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DEVELOPMENT OF CUSTOM KNEE IMPLANTS AND PROPERTY ANALYSIS

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ABSTRACT:

In last decade, cluster of research has been carried out in order to provide better medical treatment to human. Huge number of surgeries carried out in the world every day. In this era, medical surgery is carried out to replace or recur the damaged bone with artificial components i.e. Implant. The joint surface is recreated by replacement of knee with metal components. Authors have carried out the research to use rapid prototyping and investment casting route in medical implant. Knee implant has been selected for the present research work. Material selected is 316L Stainless Steel. To characterize the manufactured parts different tests are performed. To check the microstructure of the castings microstructure authors have used Metallurgical Microscope. Use of Rockwell Hardness Tester is implemented for testing the surface hardness. While roughness of the casting surface has checked by using surface finish tester in order to check the surface characteristics. The tensile strength of the implant material is checked on Universal Testing Machine. Authors have compared the results with present studies.

KEYWORDS: Knee implants, casting simulation, investment casting, and rapid -prototyping.

INTRODUCTION:

Currently over 8 lakhs knee joint operations are carried out per year. Current replacements are designed with respect to human anatomy. In general, each individual has a unique knee shape. So the objective should be to adapt the knee joint replacement to the original shape of the particular patient as much as possible. Data gained from CT or MRI (Magnetic Resonance Imaging) is utilised to produce a particular knee joint replacement [1].

RP requires that CAD files be provided in layers. Rapid Prototyping (RP) is the ability to generate three-dimensional models that need no machining or tooling. RP adds material film by film until the desired shape is achieved, instead of cutting the material with machine. Accuracy of RP is better than machine. 3D models generated by RP are more accurate and cheaper for development as that of complex in case of machines [2-3].

Nowadays, the productivity will be improved by implementation of computer applications and simulation tools [4]. Any complex machining operations will be done accurately by little tolerance to produce the complex shapes with the tolerance of 0.5% or less in investment casting.

The ceramic shell investment casting is an important technique for precision casting of various high melting point alloys. After wax injection, thermal contraction of wax shrinks in the dies during solidification and/or crystallization phenomena and subsequent cooling at the end of the settle time. The patterns are removed from dies even though they are only partially solid, and continue to shrink after their removal from the die as they cool down. The ceramic shell is then broken off the casting with a hammer. The parts are cut off the tree with an abrasive saw and any remaining mould material is removed by sandblasting. Production of the mould is time consuming, taking up to 72 hours depending upon the component, due to the need to use guarded moisture elimination. Production time and cost is affected by drying and strength development.

Thus investment casting has various advantages over other methods of manufacturing: components can be produced with net shape without resorting to machining operations. While the cost of the process itself is quite low, the cost of the tooling (dies) and the time taken to develop them is the main bottleneck [5].

CASTING SIMULATION:

Auto CAST-X is a software program developed for casting methods design, simulation and optimization developed by IIT Bombay. It uses geometric reasoning for automating the design of casting methods elements – cores, mould cavity layout, feeders, feed aids and gating channels. Simulation tools play a vital role in mould filling and casting solidification. Internal defects in casting will be removed by 3D models and better accuracy is achieved in manufacturing with small modification. Hence chances of defects will be less. The material selected for implants is 316L Stainless Steel. 3D CAD models of the three parts of knee implant were developed. For Optimum design for the CAD models AUTOCAST- X simulation software has been used. Both simulation of flow and solidification can be achieved on FLOW+ module of AUTOCAST-X software.

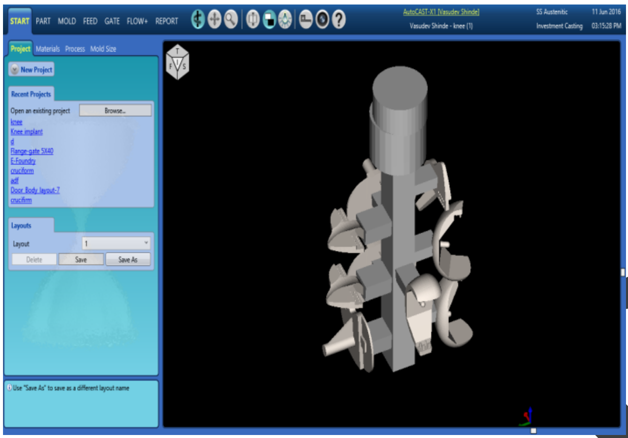

Fig- 1: Wax Pattern Tree

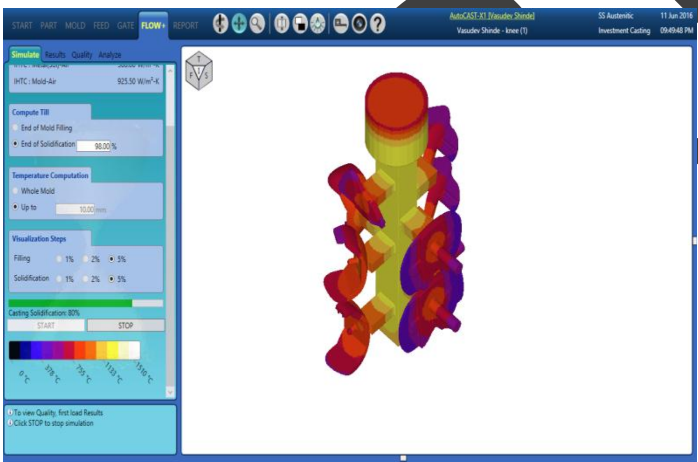

Fig-2: Solidification of castings

Nine patterns are connected to the sprue with the help of nine in gates to the common central feeder.

MANUFACTURING OF IMPLANTS:

As mentioned, in RP method three dimensional will be generated without machines. It allows more litheness than machining because the complexity of the model does not affects its production. RP generates helps in product design and development. RP is the method of create an object directly from its digital representation in CAD/CAM system [6].

Investment casting can be used for casting and less numbered production applications. ABS materials patterns for investment casting route requires less time and money on less numbered production applications as well as tooling required in investment casting. Rapid prototyping and Investment Casting route can be used to manufacture customized knee implants.

The total knee implant assembly has been divided into nine parts viz. Anterior Plate, Condoyle Lateral, Condoyle Medial, Lateral Plateau, Medical Plateau, Polyethylene Insert, Tibial Tray. Anterior Plate, Condoyle Lateral, and Tibial Tray are found to be the critical parts of the implant. Hence, these three parts are selected for present research work.STL files of Anterior Plate, Tibial Tray and Condoyle Lateral are shown in Figure 3.

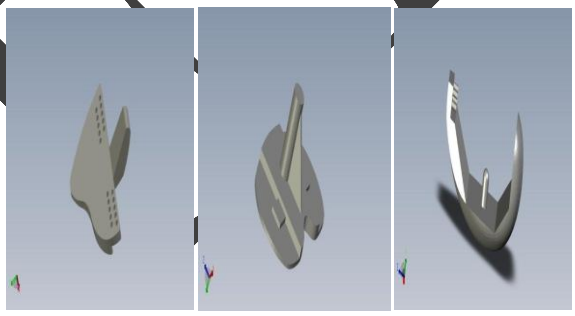

Fig-3: STL formats of Anterior Plate (left), Tibial Tray (centre), Condoyle Lateral (right)

The CAD model is sent to a Flash forge Dual Creator Pro Fused Deposition Modelling (FDM). This machine is used to fabricate Acryl butadiene stride (ABS) models of knee implants. A silicone rubber mould is prepared of the three knee implants are prepared by using the ABS parts. Various wax patterns are prepared by injecting wax in the silicone rubber mould.

Nine wax patterns were arranged and a tree containing three components was prepared. The primary coat of sand was applied to this wax tree and dried it for four hours and then another coat was applied which is followed by drying of mould. After two primary sand coats, remaining required coats of refractory sand (supportive coats) were given for providing sufficient strength to the tree. Moulds were placed for drying for four hours after each coating. Finally a seal coat was given to prepare shell mould. The wax was removed from shell mould by heating the tree upright down. The moulds were kept for pre-heating at a temperature of 1100^0C for minimum four hours. Then pre-heated mould was kept for pouring carefully. The liquid metal having

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1580^{0}C temperature was poured in pre-heated moulds. Gating system was removed and shot blasting was done after cooling the castings. Each casting was checked for quality, surface roughness and surface hardness.

The steps involved in the research work are shown in Figure no.

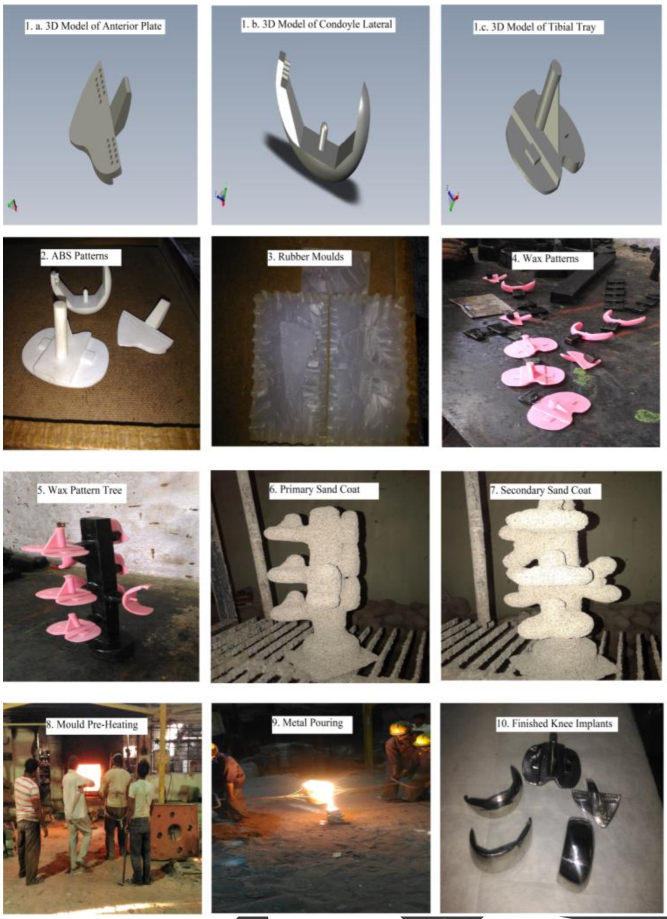

Fig-4: Steps in Research Work

RESULTS:

The final castings of the medical implants were tested for surface hardness and tensile strength of 316L Stainless Steel.

a. SURFACE HARDNESS RESULTS:

Surface hardness was measured on the "Yama Rockwell Hardness Tester". The results of Anterior Plate, Condoyle Lateral, Tibial Tray are mentioned in the tables below.

Table- 1: Hardness values for Anterior Plate

Component	Surface Hardness (HRB)			
	1	2	3	Average
1	72.0	75.0	75.0	74
2	73.5	71.0	71.0	71.8
3	74.0	74.0	78.0	75.3

Table -2: Hardness values for Condoyle Lateral

Component	Surface Hardness (HRB)			
	1	2	3	Average
1	86.0	84.5	85.0	85.1
2	84.5	85.0	85.0	84.8
3	86.0	84.5	84.0	84.8

Table-3: Hardness values for Tibial Tray

Component	Surface Hardness (HRB)			
	1	2	3	Average
1	72.0	75.0	75.0	74
2	73.5	71.0	71.0	71.8
3	72.5	73.0	72.0	72.5

b. TENSILE STRENGTH RESULTS:

The tensile strength of 316L Stainless Steel material was checked on The Universal Testing Machine. Results of tensile test conducted are mentioned in the Table.

Table- 4: Mechanical Properties of 316L Stainless Steel

Material	Ultimate Load (N)	Yield Load (N)	Sut (N/mm^2)	Syt (N/mm^2)	Elongation (%)	Max.Disp. (mm)	Reduction in Area (%)
316L SS	76.78	52.24	578.225	393.416	46	39.8	34.763

CONCLUSIONS:

1. Casting Simulation Software AUTOCAST-X provides the feasibility check of the castings. Simulation is tool to check the possible defects in the castings. The initial layout showed cold shut defect that was observed in the actual castings. The final layout shows casting after removing defects, which was used for manufacturing of the castings.
2. The surface hardness of medical knee implants was checked on Rockwell Surface hardness tester. The average value of surface hardness for Condoyle Lateral is 85.1 HRB. The average values of surface hardness for Tibial Tray and Anterior Plate were observed to be 74 HRB and 75.3 HRB.

3. The ultimate tensile strength value for 316L Stainless Steel was observed as 578.225 N/mm^2 and yield strength as 393.416 N/mm^2.
4. The customized knee implants can be successfully manufactured by Rapid prototyping and Investment Casting route. The properties of the medical knee implants are validated by available resources and were found to be within limits.

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