# Vacuum assisted casting of aluminum 6060 alloy using rapid prototyping pattern\*

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#### ABSTRACT

*Keywords:* Rapid Prototyping, RP pattern, Vacuum casting, AutoCAST X1 The manufacturing of parts in aerospace and medical industries is most critical where materials of the part plays important role. The material composition of part decides the performance of part during the operation. The casting process is the only manufacturing process where innovative parts having non-linear geometries can be manufactured using rapid prototyping (RP) pattern. The CAD part can be directly converted into pattern (physical part) without human intervention and tooling using rapid prototyping and the design engineer is free from constraint from manufacturing. In this paper, the manufacturing of orthopedic implant using casting process is discussed where pattern is fabricated using rapid prototyping. Use of simulation software in casting viz. AutoCAST makes the otherwise complex process of casting much simpler and efficient. The medical implants are manufactured using the biocompatible metals like SS 316L, Co- Cr alloy. The Titanium is most preferred metals in medical implants as it is more biocompatible than SS 316 L and Co- Cr Alloy. The stress shielding effect is also not observed in Titanium made implant because of low modulus of elasticity compared to SS 316L and Co-Cr alloy. One of the major issues in the casting of medical implant is oxidation of metal during melting and pouring. The vacuum assisted casting is the only solution while using casting as the process of manufacturing for medical implant. The authors of the paper carried out the casting of part using vacuum for aluminum alloy 6060. The work will be further extended to biocompatible metals. The in-house induction furnace, having capacity of 5 kg is modified for meting and pouring unit in vacuum. The 500 LPM double stage direct drive rotary high vacuum pump is used for creating vacuum. The bottom pouring arrangement is used for pouring the molten metal in mould. The trial is successfully carried out for casting the part with and without vacuum. The result of as cast part using vacuum is very much promising compared to as cast part without vacuum. The biocompatible materials will be used for casting with vacuum which will help in designing the patient specific medical implants.

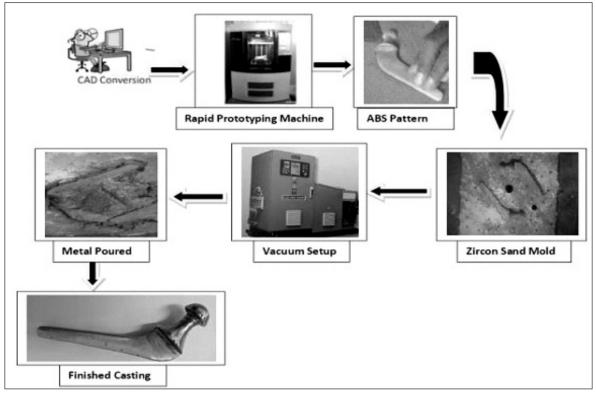
#### 1. Introduction

The manufacturing of the part like orthopedic medical implant and part used in aircraft is not generally considered by the foundries in India as it involves high precision and quality. The resources required for manufacturing the said product are more and competition from imported part is very stiff. As the orthopedic medical implant are fitted in the patient body and being the Class III medical device, the part is required to pass stringent quality standards. The major lacuna in Indian

\*Corresponding author, E-mail: amkme2002@yahoo.com (Dr. A. M. Kuthe) foundries is absence of knowledge of casting simulation and inability to use new technique like Rapid prototyping. The imported medical implant is expensive and not affordable to common man in India. The unwillingness of Indian foundry to enter in this domain, push the prices of imported medical implant on higher scale. The government is interfering in the price matter.

But the immediate step to upgrade Indian foundries for manufacturing such high quality products is required.

The simulation of casting process using software like AutoCAST and use of Rapid prototyping in the process of manufacturing is the need of an hour.



**Fig. 1.** A generalized standard methodology for the development of customized product (medical implant) using vacuum and sand casting method.

The simulation software decides the parameter to be set during the casting process so that the as cast product is defect free. The RP process can be used for getting the physical part viz. pattern or die from Computer Aided Design (CAD) model without human interference and tooling. Generalized standard workflow of process for the development of customized product (medical implant) with the low-cost vacuum facility is illustrated in Fig 1.

# 2. Methodology

# 2.1. Fabrication of pattern using RP

The pattern building using RP is now wellestablished method but many foundries in India are not willing to work in this field because of absence of manpower with knowledge of 3D modeling software in foundry and unwillingness to recruit such people. The medical implant is intricate product with many non-linear features in its geometry. The part can be easily drafted on computer using 3D modeling software and same can be converted into physical part i.e. pattern, using RP process [1]. The conventional pattern making process is unable to cope the challenge of handling the customization of part and also non-linear geometrical features of the part. The pattern thus obtained using RP process can be used to prepare the mould and then follows the molten metal pouring in the mould. The parameters for fabrication of mould and molten metal pouring can be set as per simulation software. The input for the simulation software is the 3D modeling of the part in STL format. The as-cast part is defect free as the complete process of casting is controlled by the simulation software.

# 2.2. Vacuum casting

Vacuum casting is a casting process for elastomers using a vacuum to draw the liquid material into the mold. This process is used when air in casting is a problem. Presently this process is very expensive. It is highly versatile technology capable of producing part for medical grade implant. The proposed setup in this paper for the casting of aluminium under vacuum was designed and developed in-house. Induction furnace is used for melting of aluminium and moltan metal directly poured with the help of bottom pouring crucible mechanism into mold. The pattern used for mold making is made on rapid prototype machine having material acrylonitrile butadiene styrene (ABS). A promising new technique for direct melting and pouring of aluminium alloy for medical implants emerged from this study. This research demonstrated the feasibility of direct melting

#### Technical Paper

and casting of the aluminium alloy 6060 vacuum technology. [5]

#### 3. Experimentation

# 3.1. The experimental set up for RP assisted pattern making

The CAD model of the implant with the allowance is prepared in 3D modeling software and STL file is sent as input to RP machine to get the pattern. Refer Fig. 1 and Fig 2. The customization of implants (i.e. consideration of neck shaft angle, vertical offset, horizontal offset as per patient anatomy) is possible by RP assisted pattern making [2].

From the CAD model of implant with added allowances STL file is generated which is shown in Fig 3.



Fig. 2. CAD model of implant.



Fig. 3. STL model of implants.

Allowances added: 2.5% of the length or volume to be added.

Shaft length before adding allowance: 137.5mm Shaft length after adding allowance: 140.98mm

Length of small cylinder before adding allowance: 17 mm

Length of small cylinder after adding allowance: 17.35 mm

Length of large cylinder before adding allowance: 15 mm

Length of large cylinder after adding allowance: 15.3 mm

Additional machining allowance of 1-1.5mm is added to the surface and other miscellaneous allowances are dimensionally insignificant.

The Auto CAST software is used to get the mould layout and gating design analysis (Refer Fig 4). The data generated using AutoCAST is shown in table 1.

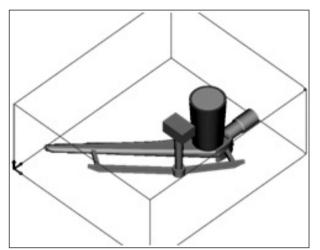


Fig. 4. Model layout, gating and riser designed from AutoCAST.

#### Table 1

Table 1											
Data generated from AutoCAST.											
Layout Implant Date & 02 Oct											
Name	Final	Time	17, 2.39								
			PM								
Cast Metal	Cast Steel-St	Casting	Sand								
	Low C	process	Casting								
Density	7672kg/m^3	Liquids	1493 C								
Order	1000	Yield	43.31%								
quantity	quantity										
PART											
Dimensions	102.21X138.	Part	69.63								
	31X14 (in	Surface	cm^2								
	mm)	Area									
Min.	1.38mm	Max.	11.97								
Thickness		Thickness	mm								
Part Weight	141.73g	Part	18 cm^3								
-	-	Volume									
Mold	Mold Ceramic Density										
material	Sand	-	kg/m^3								
Dimensions	170mm×200	Parting	Horizon								
	mm×140	Orientatio	tal								
	mm n										
Cavities	х	Draw	7 mm								
		Distance									
Min. Cav.	63 mm	Metal/San	5.52%								
Wall gap		d weight									
Min Cav.	NA	Metal/San	1.09%								
Cav. gap		d volume									
	FEEDER	RS									
Total Feeder	201.47g	Feeding	42.59%								
Weight	2	Yield									
FEEDER-1											
Orientation	Top	Cylindri									
	•	Shape	cal								
Weight	201.47g	Volume	25.59								
-	2		cm^3								

Diameter Top     25 mm     Diameter Bottom     18 mm       Height     61.74 mm     Number of Necks     1       NECK-1				
Height   61.74 mm   Number of Necks   1     NECK-1   NECK-1     Shape   Cylindrical   Length   4 mm     Diameter at Part   12 mm   Diameter   12 mm     GATING (OVERALL)   Filling   NA     Pouring   1640 °C   Mold   NA     Temp.   Filling   Time   Time     Total Metal   70 mm   Avg. Fill   0 mg/s     Kate   Gating   93.98 g   Gating   61.4 %     System Wt   Yield   Yield   10 mg/s   NA     Total Metal   70 mm   Avg. Fill   0 mg/s   NA     System Wt   SPRUE   20X20   Basin   X10 (in     Diameter   SPRUE   Basin   X10 (in   mm)     no   Server PARAMETERS   Shape   Cylindrical   Height   70 mm     Top   10 mm   Bottom   6 mm   mm^2   mm^2     Shape   Cylindrical   Height   6.99   mm^2     Mameter   10 mm   Bottom   6 mm   16.57, <td< td=""><td></td><td>25 mm</td><td></td><td>18 mm</td></td<>		25 mm		18 mm
NECK-1       Shape     Cylindrical     Length     4 mm       Diameter at Part     12 mm     Diameter at feeder     12 mm       GATING (OVERALL)     Pouring     1640 °C     Mold     NA       Temp.     Filling     Time     Time       Total Metal     70 mm     Avg. Fill     0 mg/s       Head     Rate     Rate     Gating     93.98 g     Gating     61.4 %       System Wt.     Yield     Yield     Total Poured     402.93 g     Wt.     SPRUE       Pouring     Rectangular     Pouring     20X20     Basin     Shape     X10 (in       Diameter     Diameter     Diameter     mm)     ns     SPRUE PARAMETERS     Shape     Cylindrical     Height     70 mm       Top     10 mm     Bottom     6 mm     mm     mm     GATES       No. of Gates     3     Total Gate     719.73     mm^2       GATES     No. of     2     Total Gate     719.73       Weight     Volume     Mea		61.74 mm	Number	1
Shape   Cylindrical   Length   4 mm     Diameter at Part   12 mm   Diameter at feeder   12 mm     GATING (OVERALL)   Pouring   1640 °C   Mold   NA     Temp.   Filling   Time   Time     Total Metal   70 mm   Avg. Fill   0 mg/s     Head   Rate   Gating   61.4 %     System Wt   SPRUE   Spread   120.20     Basin   Sating   Spread   20.20     Basin Shape   Rectangular   Pouring   20.20     Basin Shape   Rectangular   Pouring   20.20     Basin Shape   Cylindrical   Height   70 mm     Top   10 mm   Bottom   6 mm     Diameter   Diameter   mm <sup>*/2</sup> 70 mm     GATES   Shape   Cylindrical   Height   6.99     mm   GATES   Mea   Area   mm <sup>*/2</sup> Total Gating   5.67   Total Gate   48   16.57, 25.98 & 15.95 (in     mm)   mm)   mm)   mm)   mm)   mm)     Height		100		
Diameter at Part 12 mm at feeder   GATING (OVERALL)   Pouring Temp. 1640 %C   Mold Temp. Mold Filling Time   Total Metal 70 mm   Avg. Fill 0 mg/s   Head Rate   Gating 93.98 g   System Wt. Yield   Total Metal 70 mm   Avg. Fill 0 mg/s   Kate Gating   Gating 93.98 g   System Wt. Yield   Total Poured 402.93 g   Wt. SPRUE   Pouring Rectangular   Pouring Rectangular   Basin X10 (in   Diameter Diameter   Shape Cylindrical   Height 70 mm   Top 10 mm   Basin 6 mm   Diameter Diameter   SPRUE WELL Diameter   Diameter 10 mm   GATES No. of Gates   No. of Gates 3   Total Gating 5.67   Total Gating 5.67   Total Gating 5.67   Total Gate 719.73   Weight Volume   Munnn) nunn)   Height </td <td></td> <td></td> <td></td> <td></td>				
Part at feeder   GATING (OVERALL)   Pouring 1640 %C Mold NA   Temp. Filling Time   Total Metal 70 mm Avg. Fill 0 mg/s   Head Rate 61.4 %   Gating 93.98 g Gating 61.4 %   System Wt. Yield Yield   Total Poured 402.93 g Wt.   Wt. SPRUE Pouring Rectangular   Pouring Rectangular Pouring 20X20   Basin Shape Basin X10 (in   Dimensio mm) ns   SPRUE PARAMETERS Shape Cylindrical   Shape Cylindrical Height 70 mm   Top 10 mm Bottom 6 mm   Diameter I0 mm Height 6.99   mm GATES mm^2   No. of Gates 3 Total Gate 48   Area mm^2 25.98 &   15.95 (in mm) mm^3   PARAMETERS FOR GATES 1,2 &3 Shape Rectangular   Iteight 4,4 &4 (in Width 4,4 &4 (in   mm) mm) mm) 16.57, 25.98 &	Shape	Cylindrical	Length	4 mm
GATING (OVERALL)     Pouring   1640 °C   Mold   NA     Temp.   Filling   Time     Total Metal   70 mm   Avg. Fill   0 mg/s     Head   70 mm   Avg. Fill   0 mg/s     Gating   93.98 g   Gating   61.4 %     System Wt.   Yield   Yield     Total Poured   402.93 g   Wt.   20X20     Basin Shape   Rectangular   Pouring   Basin   X10 ( in     Dimensio   mm)   ns   SPRUE   PRUE PARAMETERS     Shape   Cylindrical   Height   70 mm     Top   10 mm   Bottom   6 mm     Diameter   Diameter   10 mm   6.99 mm     Mm   GATES   Mo. of Gates   3   Total Gate   48 Area     GATES   No. of Gates   3   Total Gate   719.73   Weight   Volume   mm^3     PARAMETERS FOR GATES 1,2 &3     Shape   Rectangular   Length   16.57, 25.98 & 15.95 (in mm)     mm)   RUNNERS   Mo. of   2   Total </td <td></td> <td>12 mm</td> <td></td> <td>12 mm</td>		12 mm		12 mm
Temp.   Filling Time     Total Metal   70 mm   Avg. Fill   0 mg/s     Rate   Gating   93.98 g   Gating   61.4 %     Gating   93.98 g   Gating   61.4 %     Yield   Yield   Yield     Total Poured   402.93 g   Wt.     Basin Shape   Basin   X10 (in Dimensio mm)     Basin Shape   Cylindrical   Height   70 mm     Top   10 mm   Bottom   6 mm     Diameter   Diameter   SPRUE PARAMETERS     Shape   Cylindrical   Height   70 mm     Top   10 mm   Bottom   6 mm     Diameter   Diameter   Diameter   9 mm     GATES   No. of Gates   3   Total Gate   719.73     Weight   Volume   mm^3   PARAMETERS FOR GATES 1,2 &3   Shape   Rectangular   Length   16.57, 25.98 & 15.95 (in mm)     mm)   RUNNERS   No. of   2   Total   48 mm^2   Runner     No. of   2   Total   48 mm^2   25.98 & 15.95 (in mm)   1.29 cm^3		GATING (OV		
Temp.   Filling Time     Total Metal   70 mm   Avg. Fill   0 mg/s     Rate   Gating   93.98 g   Gating   61.4 %     Gating   93.98 g   Gating   61.4 %     Yield   Yield   Yield     Total Poured   402.93 g   Wt.     Basin Shape   Basin   X10 (in Dimensio mm)     Basin Shape   Cylindrical   Height   70 mm     Top   10 mm   Bottom   6 mm     Diameter   Diameter   SPRUE PARAMETERS     Shape   Cylindrical   Height   70 mm     Top   10 mm   Bottom   6 mm     Diameter   Diameter   Diameter   9 mm     GATES   No. of Gates   3   Total Gate   719.73     Weight   Volume   mm^3   PARAMETERS FOR GATES 1,2 &3   Shape   Rectangular   Length   16.57, 25.98 & 15.95 (in mm)     mm)   RUNNERS   No. of   2   Total   48 mm^2   Runner     No. of   2   Total   48 mm^2   25.98 & 15.95 (in mm)   1.29 cm^3	Pouring	1640 °C	Mold	NA
Time     Total Metal   70 mm   Avg. Fill   0 mg/s     Rate   Gating   93.98 g   Gating   61.4 %     System Wt.   Yield   Yield   10.4 %     Total Poured   402.93 g   Wt.   SPRUE     Pouring   Rectangular   Pouring   20X20     Basin Shape   Basin   X10 (in   Dimesion     Diameter   Diameter   SPRUE PARAMETERS   Shape   Cylindrical     Shape   Cylindrical   Height   70 mm     Top   10 mm   Bottom   6 mm     Diameter   SPRUE WEIL   Diameter   mm     GATES   No. of Gates   3   Total Gate   48     Area   mm^2   Total Gating   5.67   Total Gate   719.73     Weight   Volume   mm^3   PARAMETERS FOR GATES 1,2 &3   Shape   Rectangular   Length   16.57, 25.98 & 15.95 (in mm)     mm)   RUNNERS   No. of   2   Total   48 mm^2   Runner     Area   mm)   mm)   mm)   16.57, 25.98 & 15.95 (in mm)   15.95 (		1010 0		
Total Metal Head   70 mm   Avg. Fill Rate   0 mg/s     Gating System Wt.   93.98 g   Gating Gating   61.4 %     Total Poured Wt.   402.93 g   1.4 %     Pouring Basin Shape   Rectangular Basin   Pouring Basin   20X20     Basin Dimensio   Basin Dimensio   X10 (in Dimensio   0.0 mm)     SPRUE   PARAMETERS   Shape   Cylindrical   Height   70 mm     Top   10 mm   Bottom   6 mm   0.0 mm   0.0 mm     Diameter   Diameter   Diameter   0.0 mm   6.99 mm     GATES   No. of Gates   3   Total Gate   48 Area   Area   mm^22     Total Gating   5.67   Total Gate   719.73   Weight   Volume   mm^33     PARAMETERS FOR GATES 1,2 & 3   Shape   Rectangular   Length   16.57, 25.98 & 15.95 (in mm)     mm)   mm)   mm)   mm   mm^2     Runners   Runner   Area   10.16 g   Total   1.29 cm'3     No. of   2   Total   1.29 cm'3   Runner   Area   10.16 g   55.55(in mm	remp.			
Head   Rate     Gating   93.98 g   Gating   61.4 %     System Wt.   Yield   Yield     Total Poured   402.93 g   Wt.     SPRUE   Basin   X10 (in     Dimensio   Dimensio   mm)     rs   SPRUE PARAMETERS     Shape   Cylindrical   Height   70 mm     Top   10 mm   Bottom   6 mm     Diameter   Diameter   SPRUE VELL   0 mm     Diameter   10 mm   Height   6.99     mm   GATES   mm^2   10 mm     GATES   No. of Gates   3   Total Gate   48     Area   mm^2   19.73   Weight   Volume   mm^3     PARAMETERS FOR GATES 1,2 &3   Shape   Rectangular   Length   16.57, 25.98 & 15.95 (in     mm)   mm)   mm)   mm)   mm/2     Volume   Area   Area   15.95 (in     mm)   mm)   mm)   mm/2   25.98 & 15.95 (in     Munner   Area   Area   10.16 g   Total   1.	Tetal Metal	70		0 /
Gating System Wt.   93.98 g Yield   Gating Yield   61.4 % Yield     Total Poured Wt.   402.93 g Wt.   SPRUE     Pouring Basin Shape   Rectangular Basin Sim   Pouring Basin X10 (in Dimensio   20X20 Basin Min     Shape   Cylindrical Cylindrical   Pouring Basin Min   20X20 Basin Min     Top   10 mm   Basin Min   X10 (in Dimensio     Top   10 mm   Bottom   6 mm     Diameter   Diameter   Min   6.99 mm     GATES   Mo. of Gates   3   Total Gate   48 Area     Mo. of Gates   3   Total Gate   719.73 Weight   Yolume   mm^2     PARAMETERS FOR GATES 1,2 & 3   Shape   Rectangular   Length   16.57, 25.98 & 15.95 (in mm)     Height   4, 4 & 4 (in   Width   4, 4 & 4 (in mm)   Min     Runners   Runner   Area   Area     Total   10. 16 g   Total   1.29 cm^3 Runner     Runner   Area   Area   Area     Total   10. 16 g   Total   1.29 cm^3 Runner     Runner   Runner   Area   S5.55(in mm) <td></td> <td>70 mm</td> <td></td> <td>0 mg/s</td>		70 mm		0 mg/s
System Wt.   Yield     Total Poured   402.93 g     Wt.   SPRUE     Pouring   Rectangular   Pouring   20X20     Basin Shape   Basin   X10 (in   Dimensio   mm))     Basin Shape   SPRUE PARAMETERS   Shape   Cylindrical   Height   70 mm     Top   10 mm   Bottom   6 mm   Diameter   0   mm     Diameter   10 mm   Bottom   6 mm   mm   mm     GATES   No. of Gates   3   Total Gate   48     Area   mm^2   Total Gate   719.73     Weight   Volume   mm^3   PARAMETERS FOR GATES 1,2 &3     Shape   Rectangular   Length   16.57, 25.98 & 15.95 (in mm)     mm)   mm)   mm)   mm)   mm     Runners   Runner   Area   15.95 (in mm)     mm)   mm   Area   15.95 (in mm)     mm)   mm   mm   mm^2     Runners   Runner   Area     Total   10.16 g   Total   1.29 cm^3 <tr< td=""><td></td><td>03.08 m</td><td></td><td>61.4.%</td></tr<>		03.08 m		61.4.%
Wt.   SPRUE     Pouring Basin Shape   Rectangular Basin   Pouring Basin   20X20 Million     Basin   X10 (in Dimensio   mm)     ns   SPRUE PARAMETERS     Shape   Cylindrical   Height   70 mm     Top   10 mm   Bottom   6 mm     Diameter   Diameter   0   0     Mo. of Gates   3   Total Gate   48     Area   mm^22   Total Gating   5.67   Total Gate   719.73     Weight   Volume   mm^3   PARAMETERS FOR GATES 1,2 &3   Shape   Rectangular   Length   16.57, 25.98 & 15.95 (in mm)     Munners   RUNNERS   num)   mm)   mm)   mm     Runners   Runner   Area   10.16 g   Total   1.29 cm/3     Runners   Runner   Runner   Meight   Volume   M/2     No. of   2   Total   48 mm^22   1.29 cm/3     Runners   Runner   Munner   Area   1.29 cm/3     No. of   2   Total   1.29 cm/3   Sunne/2     Runner	System Wt.	-		01.4 /0
SPRUE   Pouring Basin Shape Rectangular Rectangular Pouring Basin 20X20 X10 (in Dimensio   Basin X10 (in Dimensio Basin X10 (in mm)   Image: SPRUE PARAMETERS SPRUE PARAMETERS   Shape Cylindrical Height 70 mm   Top 10 mm Bottom 6 mm   Diameter Diameter Diameter   SPRUE WELL Diameter 10 mm Height 6.99 mm   GATES No. of Gates 3 Total Gate 48 Area   Meight Volume mm^22   Total Gating 5.67 Total Gate 719.73   Weight Volume mm^3 PARAMETERS FOR GATES 1,2 &3   Shape Rectangular Length 16.57, 25.98 & 15.95 (in mm)   Minima Minima mm) mm) mm)   Height 4, 4 &4 (in Width 4, 4 &4 (in mm)   No. of 2 Total 48 mm'2   Runners Runner Area   Total 10.16 g Total 1.29 cm'3   Runner Runner Runner   Weight Volume PARAMETERS FOR RUNNERS 1&2   Shape Rectangular Length 37.58 & 55.55(in mm)		402.93 g		
Pouring Basin Shape Rectangular No. Pouring Basin 20X20 X10 (in mm)   Shape SPRUE PARAMETERS   Shape Cylindrical Height 70 mm   Top 10 mm Bottom 6 mm   Diameter Diameter 0 0   SPRUE VELL Diameter 0 0   Diameter 10 mm Height 6.99   Mmm GATES 0 0   No. of Gates 3 Total Gate 48   Area mm^22 0 0   Total Gating 5.67 Total Gate 719.73   Weight Volume mm^3 0 0   PARAMETERS FOR GATES 1,2 & 3 0 0 0   Shape Rectangular Length 16.57, 25.98 & 15.95 (in mm)   Minima mm) mm) mm) 0   RUNNERS No. of 2 Total 48 mm'2   Runners Runner Area 10.16 g Total   Total 10.16 g Total 1.29 cm'3   Runner Runner Runner S5.55(in mm)   Minner Runner S5.55(in mm)   Minner Minner 55.55(in mm)		SPRU	Ē	
Basin Shape   Basin Dimensio mm)   X10 (in Dimensio mm)     ns     SPRUE PARAMETERS     Shape   Cylindrical   Height 70 mm     Top   10 mm   Bottom   6 mm     Diameter   Diameter   6 mm     Diameter   Diameter   0 mm     GATES   No. of Gates   3   Total Gate   48     Area   mm^2   10 mm   Area   mm^2     Total Gating   5.67   Total Gate   719.73   Weight   Volume   mm^3     PARAMETERS FOR GATES 1,2 &3   Shape   Rectangular   Length   16.57, 25.98 & 15.95 (in mm)     mm)   mm)   mm)   mm)   mm)     Height   4, 4 &4 (in Width   4, 4 &4 (in mm)     Mo. of   2   Total   48 mm'2     Runners   Runner   Area     Total   10. 16 g   Total   1.29 cm'3     Runner   Runner   Area   55.55(in mm)     PARAMETERS FOR RUNNERS   1&2   Shape   Shape   55.55(in mm)     Muner   PARAMETERS FOR RUNNERS	Denning			20220
Dimensio mm )   ns   SPRUE PARAMETERS   Shape Cylindrical Height 70 mm   Top 10 mm Bottom 6 mm   Diameter Diameter   SPRUE WELL   Diameter 10 mm Height 6.99   mm   GATES   No. of Gates 3 Total Gate 48   Area mm^22   Total Gating 5.67 Total Gate 719.73   Weight Volume mm^3 PARAMETERS FOR GATES 1,2 &3   Shape Rectangular Length 16.57, 25.98 & 15.95 (in mm)   Height 4, 4 &4 (in Width 4, 4 &4 (in mm)   MUNNERS   No. of 2 Total 48 mm'2   Runners Runner Area   Total 10.16 g Total 1.29 cm'3   Runner Runner Area   Total 10.16 g Total 1.29 cm'3   Runner Runner S5.55(in mm)   Mun)   Height 4 & 4 (in mi)		Rectangular		
Ins   SPRUE PARAMETERS   Shape Cylindrical Height 70 mm   Top 10 mm Bottom 6 mm   Diameter Diameter   SPRUE WELL   Diameter 10 mm Height 6.99   mm   GATES   No. of Gates 3 Total Gate 48   Area mm^22   Total Gating 5.67 Total Gate 719.73   Weight Volume mm^3 PARAMETERS FOR GATES 1,2 &3   Shape Rectangular Length 16.57, 25.98 & 15.95 (in   mm)   Height 4, 4 &4 (in Width 4, 4 &4 (in   mm)   Height 4, 4 &4 (in   Minor   Minor   Minor   Diameter   No. of Colspan="2">Colspan="2">Colspan="2">Cotal   No. of 2 Total   RUNNERS   No. of 2 Total 48 mm'2   Runner Area Area   Total 10.16 g Total 1.29 cm'3   Runner Runner	Dasin Snape			
SPRUE PARAMETERS     Shape   Cylindrical   Height   70 mm     Top   10 mm   Bottom   6 mm     Diameter   Diameter   Diameter     SPRUE WELL   Diameter   0.0   6 mm     GATES   Mo. of Gates   3   Total Gate   48     Area   mm^22   Total Gating   5.67   Total Gate   719.73     Weight   Volume   mm^3   PARAMETERS FOR GATES 1,2 &3   Shape   Rectangular   Length   16.57, 25.98 & 15.95 (in mm)     Mo. of   2   Total   4.4 &4 (in mm)   mm)   mm     Height   4, 4 &4 (in Midth   4, 4 &4 (in mm)   Mo. of   2   Total   48 mm^2     No. of   2   Total   48 mm^2   Runner   Area     Total   10.16 g   Total   1.29 cm^3   Runner     Weight   Volume   37.58 & 55.55(in mm)     Height   4 &4 (in   4 &4 (in Midth   4 &4 (in Midth			Dimensio	mm)
Shape   Cylindrical   Height   70 mm     Top   10 mm   Bottom   6 mm     Diameter   Diameter   0     SPRUE WELL     Diameter   10 mm   Height   6.99     mm     GATES     No. of Gates   3   Total Gate   48     Area   mm^22     Total Gating   5.67   Total Gate   719.73     Weight   Volume   mm^3   PARAMETERS FOR GATES 1,2 &3     Shape   Rectangular   Length   16.57, 25.98 & 15.95 (in mm)     Mo. of   2   Total   48 mm^2     Runner   Runner   Area   15.95 (in mm)     Mo. of   2   Total   48 mm^2     Runners   Runner   Area   129 cm^3     Runners   Runner   Area   1.29 cm^3     Runner   Runner   S5.55(in mm)   55.55(in mm)     Height   4 & 4 (in   Width   4 & 4 (in mm)		CODIT: DADA		
Top 10 mm Bottom 6 mm   Diameter Diameter Diameter   SPRUE WELL Diameter 10 mm Height 6.99 mm   GATES mm GATES   No. of Gates 3 Total Gate 48 Area   Area mm^22 Total Gating 5.67 Total Gate 719.73   Weight Volume mm^3 PARAMETERS FOR GATES 1,2 &3 Shape Rectangular Length 16.57, 25.98 & 15.95 (in mm)   Height 4, 4 &4 (in Width 4, 4 &4 (in mm) mm) mm)   Height 4, 4 &4 (in Width 4, 4 &4 (in mm)   No. of 2 Total 48 mm^2   Runners Runner Area   Total 10.16 g Total 1.29 cm^3   Runner Runner Runner Volume   PARAMETERS FOR RUNNERS 1&2 Shape Shape \$5.55(in mm)   Height 4 & 4 (in Width 4 & 4 (in mm)				
Diameter     SPRUE WELL       Diameter     10 mm     Height     6.99 mm       GATES     GATES     mm^22       No. of Gates     3     Total Gate     48 Area       Area     mm^22     Total Gating     5.67     Total Gate     719.73       Weight     Volume     mm^3     PARAMETERS FOR GATES 1,2 &3     Shape     Rectangular     Length     16.57, 25.98 & 15.95 (in mm)       Shape     Rectangular     Length     16.57, 25.98 & 15.95 (in mm)     mm)       Height     4, 4 &4 (in     Width     4, 4 &4 (in mm)     mm)       RUNNERS     No. of     2     Total     48 mm^2       No. of     2     Total     48 mm^2       Runners     Runner     Area       Total     10.16 g     Total     1.29 cm^3       Runner     Runner     State     55.55(in mm)       PARAMETERS FOR RUNNERS 1&2     Shape     State     55.55(in mm)       Minimit     4 & 4 (in     Midth     4 & 4 (in mm)	-			
SPRUE WELL       Diameter     10 mm     Height     6.99 mm       GATES       No. of Gates     3     Total Gate     48 Area     mm^22       Total Gating     5.67     Total Gate     719.73     Weight     Volume     mm^3       PARAMETERS FOR GATES     1,2 &3     Shape     Rectangular     Length     16.57, 25.98 & 15.95 (in mm)       Runner     Mo. of     2     Total     4, 4 &4 (in mm)     mm)       Height     4, 4 &4 (in Midth     4, 4 &4 (in mm)     mm)     mm       RUNNERS       No. of     2     Total     48 mm^2       Runners     Runner     Area       Total     10.16 g     Total     1.29 cm^3       Runner     Runner     St.55(in mm)     mm)       Height     4 & 4 (in Midth     4 & 4 (in Midth     4 & 4 (in mm)		10 mm		6 mm
Diameter     10 mm     Height     6.99 mm       GATES       No. of Gates     3     Total Gate     48 Area       Area     mm^22       Total Gating     5.67     Total Gate     719.73       Weight     Volume     mm^3       PARAMETERS FOR GATES 1,2 &3     Shape     Rectangular     Length     16.57, 25.98 & 15.95 (in       Shape     Rectangular     Length     16.57, 25.98 & 15.95 (in     15.95 (in       mm)     mm)     mm)     mm)     mm)       Height     4, 4 &4 (in     Width     4, 4 & 4 (in       Mo. of     2     Total     48 mm^2       Runners     Runner     Area       Total     10.16 g     Total     1.29 cm^3       Runner     Runner     Stape     55.55(in       PARAMETERS FOR RUNNERS 1&2     Shape     Stape     55.55(in       mm)     Height     4 & 4 (in     4 & 4 (in     4 & 4 (in	Diameter			
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mm)       Height     4, 4 & 4 (in     Width     4, 4 & 4 (in       mm)     mm)     mm)       RUNNERS     No. of     2     Total     48 mm^2       No. of     2     Total     48 mm^2       Runners     Runner     Area       Total     10. 16 g     Total     1.29 cm^3       Runner     Runner     Runner       Weight     Volume     PARAMETERS FOR RUNNERS 1&2       Shape     Rectangular     Length     37.58 & 55.55(in       mm)     Height     4 & 4 (in     Width     4 & 4 (in				
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Area       Total     10. 16 g     Total     1.29 cm^3       Runner     Runner     Weight     Volume       PARAMETERS FOR RUNNERS 1&2     Shape     Rectangular     Length     37.58 & 55.55(in mm)       Height     4 & 4 (in     Width     4 & 4 (in     Midth     4 & 4 (in		-		
Total     10. 16 g     Total     1.29 cm^3       Runner     Runner     Weight     Volume       PARAMETERS FOR RUNNERS 1&2     Shape     Rectangular     Length     37.58 & 55.55(in mm)       Height     4 & 4 (in     Width     4 & 4 (in				
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Weight     Volume       PARAMETERS FOR RUNNERS 1&2       Shape     Rectangular     Length     37.58 & 55.55(in mm)       Height     4 & 4 (in     Width     4 & 4 (in				
PARAMETERS FOR RUNNERS 1&2       Shape     Rectangular     Length     37.58 & 55.55(in 55.55(in mm))       Height     4 & 4 (in     Width     4 & 4 (in 55.55(in mm))				
Shape     Rectangular     Length     37.58 & 55.55(in 55.55(in mm)       Height     4 & 4 (in     Width     4 & 4 (in		METERS FOR		&2
55.55(in mm) Height 4 & 4 (in Width 4 & 4 (in				
Height 4 & 4 (in Width 4 & 4 (in				55.55(in
	Height		Width	
		mm)		mm)



Fig. 5. RP Pattern fabricated on 3D printing machine.

The RP pattern Fig 5 is fabricated on 3D printing machine using STL file develop from CAD model is shown in Fig 5.

# 3.2. The experimental set up for vacuum assisted casting

#### 3.2.1. Vacuum chamber design

Fig 6 show a conceptual CAD model of the setup designed and fabricated for pouring the molten metal. The vacuum chamber is suitable for ferrous and non- ferrous metal. The completed system comprises of the three main sub-system viz. bottom pouring mechanism, heating of the metal and vacuum system.

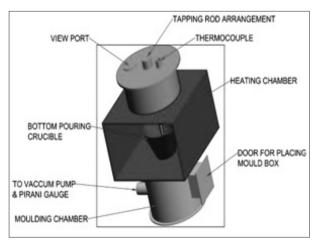


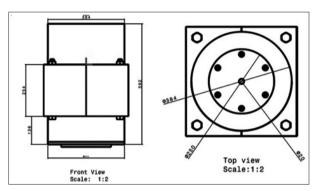
Fig. 6. CAD model of the setup.

A vacuum chamber is a rigid enclosure from which air and other gases are removed by a vacuum pump. These results in a low-pressure environment within the chamber commonly referred to as a vacuum. In low vacuum applications, chambers are sealed with elastomeric O-rings. Pressure vessel is designed which can sustain the vacuum level of  $10^{-3}$ mm of Hg. pressure on the inner side of the chamber, while the outer surface is exposed to the atmosphere.

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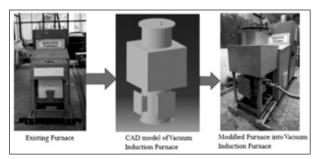
#### **Technical Paper**

From ASME Design, Mild Steel and Stainless steel are selected for fabrication of vacuum chamber. Tapping rod chamber is made up of Stainless steel and melting chamber and mold placing chamber is made up of mild steel. Thickness of MS and SS metal sheets are 8 mm. Dimension of vacuum chamber are shown in Fig.7.



**Fig. 7.** Dimensions of front view and top of vacuum chamber (dimension are in mm).

Fig. 8 shows the modified vacuum chamber unit for the reactive material. This vacuum chamber unit is for both melting and pouring.



**Fig. 8.** Modification of existing induction furnace into vacuum induction furnace.

# 3.2.2. Vacuum pump

As metal is very prone to oxygen, the whole chamber must be free from the oxygen and any other gases. To evacuate vacuum chamber, we used vacuum pump of Model IVP 600 with electro mechanical anti suck back valve mounted at the inlet of the pump, displacement 50 Hz: 600 LPM and Ultimate Pressure range: <  $1 \times 10^{-3}$  torr with Gas Ballast Closed. Pirani gauge is used for measuring of pressure inside the vacuum chamber, specification of which is as follows-

Model DPRG-1GH, Display Range:0.001 To 1000 Mbar and dependable measuring range: 20 To 0.001 Mb. Fig. 9 shows vacuum pump and pirani gsuge.

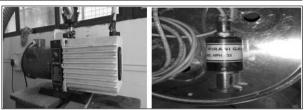


Fig. 9. Vacuum pump and pirani gauge.

3.2.3. Bottom pouring crucible mechanism



Fig. 10. Bottom pouring graphite crucible with tapping rod.

The specially designed bottom pouring graphite crucible used for the induction melting process. Fig. 10 shows specially designed bottom pouring graphite crucibles. Bottom pouring graphite crucible with rod is used to tap the molten metal from lower end of the crucible. Conventional tilting crucible was not suitable for pouring the molten metal. The molten metal is poured through the bottom of crucible using rod shown in Fig. 11. Nut is rotated for 2 to 3 pitch to lift the rod and pour molten metal in to the mold cavity. Pouring rate is maintained by Nut rotation.



Fig. 11. Bottom pouring graphite crucible with tapping rod.

# 3.2.4. Experimental setup and standard operating procedure (SOP) of the system

A standard operating procedure is written below step-by-step instructions compiled to help operator to carry out routine operations.

**Step 1.** Charge the crucible with the desired material into the heating chamber. The material should be free from dust and dirt. Bottom pouring crucible and the tapping rod should be properly aligned with the molding box runner and riser, as the tapping of the molten metal is carried out from the bottom.

**Step 2.** Place the molding box of desired shape in the molding chamber and close the door. The top chamber is provided with door to observe the molten metal condition and to note the temperature of the molten metal.

**Step 3.** Switch on the vacuum pump and run it to achieve the desired the level of vacuum.

**Step 4.** Furnace should be operated once the vacuum chamber achieves the vacuum level. The reading can be noted from the pirani gauge digital indicator.

**Step 5**. As soon as material gets melted, lift the rod and tap out the material.

**Step 6.** The whole system of melting and pouring should be operated in the vacuum environment only.



Fig. 12. The Experimental set up with vacuum system.

Fig. 12 shows the experimental setup with vacuum system.



Fig. 13. As cast part: fabricated using RP

The preparation of mould as per the software, melting and pouring of molten metal (Aluminum alloy 6060) under vacuum was carried out in CAD CAM center of VNIT Nagpur and as cast part is shown in Fig 13.

# 4. Results

# 4.1. Evacuating the vacuum chamber

It is essential to evacuate the vacuum chamber before the experimentation. Fig. 14 shows the time required to evacuate the vacuum chamber with rotary vane pump having a capacity of 500 lit/min.

It was proposed to melt and test the casted sample of Aluminum with and without vacuum environment. The physical and chemical properties of the aluminum were studied.

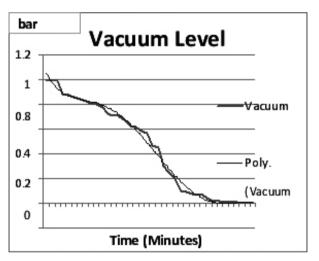


Fig. 14. Time required evacuating the chamber.

# 4.2. Experimental trials on aluminium casting

An experimental analysis is carried out on the aluminium alloy. The chemical composition of 6060 aluminum alloy given in Table 2 and weight of 250 g were induction melted in graphite crucibles in open atmospheric temperature.

The alloy was induction heated to a melt temperature of 760.3 °C and hold at this temperature for 10 minutes. Melted aluminum is poured into the mold and as cast part is obtained. As cast part is tested for chemical analysis in lab and the result of chemical analysis is shown in table 3. Similar experimentation is carried out with the vacuum induction Furnace. Instead of open atmosphere the aluminum alloy is melted in vacuum chamber. Vacuum chamber of induction melting furnace was evacuated to a vacuum pressure of 0.56 bar.

#### **Technical Paper**

#### Table 2

Chemical analysis of AL6060 alloy.

	Alloy 160 Al	Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zi	Residuals
We	ight %	97.9-99.3	0.05 Max	0.1 Max	0.1 -0.3	0.35 - 0.5	0.10	0.3-0.6	0.1 Max	0.15 Max	0.15 Max

#### Table 3

Chemical analysis of AL6060 alloy melting in without vacuum induction furnace.

Alloy 6060 Al	Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zi	Residuals
Weight %	85.291	0.0211	1.78	1.09	0.188	0.1709	1.558	0.0273	0.121	0.15 Max

#### Table 4

Chemical analysis of AL6060 alloy melting in vacuum induction furnace.

_			,	<u> </u>							
	Alloy 6060 Al	Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zi	Residuals
	Weight %	98.175	0.0204	0.029	0.54	0.45	0.0436	0.6	0.156	0.114	0.15 Max

As cast part of vacuum induction melting is tested for chemical analysis and the results are shown in table 4.

# 5. Discussion

The manufacturing of part using RP pattern and vacuum assisted sand casting is thus possible for AL6060 Alloy. The result of chemical of the part casted using vacuum is very promising. The part having irregular geometries mostly used in medical implants can be manufactured using vacuum assisted casting.

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