Research Article **Biomaterial Science**

International Journal of Pharma and Bio Sciences **ISSN 0975-6299**

DESIGN AND FABRICATION OF POLYMER-CERAMIC COMPOSITE HIP PROSTHESIS

S BAG* AND S PAL

JIS College of Engineering, Kalyani, West Bengal, India
School of Bioscience & Engineering, Kolkata, India

ABSTRACT

A composite hip prosthesis (CHP) made from alumina reinforced ultra high molecular weight polyethylene (UHMWPE) was designed and manufactured. The main objective of the study was to fabricate the composite hip prosthesis which would be an ideal replacement of metallic one as bone is a composite material consisting of collagen fibre matrix and embedded hydroxyapatite mineral. With this idea we developed a composite material using UHMWPE (Ultra High Molecular Weight Polyethylene) and alumina ceramic in various percentages whose properties are similar to that of bone. Hip prosthesis mould was designed and developed as per standard size and shape of Austein Moore metallic hip prosthesis and the alumina reinforced UHMWPE (GUR 4020) composite hip prosthesis was fabricated in the 3 piece hip mould using compression moulding technique. After fabrication, a static compression test was carried out to observe the deflection under loading condition. From the graph, it was calculated that the deflection without any cement was 30% higher than that with bone cement fixation. This type of composite hip prosthesis may be used in patient with lesser body weight.

KEYWORDS: Bone cement, Composite, Compression test, Deflection, Hip prosthesis.

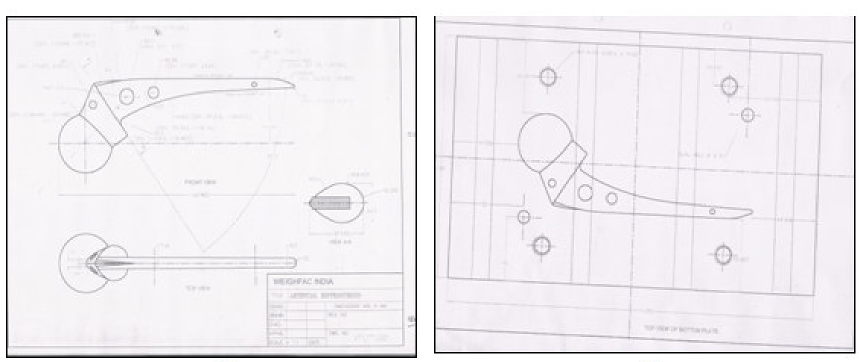
S BAG
JIS College of Engineering, Kalyani, West Bengal, India
School of Bioscience & Engineering, Kolkata, India

INTRODUCTION

Hip joint is one of the most vulnerable joint in human body requiring replacement surgery. Hip replacement is a common phenomenon in advanced orthopedic surgery. It has become the most widely accepted procedure for the treatment of disabling hip arthritis in modern orthopedic surgery[1]. The ball-and-socket hip joint is then replaced with an artificial implant. The materials used in the implant depend on several factors, including the age of the patient, the activity level of the patient, and the surgeon's preference. Since hip joint is a load bearing joint, so it is replaced only by the material having load bearing capacity. Generally hip prostheses made of stainless steel (316L) are widely used because it has good load bearing properties[2]. The density of this metal is heavier by 6-7 times compared to bone, the density of which ranges between 0.8-2.1gm/cc. Similarly the modulus of elasticity of surrounding bone (3-30 GPa) is nearly 10-20% that of stainless steel[3, 4]. So the applied load is mostly transferred through the metal not to the bone[5]. This results in the bone being inadequately loaded and consequently it resorbs and also changes the biomechanical environment[6]. To make suitable hip prosthesis in terms of density and modulus of elasticity ceramic reinforced polymer composite material would be the ideal material as bone is a composite material[7, 8, 9, 10]. Since the portions of the human body are composite structures, the progression towards the use of composite materials for application in the human body is natural[11, 12, 13, 14]. Because the properties of the materials and interfaces in the body are unique, it is difficult to duplicate these properties or even to accommodate them without considering the potential advantages of engineered composite materials custom tailored mechanical properties[15, 16, 17]. Therefore, the objective of this work is to prepare a simple light weight hip joint prosthesis with a composite material made of polymer (as matrix material) and ceramic filler (as reinforcing material using compression moulding technique and then using these prostheses as push fit implant and cemented implant over human cadaver bone for its experimental validation.

Design and development of Hip prosthesis mould

For fabrication of composite hip prosthesis, a mould was designed and developed by us as per the standard size and shape of Austein Moore metallic hip prosthesis. These were highly specialized job, requires the details drawing of the mould and size are given in Fig-1. EDM and program controlled wire cut technology were used to develop the mould. Three piece moulds were developed in which lower part contains half portion of the mould and another half is on the top. The middle part of the mould is guided part. The system contains heating arrangement inside the mould. The desired fabricated mould parts were shown in Fig-2.



(a) (b)

Figure 1
Details drawing of the hip prosthesis mould (a) front view and top view (b) top view of bottom plate

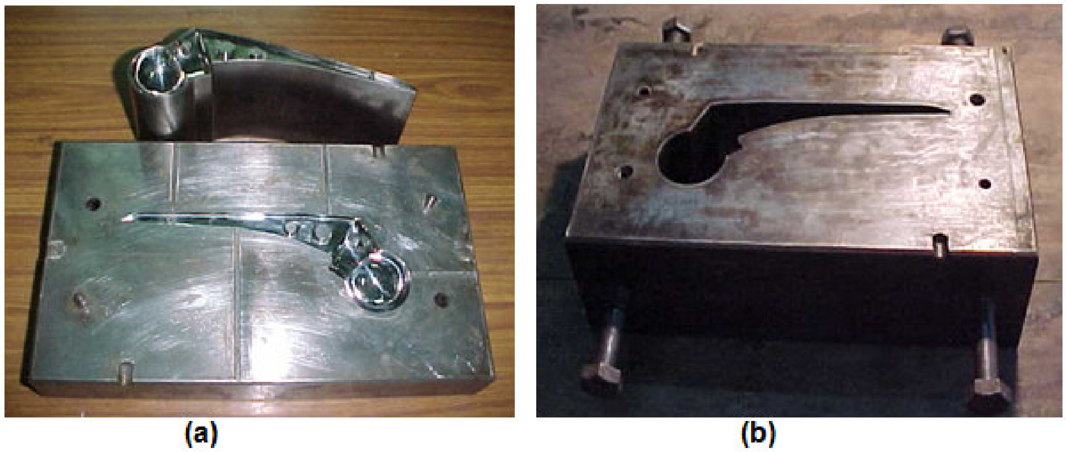


Figure 2
3-piece hip prosthesis mould a) shows the two components of the mould and b) shows the main Die with heating coil.

Preparation of Composite Hip Prosthesis

Ultra High Molecular Weight Polyethylene is used as matrix or base material and alumina powder is used as reinforcing material in this present work. The UHMWPE powder was chosen as polymer material to prepare the composite due to its unique combinations of physical and chemical properties[18], which includes self lubricating, excellent chemical and corrosion resistance, light weight, good machinability, high fatigue resistance & excellent biocompatibility. Alumina ceramic was used in this composite preparation because of its excellent biocompatibility due to chemical inertness[19]. Alumina has been used in the area of orthopaedics for more than a quarter of a century[20]. Alumina is preferred materials for application of bearing surfaces because of its extreme hardness should result in greater durability.Al_2O_3 powders are stable oxides, chemically inert and well tolerated by the body. The ultra high molecular weight polyethylene used in the present work was Hostalain GUR 4220 (GUR 4120 with heat stabilizer) supplied by Ticona (Belgium). The molecular weight was in the range of 3.6 to 5.6 million as per the manufacturer's data. The apparent density was measured to be 0.94 to 0.96 gm/cc for the powder samples and as well as compressed moulded samples. High purity alumina of particle size (74μ) obtained from Alcoa through Central Glass & Ceramic Research Institute, Kolkata, was used as reinforcing material for composite preparation. Polymer and ceramic powders are weighed accurately in weight percent of 65:35 and mixed in a high-speed rotary mixing machine. The nearly uniform powder mixture (60 gm) is charged into the properly lubricated 3 piece mould using compression moulding technique. Initially by pressing the top part of the mould over the powder, the structure of hip prosthesis was made and the top part kept intact. The total assembly was placed between the two plates of a compression machine (ALMIL hydraulic press m/c of capacity 2000kN). The powder was cold compressed repeatedly for 5-10 minutes under a pressure of (10 MPa) in order to expel the air entrapped between the mixtures. The temperature of the thermocouple-programmed controller was set to 160^0C and held constant for sufficient time to melt the powder material properly. After plasticization the compression mould is subjected to air cooling. Cooling is the most important part in compression moulding, otherwise shrink marks, and voids will appear in the final product. As the shrinkage of the material progresses, pressure is gradually increased and brought up to 8-10 MPa (load 300KN). This load is maintained constant until the total mass came back to ambient temperature. The mould is taken out from the press and the desired composite prosthesis was removed from the mould. A complete set up is shown in Fig-3.

Figure 3 Mould of Hip prosthesis along with heating arrangement placed in compression machine

Figure 4 Composite Hip prosthesis

Mechanical Testing

A static compression test was carried out to observe the stiffness of the composite femoral head by deflection under loading condition. To perform such experiment, six numbers of the femur bones were collected from the hospital and all the femoral heads were removed and cleaned the marrow cavity by an orthopaedic surgeon. After that the composite hip prosthesis was fixed in the cadaver bone by either press fit (3 Nos.) or using bone cement (3 Nos.) and placed in the INSTRON material testing machine for compression test. The deflection of the femoral heads was recorded under the loading condition.

Figure 5 Press fit Composite hip Prosthesis

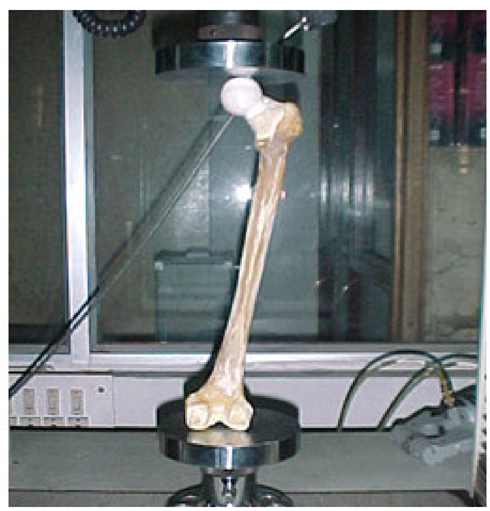


Figure 6 Composite Hip Prosthesis Fixed with Bone Cement.

RESULTS AND DISCUSSION

The deflection of the femoral heads in both cases was recorded under the loading condition. From the recording graph, it was observed that the deflection of the femoral head without any cement was 30% higher than that with bone cement fixation. It is observed that the composite prostheses will need some metallic insertion to make it more rigid, if it is to be used without cement.

CONCLUSION

In this work we have successfully developed the polymer-ceramic composite using compression moulding technique. The static compression test over composite prosthesis indicates that this may be used in a patient having lesser body weight. If we want to use such prosthesis without cement then it needs some metallic insertion to make it more rigid. This composite material may also used in lesser load bearing joints like shoulder joint as well. We have tried it in canine hip prosthesis and received encouraging results.

ACKNOWLEDGEMENT

This work was supported by DRDO, Govt. of India, to the 2nd author. The corresponding author also acknowledges the TEQIP grant of JIS College of Engineering for providing the publication fees.

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