INTEGRATION OF INVESTMENT CASTING WITH RAPID PROTOTYPING TECHNIQUE

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ABSTRACT

Use of rapid prototyping for manufacturing the tailor made product is one of the important areas of research today. This has lot of significance in automobile industries in manufacturing of mechanical components and also for orthopedic and dental implants in medical application. The manufacturing feasibility of new engineering product invented using techniques like Bionics, TRIZ is possible because of rapid prototyping.

In this research paper, analysis of investment casting using fused deposition modeling (FDM) technique is carried out. FDM is used for getting physical part in Acrylonitrile Butadiene Styrene (ABS) polymer from Computer Aided Design (CAD) data and using it as pattern for investment casting. Feasibility of manufacturing the customized/tailor made part using FDM is the main focus in this paper. The experimentation is carried out to develop mathematical model so as to minimize the defects in casting. Zero defect casting is possible using the mathematical model and simulation software thus setting the parameter to design correctly the gating and riser.

Practical implications of this research aim to address the issue of manufacturing cost effective, defect free customized part using FDM.

Keyword : - *Customized product, Fused deposition modeling, Zero defect casting, Rapid prototyping, Bionics, TRIZ*

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1. Introduction

In the present technical scenario, product design and development that suits to customer is always aimed at. It is equally mandatory to bring the product in the market at the earliest to compete in the global market. To compete in today's industry environment, companies must keep up with the leading technologies and processes and also push the boundaries and develop new and improved products and processes. Shortening the lead-time for introducing a new product to the market has always been important to maximize profits and competitiveness. Recent developments in Computer Aided Design (CAD) technologies have significantly reduced the overall design cycle. However, the manufacturing process of the production mold still relies on slow and expensive processes. In the manufacturing industry time, efficiency and accuracy are the major driving forces behind innovation and research.

The most competitive companies are those who continually reduce process times, increase efficiency and improve accuracy. Rapid Prototyping reduces production time and increase efficiency and accuracy in developing and manufacturing prototypes compared to traditional prototype manufacture. The research development in Rapid Prototyping (RP) gives the manufacturing industry needed confidence to go on to customized/tailor made Product.

Investment casting process is improved by developments in Rapid Prototyping. The process for Lost RP pattern has evolved new research avenues in the Block mold Investment Casting[10].

2. Rapid Prototyping

Rapid Prototyping (RP) is the technique to generate three-dimensional models that need no machining or tooling. RP adds material layer by layer until the desired shape is achieved, instead of cutting away material by machining. RP allows for more flexibility than machining because the complexity of the model does not give any limitations to its production. RP generates 3D models quickly and accurately which helps in product design and development**.** Rapid prototyping is the process of generating an object directly from its digital representation in CAD/CAM system by adding material layer by layer as shown in fig 1. The main benefit of this process is to reduce the time to produce a prototype, which in turn speeds up the entire development process.

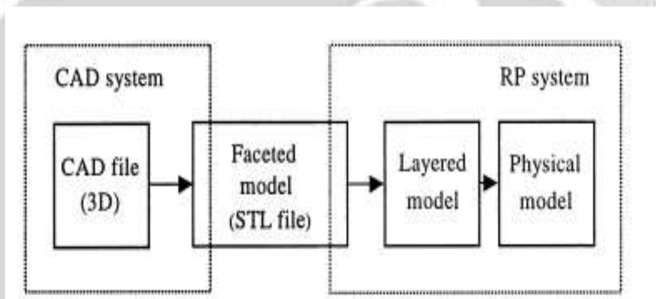


Fig 1- Rapid Prototyping approach

2.1 FDM

FDM is the second most widely used rapid prototyping technology, after stereo lithography. A plastic filament, approximately 1/16 inch in diameter, is unwound from a coil (A) and supplies material to an extrusion nozzle (B) as shown in fig 2. Some configurations of the machinery have used plastic pellets fed from a hopper rather than a filament. The nozzle is heated to melt the plastic and has a mechanism which allows the flow of the melted plastic to be controlled. The nozzle is mounted to a mechanical stage (C) which can be moved in horizontal and vertical directions. As the nozzle is moved over the table (D) in the required geometry, it deposits a thin bead of extruded plastic to form each layer. The plastic hardens immediately after being squirted from the nozzle and bonds to the layer below.

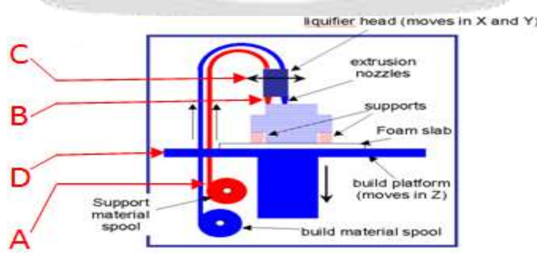


Fig 2- Principal of FDM

The entire system is contained within an oven chamber which is held at a temperature just below the melting point of the plastic. Thus, only a small amount of additional thermal energy needs to be supplied by the extrusion nozzle to cause the plastic to melt. This provides much better control of the process. Support structures must be designed and fabricated for any overhanging geometries and are later removed in secondary operations. Several materials are available for the process including a nylon-like polymer and both machinable and investment casting waxes. The introduction of ABS plastic material led to much greater commercial support material which is easily removable by simply breaking it away from the object. Water-soluble support materials have also become available which can be removed simply by washing them away.

2.2 Rapid Manufacturing

Rapid manufacturing (RM) is the use of additive fabrication technology like RP to produce useable products or parts. As is the case with rapid prototyping, the field is also known by several other names such as additive manufacturing, direct fabrication and direct digital manufacturing. RM is one of the three major blossoming outgrowths of rapid prototyping. The others are three-dimensional printing - a lower-cost flavor of RP, and rapid tooling - actually a special case of rapid manufacturing. Today the distinctions among the trunk and branches of the RP tree are not very clear. Moreover, these differences can be expected to continue to blur as the technologies mature and applications, specifications and capabilities of the branches increasingly overlap.

2.3 Geometric Freedom

Essentially all additive fabrication technologies provide the ability to fabricate with unbounded geometric freedom. It is the most important advantage over subtractive methods and main reason to exist. Geometric freedom comes with several limitations. The speed of fabrication using RP is much slower compared to standard manufacturing methods. By some estimates, existing mass production methods are 10 to 1,000 times faster. The finishes and accuracy are also not on a par with conventional technology.

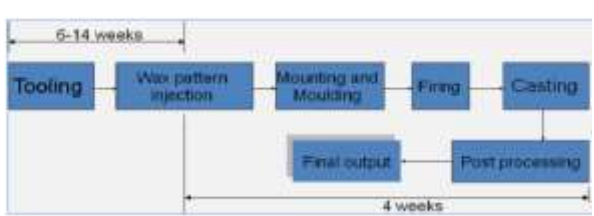
3. Investment casting using RP

3.1 Investment castings

Investment casting is a process that has been practiced for thousands of years, with lost wax process being one of the oldest known metal forming techniques. From 5000 years ago, when bees wax formed the pattern, to today's high technology waxes, refractory materials and specialist alloys, the castings are produced with the key benefits of accuracy, repeatability, versatility and integrity. Investment casting is one of the most economical ways to produce complex shaped parts from metal. It is widely used for producing ferrous and nonferrous metal parts. The only process that matches this group of materials is machining, but it cannot produce the complex geometries that investment casting can deliver. Each metal casting requires one wax pattern, and these patterns are injection molded. As design complexity rises, the tooling often becomes too costly and too time consuming to make prototyping and low-volume production practical.

3.2 FDM & Investment Casting

The key advantage of FDM (fused deposition modeling) is that it eliminates the need for tooling. Injection molds for wax patterns range from $3,000 to $30,000, and building the tools can take four to six weeks. The time and cost savings are true no matter how complex the part design as shown in fig 3.



(a)

(b)

Fig 3-(a) Traditional method of Investment Casting and (b) Rapid Casting (RC) method

Since FDM is an additive fabrication technology, there is no impact on the investment or delivery schedule as the pattern becomes more complex. Another advantage, which is unique to FDM, is that the soluble support technology allows interior passages to be constructed. Additional time savings also occur in casting design, since FDM patterns can be produced without adding draft angles to the CAD data. A final consideration is the durability of the pattern. Patterns made from foundry molding wax and other additive fabrication technologies are easily damaged[10]. And, transportation and routine handling can result in broken patterns. The ABS material is also resistant to distortion from heat, humidity and post curing which can be an issue with other additive fabrication technologies[3].

4. EXPERIMENTATION

Investment casting process is quite different process when compared to the sand casting or other similar casting process. ABS part of which mould cavity is to be prepared is placed on surface and around it x-ray film or any other film is placed and fix with packing wax. With the help of simulation software, runner and pouring basin are designed. Slurry is made by mixing Zirconium sand with water or biosol liquid[9]. The slurry is poured into the assembly and allowed to settle. The details about experimental setup are shown in fig 4 which are self explanatory.

Fig 4(a) - X-Ray film around ABS part

Fig 4(b) – Gating and feeder system of wax attached to spcimen

Fig 4(c) – Biosint extra powder

Fig 4(d) – Powder clinging using vibrator machine

Fig 4(e) – Mold after soaking for 40

Fig 4(f) – Furnace and Baked mold

Mathematical expression for deciding temperature range at which ABS part in mould cavity completely evaporates is obtained.. Surface response approach is used for development of a model and analysis of temperature (T), with volume of RP ABS part, Shell thickness, and set time as input parameters. Mathematical expression is completely based on RSM (Response Surface Methodology) theory the correlation between the response and the variables. The mathematical model is then developed that illustrate the relationship between the process variable and response [6].

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{i=1}^{k-1} \sum_{j=2}^{k} \beta_{ij} X_i X_j$$

Based on the experimental observations the following expression is obtained.

$$T = 491.280 + 0.278*V - 4.279*S_t - 0.002*V^2 + 6.230*S_t^2 + 0.129*V*S_t$$

Where V-Volume of ABS part

S_t –Shell Thickness.

By using this temperature range we calculate the temperatures for various shell thickness. As in our research work we take nonlinear shape so that shell thickness is not constant for single part. So we calculate the shell thicknesses at different locations and take average of all.

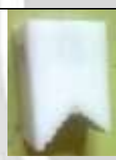
S.N	PART	VOLUME OF ABS PART cm^3	SHELL THICKNESS cm	TEMP ^{O}C	RESULT
s1.		29.65	2.3	522	Completely Burn
2		27.94	1.8	515	Complete Burn
3		49.53	2.0	529	Complete Burn
4		20.35	1.6	511	Complete Burn
5		23.36	1.7	512	Complete Burn
6		63.87	1.5	538	Complete Burn

Fig 5- Complete burn condition for RP part

From fig 5 we observed that by using mathematical expression of temperature we get the completely burn cavities.

5. Observations and Analysis

During experimentation readings for mold filling time and solidification time for the parts of which photographs are shown in fig 6, are noted. Using simulation software the same parameters i.e. mold filling time and solidification time for parts are also calculated. Data of the readings are shown in fig 6.

The difference in the readings is also shown in fig 6. The difference between the actual values and values obtained using simulation software is mainly because of the limitation of simulation software[5]. In fig 7 dimensions and weights of the parts in actual and as obtained in simulation software for the same part are also shown. The difference as noted in the fig 7 is mainly because of the limitations of the software as the simulation software uses .stl format as file and there is no facility of providing information regarding shrinkage allowance[13]. If observed the data given in table below, by seeing first instance, it can concluded that there are lots of mismatching between data given by simulation software and actual result, but it is not like that. After pouring the molten metal into mould cavity, metal has capability to shrink during solidification. Therefore there may be some changes in dimension of actual RP part and casting part. It gives part values and probable wt. after casting.

S.N	PART	AUTOCAST Dimension mm	AUTOCAST Wt. in gm	ACTUAL Dimension in cm	ACTUAL Wt in gm
1.		X= 13mm Y=55mm Z=55mm	146.03g	X=12mm Y=53mm Z=53mm	130gm
2.		X=22.0mm Y=65.0mm Z=65.0mm	200 gm	X=20mm Y=63mm Z=63mm	190gm
3.		X=16.0mm Y=65.0mm Z=65.0mm	355.45gm	X=14mm Y=63mm Z=63mm	290gm
4.		X=56.75mm Y=141.17mm Z=32mm	245.38 gm	X=55mm Y=140mm Z=24mm	230gm
5.		X=18.0mm Y=34.50mm Z=50.0mm	170.43 gm	X=17mm Y=32.5mm Z=48.5mm	160 gm
6.		X=49.67mm Y=50.0mm Z=50.0mm	477.34 gm	X=48.5mm Y=49mm Z=49mm	380gm

S.N	PART	AutoCast	Actual		Autocast	Actual	
	Time	Mold Filling Time	Mold Filling Time	Err	Solidi. Time	Solidi. Time	Err
1.		0.58 sec	0.71 sec	0.13	2.32min	3.5 min	1.18
2.		0.37 sec	0.53sec	0.16	1.70min	2 min	0.3
3.		0.93 sec	1.21sec	0.28	2.32min	3.1 min	0.78
4.		0.43 sec	0.62sec	0.19	3.32 min	3.4 min	0.08
5.		0.40 sec	0.67sec	0.27	3.25 min	3.6 min	0.35

Fig 6- Results of dimension and weight between software and actual

4. CONCLUSIONS

In casting product development, design information is important in process determination, tooling design, casting system, and product assurance and control. Traditionally, this information can only be revealed via the tryout realization of design solution in workshop. Use of simulation software, however, is an efficient approach in providing design information to casting product design.

With FDM patterns, investment casting is practical for casting and low volume production applications. Making investment casting patterns out of ABS materials saves both time and money on low volume production applications as well as tooling in investment casting. With only minor modification to the pattern design and the burnout process, FDM technology eliminates the costly and time-consuming tool making step needed for lost wax casting. Industries thus can take advantage of this technique on the efficiency, capability and quality of investment casting.

5. ACKNOWLEDGEMENT

The research work is possible because of RGSTC grant of Government of Maharashtra.

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