two surfaces rubbing together continuously, and it indicates the mechanics of adhesive / fatigue wear. Gispert et al [14] also mentioned that ripple-like structures can occur from the accumulation of plastic strain caused by continuous shifting (metal femoral head) during the wear test. Then Chandrasekaran and Loh [15] explained that ripple causes the surface layer of UHMWPE to peel off. This trend is connected to the properties of materials in the load used, contact, lubrication conditions, and relative displacement speed [16]. Scratch damage to the femoral head has been reported by [17] to significantly increase UHMWPE wear due to transformation to the abrasive wear mechanism of adhesive / fatigue. The wear mechanism that occurs in this study is the third body abrasion and is one of the differences in the test results, namely the depth of wear and the wear coefficient.



a b c

Figure 2. SEM of UHMWPE Acetabular Liner Surface (a) Without Crosslink, (b) with 50 kGy crosslink, (c) 100 kGy crosslink in contact with AISI 316 L Femoral Head

4. Conclusion

Based on the experiments that have been done, it shows that the specimens without crosslinks show more particles and scratches. The specimens with the highest crosslink dose (100 kGy) looked smoother after the wear testing process was carried out. This indicates that the specimens treated with crosslink have higher wear resistance than those without. In addition, the higher the crosslink dose, the higher the wear rate. The wear mechanism that occurs for all samples is the third body abrasion.

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