Manufacturing of Patient Specific Implant Models by 3D Printing Assisted Investment Casting

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Abstract – *Development of medical implants in orthopedic field is having large research now days. Reverse engineering approach is used to develop patient specific bone joint implants. The implants are developed from CT (Computed Tomography) scanned bone geometry data. These developed implant's STL file can be used for rapid prototyping and metallic functional implants can be manufactured by investment casting technique. The 3D printed model of implants used for wax pattern making and these wax patterns are used in investment casting process to produce metallic implant. The casted metallic implants are finished and validated by 3D scanning. The 3D scanned data of casted, finished metal implant is compared with the implant model STL file which is used for 3D printing.*

Key Words: Medical implant, STL (Stereolithography) file, Fused Deposition Modelling (FDM), Rubber mould, POP mould, Investment casting, 3D scanning.

1. INTRODUCTION

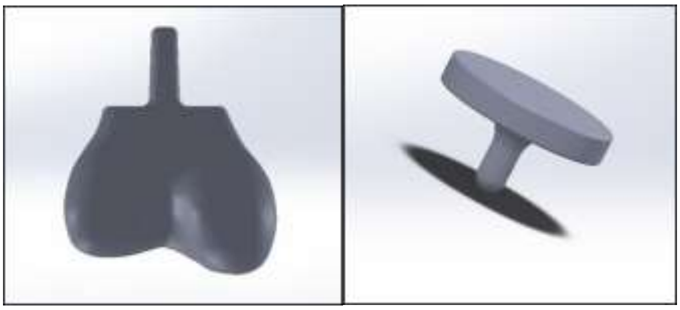
Patient specific medical implants refers to a biomedical device used to replace or cure damaged bone part and function according to host, which is developed with consideration of patient anatomy and bone geometry. The advantage of patient specific medical implant is quick cure, easy acceptance of implant by body anatomy and adjacent tissues, less pain [1].

Reverse engineering approach is used in development of patient specific medical implant. The data acquisition of damaged bone geometry is done through CT scanning, this data is processed and converted to form STL file of 3D bone model. This STL file is used to develop the medical implant in CAD software [2]. Then developed implant's STL file can be used for further manufacturing with 3D printing and investment casting.

2. DEVELOPED MEDICAL IMPLANT MODELS

The medical implants models are developed in the SolidWorks software, the detailed process of data acquisition, processing and development of implants is presented in earlier paper regarding reverse engineering of implants [2].

The medical implant models for knee, hip and shoulder joint are developed. For case study, full knee implant is studied, which is in STL file format as shown in Fig.-1.



(A) (B)

Fig.-1: Developed knee implant models, (A) Femoral implant, (B) Tibial implant.

3. 3D PRINTING OF IMPLANT MODELS

The implant models developed in the CAD software converted into STL files to make 3D printing models in prototyping machines. Fused deposition modeling (FDM) method is used for 3D printing of these implant models. FDM is clean, quick, cheap, easy to operate process with good accuracy [3]. The other prototyping method such as Stereolithography is more accurate than FDM, but it is expensive and more time-consuming process.

(A) (B)

Fig.-2: 3D printed knee implant models on FDM, (A) Femoral implant, (B) Tibial implant.

The 3D printing of the developed implant models is done in the PLA material. The proper placing of STL model on base table is provided considering the supports required and accuracy of printing layer under cantilever printing conditions. While slicing in software it is required to give supports to the nonuniform bottom surface for accurate printing. The supports are required for femoral implant models and not for the knee tibial implant model, as it has flat surface to print. Supports are printed of same filament at the starting of printing. After completion of printing process, the supports are trimmed from models. Fig.-2 shows the 3D printed knee femoral implant and knee tibial implant model on FDM printer.

4. INVESTMENT CASTING OF IMPLANT MODELS

Investment casting is most suitable method for making casting of uneven shape and for less number of casting, and also preferred for reverse engineering processes. It used for making casting of unique characteristic geometry with good accuracy and surface finish [4]. The printed 3D models of implants can be used for investment casting either direct printed model as pattern or by making wax patterns from printed implant models [5]. The wax pattern method is suitable for taking number of castings.

The process requires solid 3D model of the component which is to be casted or requires the solid metal wax casting dies having negative shape cavity of component which to be casted. In case of mass production, the metal dies are used to make wax patterns. These number of wax patterns then jointed to a wax runner system called investment casting pattern tree, which has a master runner, pouring basin, gates for each wax pattern. Then this tree is provided with different coating of slurry on it to make casting mould shell. The shell is heated and burnout of casting takes place [6]. Then the molten metal is poured in this shell through basin and mould shell is broke to get metal components.

Fig.-3 shows the steps to produce investment casting of the implant models. The first step is making of rubber mould to produce wax pattern, then preparation of wax patterns and trees. Then plaster of paris (POP) moulds are created with these pattern trees. At the and melting and pouring of molten metal into these POP mould is carried out after wax burn out.

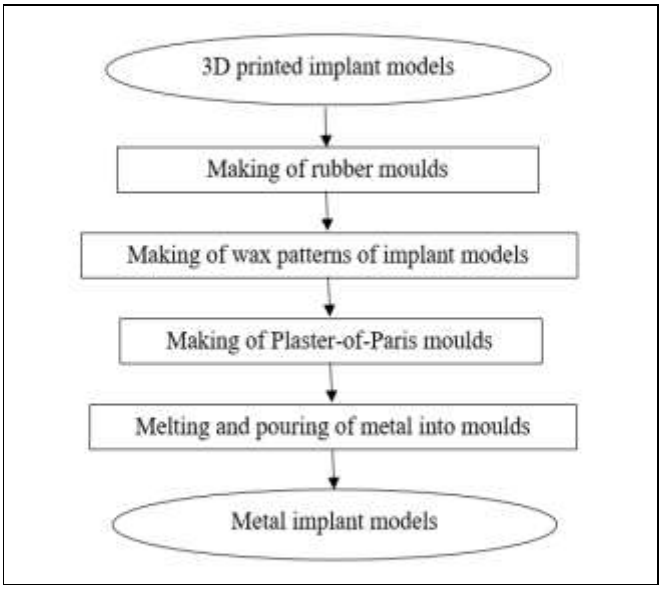
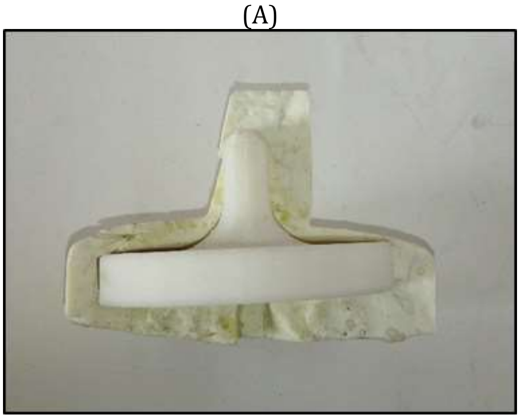


Fig.-3: Investment casting process for implant models.

4.1 Making of Rubber Mould

The 3D printed implant models are directly used for making rubber moulds of silicone rubber. A liquid silicone rubber with curing agent is used to make rubber moulds. The mixture of this liquid rubber and curing agent with appropriate ratio is poured surround the 3D implant models. The knee tibial and femoral implants are small in size; therefore, the mixture of silicon liquid rubber is directly poured in a closed cylindrical vessel in which 3D printed model is placed at middle. The mixture of liquid silicone rubber gets solidify completely in 24 hours. After that the mould is allowed to cut in zigzag path to remove 3D printed model and obtain cavity or negative shape of model.

(A)



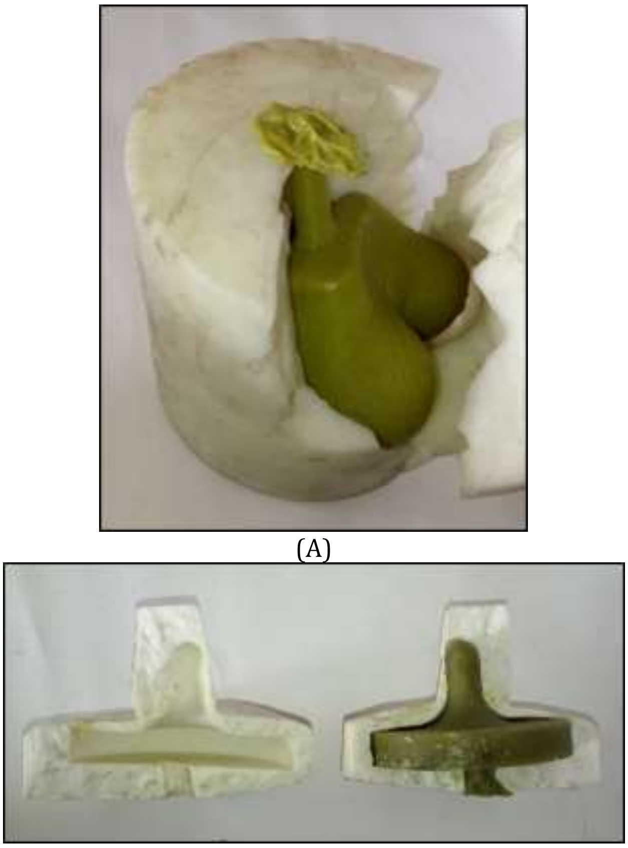
(B)

Fig.-4: Images of silicone rubber mould of knee implant models, (A) Femoral implant, (B) Tibial implant.

4.2 Making of Wax Patterns of Implant Models

The negative cavity of implant models in rubber moulds are used to create solid wax model of implant. The rubber mould is provided with small hole or opening at earlier stage or it can be cut to make opening after solidifying. The rubber moulds having two sliced parts and to hold these parts together number of rubber bands are used. The rubber bands with proper tension are provided around it to hold rigidly and avoid leakage of wax from trimmed areas of moulds while pouring. The bands are provided properly, less pressure from band can causes wax leakage and too much pressure can cause rubber mould to deform, which will give defected wax pattern.

The investment casting wax has melting temperature of 65°C, but it is heated up to 80°C to flow easily through mould while pouring. At melting point the viscosity is more than wax at 80°C temperature, more viscosity causes uneven and partial mold fulfillment. The more heated wax minimizes viscosity, allow to flow wax throughout the mould and helps to remove all air from mould. After pouring the liquid wax it is required to allow solidify wax for some time, after that the rubber band is removed to open mould and get wax patterns.



(A)

(B)

Fig.-5: Images of poured wax model into silicone rubber mould of knee implant models, (A) Femoral implant, (B) Tibial implant.

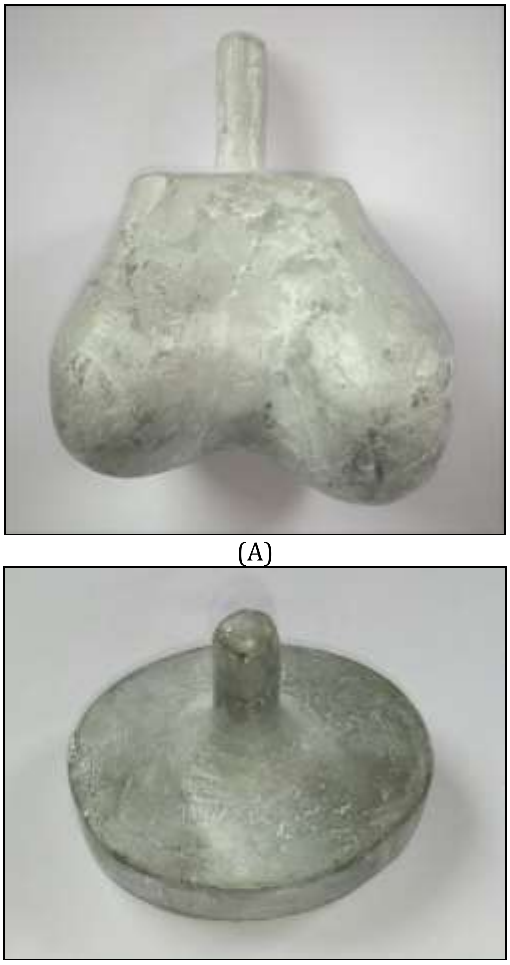
4.3 Making of Plaster-of-Paris Moulds

The wax patterns of implants models are used in making plaster of paris (POP) moulds for casting. The POP moulds are made separately for each implant wax pattern for easy handling and effective pouring. The pouring basin, runner and openings to remove gas are also created of same wax material and joined to the implant wax patterns by heat. The proper mixture of POP powder and water is poured surround the wax pattern and allow to get solidify.

After some time, the POP gets solidify and the wax burnout process is carried out by applying heat surrounding the mould. Due to the external heat the wax inside the mould get melted and comes out from openings, also the POP gets harder and all moisture get removed. The non-uniform or over heating can causes cracks in POP structure, therefore it is required to check mould for cracks and damages, also for wax remaining. The completely wax removed mould cavity can be cleaned by passing low pressure air from it remove dirt if any. Then these moulds are ready for pouring molten metal through it.

4.4 Melting and Pouring of Metal into Moulds

Generally, stainless steel alloy 316L, and Cobalt based alloys (Co-Cr-Mo alloys) are used for implant materials due to their higher modulus, higher corrosion resistance and excellent biocompatibility. But these biomaterials are difficult to cast because they having high melting temperatures, easily not available, expensive and requires special melting arrangements and techniques. Therefore, for study purpose, Aluminium is used for the making metallic implant because it is light weight, easily available, having low melting point and less cost.



(A)

(B)

Fig.-6: Images of metallic knee implants, (A) Femoral implant, (B) Tibial implant.

Aluminium has melting temperature of 660°C, which can be easily melted in small industrial or lab furnaces. For melting of Aluminium, LPG (Liquefied Petroleum Gas) gas fired furnace is used. A graphite crucible is used to melt metal in the closed furnace, which is gas fired with air speed adjusting blower. The flux additives and degassing agents are added in molten metal to remove slag and avoid bubble formation in molten metal. The molten metal is then poured in the POP moulds from crucible through pouring basin. Then the mould is allowed to cool to solidify molten metal. After that the mould is allowed to cool in the water this results in metal solidification and some POP desolation, which get easy to break POP mould. After breaking the POP mould the implant metal model with pouring basin, runners, vents are obtained.

The extra metal of pouring basin and other opening vents are cut from the implant model. The surface finish of casted Aluminium model is nearly good due to advantage of investment casting and fine POP powder. Then surface finishing processes are carried out on the casted model to obtain smooth surface [7]. Fig.-6 shows images of finished knee implants.

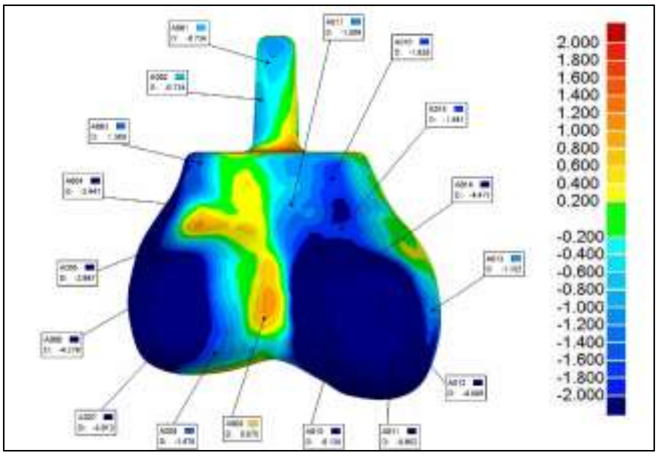
5. VALIDATION WITH 3D SCANNING

5.1 3D Scanning

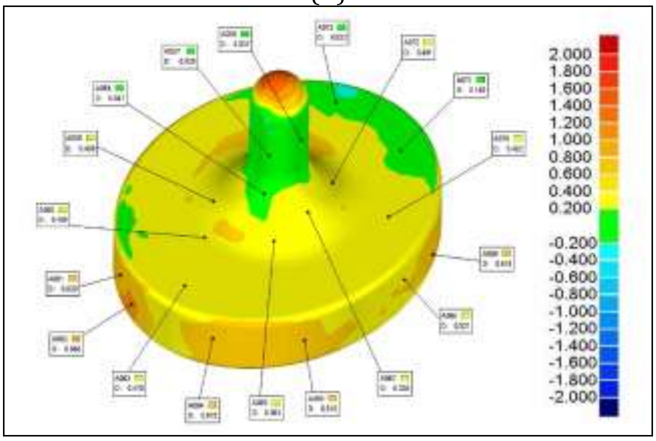
The casted and finished knee implants are inspected for the dimensions and sizes to study the process. The 3D scanning method of inspection is used to check size by comparing 3D scanned data of finished metal implants with the developed initial STL model of implants. Fig.-7 shows annotation view of compared knee models, the merging area or accurate area is shown by green zone and the blue zone indicates undersize where yellow zone indicates oversize.

5.2 Results and Discussion

The metal implant has deviation in size of -2.00mm to +1.40mm. The error in model is mainly occurs due to the rubber mould and poor casting parameters along with nonuniform manual finishing. Rubber moulds may be contracts or expands due to either non-proper holding rubber band pressure or the wax flowing pressure, this will give distorted or not accurate wax pattern which will produce errors in final casting. The use of suitable casting parameters and various allowances will reduce errors in casting process. Deviations can be occurred due to more material removal in the finishing process, more finishing process to remove casting errors produce under sizing of model whereas less finishing gives oversize. By using proper wax making process and accurate designing casting process with casting simulations, the metallic implants can be manufactured with minimum errors.



(A)



(B)

Fig.-7: 3D comparison annotation view of knee implant models, (A) Femoral implant, (B) Tibial implant.

6. CONCLUSIONS

The manufacturing of the medical implants with the help of rapid prototyping and investment casting is possible, the accuracy of manufactured model depends of reliability and accuracy of the manufacturing process. The 3D printing of model is very accurate but, accuracy metallic model depends on casting process. The use of rubber mould may produce distorted or inaccurate wax patterns due to its elasticity. The various casting allowances and other design parameters plays effective roll in producing accurate metallic component.

ACKNOWLEDGEMENT

I am grateful to to Smart Foundry Lab, DKTE Ichalkaranji for providing guidance and Aluminium ingot for casting.

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