Design and Development of Mild Steel Die for Production of Hip-Bone Joint

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***Abstract*- Failure of hip bone joint is commonly caused by injuries, arthritis or aging factor. Currently, Ti-6Al-4V alloy has been dominating for medical applications; with uses extending across many orthopedic, dental and maxillofacial devices as well as the cardiovascular products. The production technique with this material is not economical and thus, less expensive material and less expensive production procedure have been searching. Cobalt based biocompatible material has been started to use and casting technique are being employed to reduce the cost. In order to produce a typical hip-bone joint by casting process, a die or mould is required. This study includes the modification of design together with fabrication of a typical hip joint casting dies with mild steel for squeeze casting. The hip-bone joint design has been generated using CATIA V5 software. Two slabs mild steel dies were machined on Vertical Machining Center (VMC) using appropriate tools.**

***Keywords*-** *Arthritis, Replacement, Orthopedic, Biocompatible.*

I. INTRODUCTION

A total hip-bone replacement is a surgical procedure, whereby the diseased cartilage and bone for hip joint are surgically replaced items with artificial materials. The normal hip joint is a ball and socket joint. The socket is a 'cup shaped' bone of the pelvis and the ball is the head of the thigh-bone (femur). Total hip-bone replacement is performed most commonly because of the progressively severe arthritis in the hip joint. The most common type of arthritis leading to total hip replacement is degenerative arthritis (osteoarthritis) of the hip joint. This type of arthritis is generally seen with aging, congenital abnormality of the hip joint, or prior trauma to the hip joint such as fracture of femoral neck. However, in the process of designing the artificial joint, not only the shape of the articulation must be considered but also the means by which the prosthesis will be fixed to the bone. Currently, fixation is accomplished by either bone growing into prosthesis or with bone cement. Different shapes of implants are better adapted to bone in-growth and other shapes to cement. After the design of articulation and method of fixation are decided upon, complex and detailed blue prints are drawn from which manufacturers are able to produce the artificial joints.

However, surgery is very often needed for proper bone healing. The materials used in orthopedic operations vary a lot as to their source, nature and their admixture, but they are expected to share some common properties. Biomaterials, including orthopedic implants should not cause responses, such as tissue swelling or damage (ASB, 1999). The implant should have resistance against mechanical load, which is one of the basic properties of healthy bone. Some metals are suitable for load bearing implants because of their mechanical strength and biocompatibility. However, the success of total joint replacement has been directly related to the accuracy with which the surgical procedure was performed. Therefore, it is important that the surgeon must be able to technically accomplish the surgery with reproducible accuracy. In order to do so, properly designed artificial joints must be provided to assist their implantation, so that they are easily and efficiently used in the operating room and compliment the prosthetic design. After the design is complete and thoroughly checked, the actual manufacturing starts. Manufacturing has been helped immeasurably in the last few years with computer assisted design (CAD)-computer assisted manufacturing (CAM) systems (Utah, 2004). These systems assist the skilled engineers in the orthopedic factory and help drastically in virtual reality to create the design and manufacture the products as per requirement. The Engineering faculty of IIUM has also provided the new software, such as Solidworks, ANSYS, CATIA and several others to use for design analysis. This opportunity motivates the authors to design and fabricate the hip-bone casting dies for the present study.

II. DESIGN OF HIP-BONE JOINT

The design of a custom hip prosthesis can be broken up into several stages. First, a model of the femur of the patient is constructed using MasterCam. Next, an implant is designed with Solidworks using the geometric model of the femur as a guide and constraint. Third, simulations are performed using ANSYS to determine the feasibility and performance of the design under different loading conditions. Finally, shape optimization is performed on the basis of the results of the simulations and visualizations which have been computed.

The first step in designing the hip-bone joint according to the research and evaluations taking from the internet (Utah, 2004) is that the design must follow the exact form of the bone for total hip replacement. Fig. 1 shows various nomenclatures and dimensions of hip implant (Petty, 1990). In this process, using the masterCam software, the axis of stem, the geometry of the neck, the offset, the Limb Adjustable Length (LAL), the stem length and the neck length are constructed. The design is then placed on the 2D form (Fig.2) on which the design is transferred into Solidworks, which helps to construct the dimensions of the head diameter, length, angle and the offset. This 2D drawing using Solidworks is transformed later into 3D design using similar software. According to the specifications of the World Health Organization (WHO) and Food and Drug Administration (FDA) the design of the hip-bone collar that joins the socket and the ball to the stem of the femur must be between 115o to 130o that accord to the normal human bone angle (FDA, 1997). Fig. 3 shows the collar of the neck and the stem angle, but without head. However, Fig. 2 shows the relationship of the angle, which can differ according to the size of the human being and the size of that particular bone.

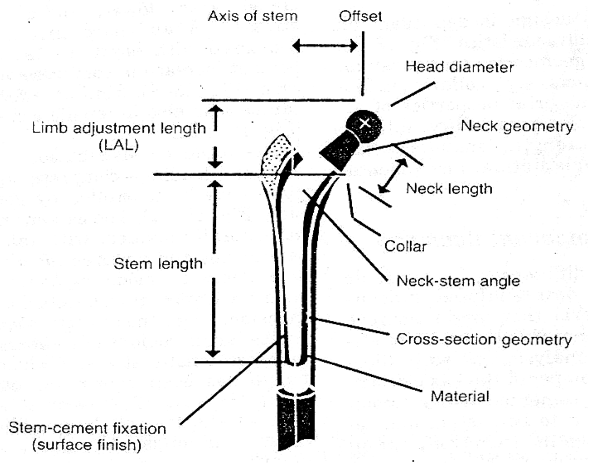


Figure 1. Nomenclatures and positions of various parts of hip-bone implantation.

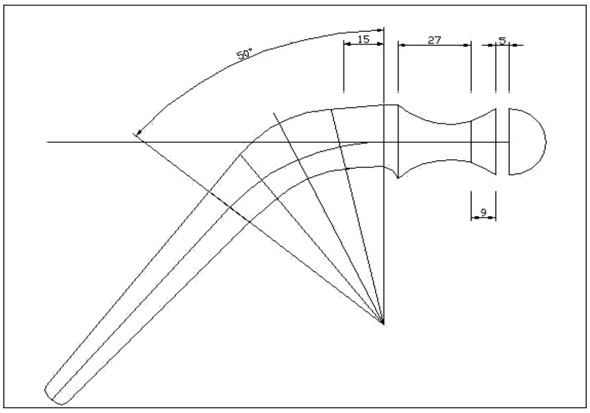


Figure 2. Drawing of the implant in 2D (all dimensions are given in mm).

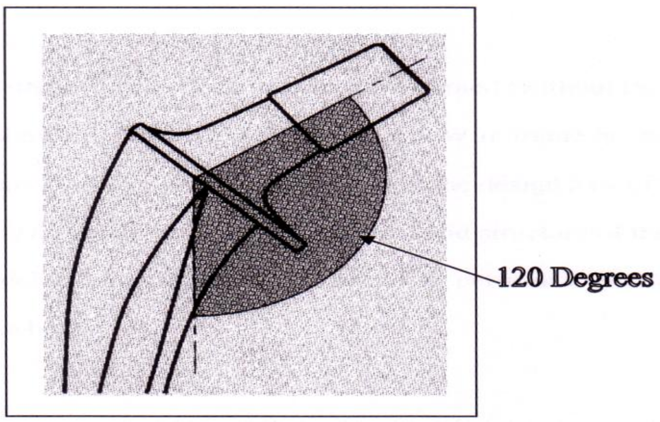


Figure 3. Showing the collar of the neck and stem angle of 120°.

The MasterCam software is used to form a hip bone implant (without head) by using wire frames and is shown in Figs. 4 (a, b and c). Wire frame or line trace is a process where imaginary lines are lined up according to the design axis of the stem and were lined up closely as possible together to form a solid structure of the bone. A volume mesh of the modeled femur is necessary in order to perform a simulation of the out side surface of the bone (Charnley, 2001). However, with the progress of the design, the concentration is given to make the solid structure and smooth surface of the product. Fig. 5 shows the various stages of construction of the hip-bone joint drawing. Fig. 5a shows the head diameter and the neck length. These stages require geometric shape for the neck and the ball of the head. In this process, the collar is under construction. Another view of the neck and the head from different angle is shown in Fig.5b, but the connection of the head diameter and the neck is made to mesh in and not in a smooth fillet as before. After carrying out the first design where the head and the neck are joined together having a contour of fillet cuts, the collar is exposed (Fig. 5c) so that the extensions can be made from the collar to the stem. Fig. 5d shows the extension of the collar from the neck being shaped, while Fig. 5e shows the entire length of the stem with neck and head.

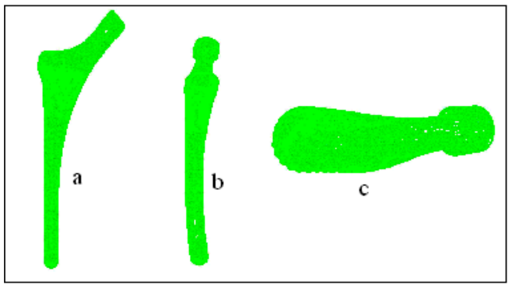


Figure 4. Wire frame construction of a hip-bone, front view, (b) side view, (c) top view.

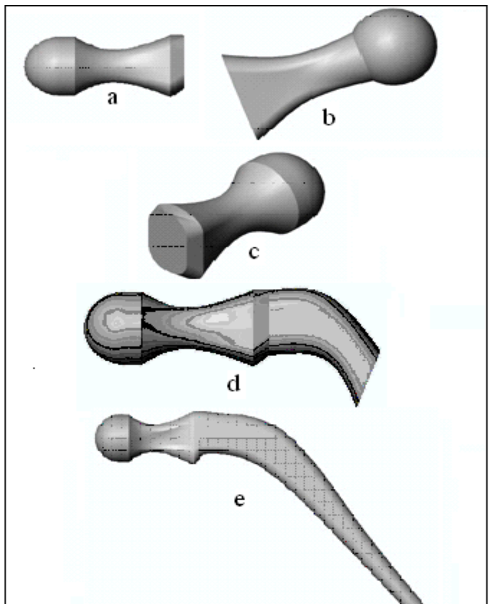


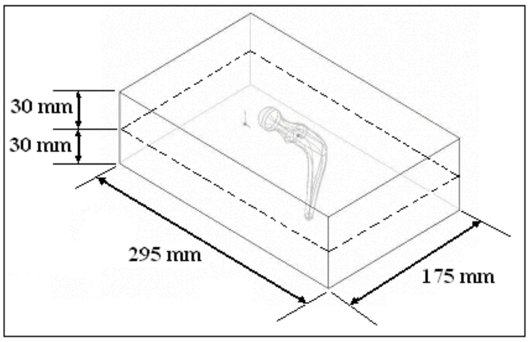
Figure 5. Construction stages of hip-bone drawing: (a) head and neck, (b) head and neck at different angle, (c) head and neck with collar, (d) extension of the collar and (e) full length of stem with neck and head.

It can be noticed that the angle of the neck-stem has caused the stem to be narrowed down and this in fact helps in the insertion of the implant into the bone. The entire pattern of the implant shows with characteristic cross sectional geometry of the stem according to the stem axis, the cross-section of the head diameter as well as the neck and the neck-stem angle, which have been clear and completely formed.

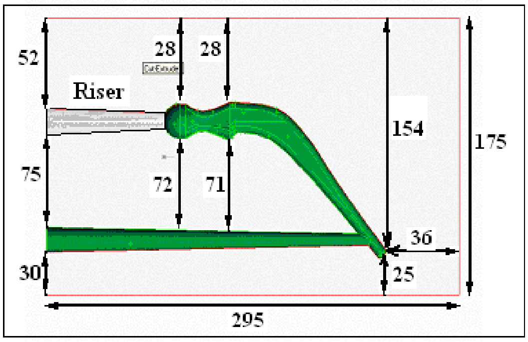
III. DIE CONSTRUCTION

Mild steel were chosen as suitable materials for fabricating the die halves. Fig. 7 (a) shows two die halves in the assembled condition having the position of the hip-bone joint cavity to be formed in the dies, while Fig. 7 (b) shows the overall dimensions and positions of the feeder and riser.

Actual cutting/machining operations took place when two blocks of mild steel were placed horizontally under milling machine and after making sure that the both die halves had correct and equal thicknesses. Then the blocks were put under the Vertical Machining Centre (VMC) one after another to do the necessary contour and the cavity. The design had been performed previously by using Solidworks and MasterCam softwares. The CAD-CAM software helped to create the die geometry to prepare the engineering details and to finish the blueprints.



(a)



(b)

Figure 7. Die halves are in (a) assembled condition, (b) Dimensions of the die cavity with feeder and riser (all are given in mm)

Figure 8. One half of the dies just after machining.

Fig. 8 shows the one half of the dies just after taking out from the VMC machine. Then the milling and grinding operations were conducted by using Vertical Milling Machine and Surface Grinding Machine, respectively. However, final polishing and finishing of the die halves had been performed by using various grades of emery paper to improve the smoothness of the surface.

IV. CONCLUSIONS

The following conclusions can be drawn from the works of the present investigation:

(i) A typical hip-bone joint has been designed successfully using software like, MasterCam, ANSYS, Solidworks, etc.

(ii) The mild steel die halves have been constructed for casting of hip-bone joint by using VMC, Wire EDM, etc.

(iii) This mild steel die can be safely used to cast the typical hip-bone joints with cobalt based biocompatible material (melting point about 1300^{o} C) for squeeze casting.

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