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A study of the compression molding method for manufacturing a UHMWPE liner

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Abstract. Hip and knee joints are some examples of the vulnerable joints in the human body. However, due to internal or external factors, the symptoms of osteoarthritis disease may occur, so the replacement of the natural joints with artificial ones becomes crucial. The most common material used for this part is one type of polymer, namely the ultra-high-molecular-weight polyethylene (UHMWPE) for the liner bearing, a component in an artificial hip or knee joint. Usually, the liner component of the artificial joint prosthesis is manufactured from machining process from a bar of UHMWPE material, which is made using ram extrusion process. This research aims to conduct a manufacturing process of UHMWPE liner using compression molding process, changing the powder UHMWPE into solid UHMWPE. The present method developed aimed to reduce the pressure and the amount of energy required during the compression molding process. The hardness and density tests were conducted for measuring several indicators related to the success of the solidification process. It was found that the resulting solid UHMWPE conformed to international standards for manufacturing the joints liners and polymer bearings for joint prosthesis. The best parameters resulting from the experiments were the UHMWPE hardness of 9.37 VHN and the density of 0.94 g/cm³. After a good manufacturing process resulting from this research, the ASTM international standards for joint liners and polymer bearing for joint prosthesis will easily be fulfilled in production in Indonesia.

1. Introduction

Joints are one of the parts of human body that are vulnerable to damage. Joints have the possibility of damage or dysfunction. There are two types of damage, namely: first, damages due to accidents as a result of over imposition that exceeds the limits of weight that can be held by the joint itself; and second, bones getting porous as it ages. The damage and abnormality of joint functions encourage the creation of artificial joints. In the medical world, the most commonly used artificial joints are the artificial hip and knee joints. Compared to other joints of the human body, the hip and knee joints are most vulnerable to damage [1].
Previous projects have researched hip joints using numerical analysis and finite element method [2-5]. Presently, our researchers focus on the manufacturing of the part in hip or knee joints. The part that becomes our focus is manufacture a part that is often affected by wear, namely, the liner. Among ways and methods to produce the liner, the researchers choose the compression molding method.

The compression molding cycle process is consolidation of resin powder into a rod- or net-shaped implants is a necessary step for the final shape machining of UHMWPE joint implants. The process of consolidation in UHMWPE requires proper designation of pressure, temperature and time. Changes in these three molding variables can impact the mechanical properties of the entire UHMWPE implants. For example, mechanical performance of UHMWPE is dependent on the degree of fusion of the powder particles during compression and can be enhanced by heating the polymer powder at temperatures above 220 °C [6].

In Indonesia, the manufacture of hip or knee joints is rare, not equitable and also don’t have International Standard compared with the others nations. Otherwise the size and quality too are far away from International Standard or ASTM because most of it used material can easily found in Indonesia is not equitable. For example, one part of the joint is made of AISI 316L, while most Indonesian industry products are ferromagnetic, which it not allowed for use as implant.

Based on the aforementioned background, a research on how to process UHMWPE powder into solid UHMWPE is needed in order to help the medical world in Indonesia. Up to now, Indonesia mostly imported the solid UHMWPE from abroad, and there is no focus on producing solid UHMWPE. In this study, the authors focus on developing compression molding method for manufacturing solid UHMWPE.

2. Method

2.1. Literature study

The first step was to conduct a literature study on standard product specifications of the liner for the hip or knee joints that use polymer have international standard for manufacturing implant process. Afterward, UHMWPE material was purchased and compression molding tools were designed. The next step was the processing of powder UHMWPE specimens into a solid one. Based on the specimens that had been produced, evaluation of measurements was conducted to find out whether the compression molding tool was capable during the manufacturing process. The next stage was the evaluation of test results data on specimens, to determine whether the specimens met the standards.

2.2. Material specification

UHMWPE resin powder that the researchers used had a molecular weight of $7 \times 10^6$ g/mol and had the same peak condition in XRD analysis as other brands of UHMWPE resin powder.

2.3. Specimen preparation

Samples or specimens had been prepared from resin powder UHMWPE and formed into solid cylinders that were obtained by compression molding method with the molding tool. The pressure and temperature
during product were varied. We conducted the best variations for performing the compression molding to the resin powder UHMWPE. The 3D design of the specimen is pictured in Figure 1 and the molding tools set is in Figure 2.

2.4. Compression molding method

![Figure 3. Compression molding method.](image)

![Figure 4. Flowchart of this research.](image)
Compression molding method chosen in this research is the best and effective way to produce liner using UHMWPE. The compression molding method chosen was varied for the case of ‘lower’ and ‘higher’ point compared to the melting point of UHMWPE, to know the effects on the result. Before the final result has been making, the resin powder was pre-compressed in a mold under the pressure of 10 MPa and at the temperature of 40 °C. Then, we use the selective variations of pressure and temperature but with different temperature in final condition to see the best sample of UHMWPE after doing the compression molding method. Finally, the solid cylinder UHMWPE removed from the mold and then was gradually cooled to room temperature (See Figure 3). The phase of this research step by step until measurement the specimen can be seen in Figure 4. After doing the compression molding method, finally the solid cylinder UHMWPE removed from the mold and then was gradually cooled to room temperature.

3. Results
In this study, the variation of temperature for process compression molding method that was used is 110 °C, 140 °C, and 160 °C and the pressure was 70 kgf (9.7 MPa), 100 kgf (13.8 MPa), and 130 kgf (18.03 MPa) in Figure 5.

![Figure 5](image)

Figure 5. The specimen (a), (b), (c), are examples of after process the compression molding method with the different temperature and pressure.

3.1. Hardness test
Hardness is one of the indicators of the quality of the produced polymer. The hardness test was conducted using Vickers HM-200 Mitutoyo. Three best samples were prepared molded with different pressure and temperature is shown in Table 1. Results showed the hardness of specimen 1 through specimen 3 is above 5 VHN. Samples 140 °C 13.8 MPa are almost 10 VHN. This data is compared with previous research shows increasing hardness value, that similar to the hardness value showed in Kurtz research [1].

| Specimen Variation | Hardness (VHN) |
|--------------------|----------------|
|                    | Test 1 | Test 2 | Test 3 | Average |
| 110 °C 9.7 MPa     | 6.5    | 6      | 5.9    | 6.13    |
| 140 °C 13.8 MPa    | 8.8    | 9.6    | 9.7    | 9.37    |
| 160 °C 18.03 MPa   | 7.8    | 9.4    | 9.9    | 9.03    |

3.2 Density test
The density of the material that we processed needed to be tested. Results from the density test showed whether the material met the standards. We tested the sample specimen with palm oil. The density test was conducted using the Vibra Density Meter. The density values shown in Table 2 indicates that the manufacture of UHMWPE that is carried out by compression molding process above melting point matches the standard mentioned in Kurtz [1].
Table 2. Density test results.

| Specimen Variation | Density (g/cm³) |
|--------------------|----------------|
| 110 °C 9.7 MPa     | 0.92           |
| 110 °C 13.8 MPa    | 0.92           |
| 110 °C 18.03 MPa   | 0.92           |
| 140 °C 9.7 MPa     | 0.94           |
| 140 °C 13.8 MPa    | 0.94           |
| 140 °C 18.03 MPa   | 0.94           |
| 160 °C 9.7 MPa     | 0.94           |
| 160 °C 13.8 MPa    | 0.94           |
| 160 °C 18.03 MPa   | 0.94           |

3.3 Shrinkage test
Polymers have a special condition after melting and resolidification called shrinkage. This is one of the anomalous effect exhibited by polymers after processes. Table 3 is shown the latest condition of UHMWPE specimen after cooled by room temperature on day 3.

Table 3. Shrinkage test results.

| Specimen Variation | Day 1 Vo (mm³) | Day 3 Vi (mm³) | % Shrinkage Volume |
|--------------------|----------------|----------------|--------------------|
| 110 °C 9.7 MPa     | 7771.50        | 389.29         | 5.01%              |
| 110 °C 13.8 MPa    | 7771.50        | 322.84         | 4.15%              |
| 110 °C 18.03 MPa   | 7771.50        | 342.62         | 4.41%              |
| 140 °C 9.7 MPa     | 7771.50        | 272.70         | 3.51%              |
| 140 °C 13.8 MPa    | 7771.50        | 264.02         | 3.40%              |
| 140 °C 18.03 MPa   | 7771.50        | 274.34         | 3.53%              |
| 160 °C 9.7 MPa     | 7771.50        | 286.95         | 3.69%              |
| 160 °C 13.8 MPa    | 7771.50        | 270.02         | 3.47%              |
| 160 °C 18.03 MPa   | 7771.50        | 273.25         | 3.52%              |

4. Discussion
All the results of this experimental research provide evidence that compression molding process is effective for making of liner components in artificial hip or knee joints. The most optimal variation for making solid UHMWPE using compression molding process conducted in UNDIP consists of a temperature 160 °C and a load of 130 kgf (18.03 MPa).

The density of the specimen after being processed at a temperature above melting point 138 °C already matched the standard density of 0.94 g/cm³ according to density properties of UHMWPE by Kurtz [1]. The average hardness value is 9.03 VHN has already exceeded the standard on journal Slouf et al. [7], which is 4.64 VHN but still below the hardness value shown Kurtz [1] which is 10 VHN for pure UHMWPE. Thus, the density and hardness value of acetabular liner specimens used in this research already meet the international standard for hip or knee joint liner.

Shrinkage effect of the polymer occurs after UHMWPE processes above melting point, the shrinkage effect stop at percentage ± 3%. The hardness value of making solid UHMWPE it should not be too hard or too soft because bad effects causes when it has become a liner. If too soft, the deformation form comes from impact load which makes part of this liner stuck in the other part or may can not accept the burden of which is supposed to receive the part. And if it is too stiff, it will result in the rest of the unwanted wear giving rise to a new problem.
5. Conclusion

UHMWPE surely influenced by heat dan pressurre, when the processing is done and UHMWPE is heated above the melting point, size of the density of the UHMWPE powder raw will be different from the UHMWPE with shaped solid form. The mechanical property of UHMWPE with different pressure that was designed 9.7 MPa, 13.8 MPa, and 18.03 MPa in this paper, the UHMWPE samples processed at 13.8 MPa obtain the best mechanical properties.

Shrinkage is one of the polymer properties after reach the melting point. The shrink factor is determined by measuring before processes, after processes, and day by day until the shrinkage percentage stop. Subtracting the length of the part from the length of the cavity, and dividing that result by the length of the core in molded part. Then measuring the samples after processes by the volume samples.

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