Investment Casting – Rapid Tooling Approach

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Abstract— Investment casting is synonym with producing precision components and investment casters usually take up the order if the volume is huge enough. This is due to high and unjustifiable tooling cost and long lead times associated with the development of metal moulds for producing wax (sacrificial) patterns for customized single casting or small quantity production. One of the feasible solutions is opt rapid tooling. In so- called rapid investment casting the most critical process will be building the investment shell and protecting it from thermal crack. This work investigates the shell crack and counter. In this work pattern are modeled on rapid prototyping machine. During the ceramic shell preparation cracking is reported. Hence a remedy is explored as to control the thermal expansion of the pattern build material-acrylonitrile butadiene styrene (ABS) by using different build styles. Thermal expansion of five distinct styled ABS rapid samples were tested on Dilatometer. The investigation indicates the possibility of 63% reduction in thermal expansion of the pattern, which is very very encouraging**.**

Keywords*: Investment Casting (IC), Rapid Prototyping (RP), Rapid Tooling (RT), Precision Castings, Fused Deposition Modeling (FDM), Acrylonitrile Butadiene Styrene (ABS), thermal expansion, Percentage Linear Change (PLC),Dilatometer.*

1. Introduction

The Investment Castings (IC) was known to our ancestors as an art of making toys and tools date back to four thousand years even. IC is synonym with precision castings [1,2]and has several critical stages of production. Fig.1(i & ii) is pictorial representation of the major stages (a to j) involved .People engaged with IC understand the enormous calendar time they elapse to arrive at the first casting – it runs to months. In this, majority of the time is spent on developing the Tooling successfully . Customarily by default the prototype development or tooling for wax pattern is costly and lengthy hence investment casters usually take up the order only if the volume is huge enough.

At the same time reduction of product development cycle time is a major concern in industries to remain competitive in the market place and hence focus has shifted from traditional product development technology to rapid fabrication techniques like rapid prototyping (RP) . RP process is capable of building part of any complicated geometry in least possible time without incurring extra cost due to absence of tooling. Another advantage with RP is

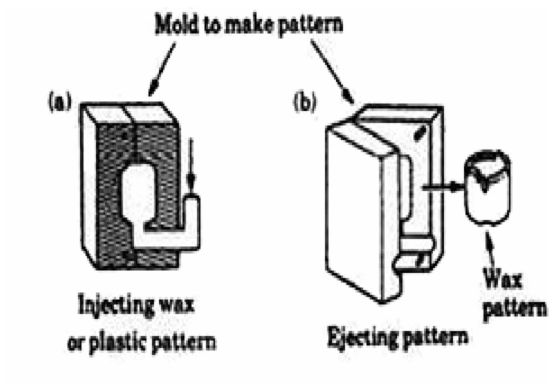


Fig.1(i)
a&b Design & development of the mould for wax pattern is the critical delay factor in IC

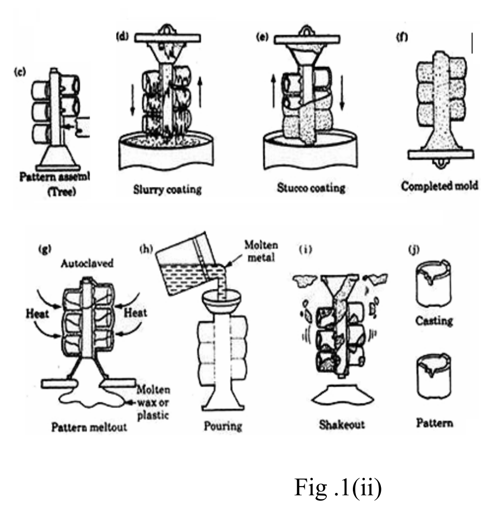


Fig .1(ii)

-the scope of unlimited –no –cost design iterations on digital data. RP offers several other benefits.[3,4]

Although RP is an efficient technology full scale application and exploitation has not gained much attention because of various reasons, primarily compatibility of presently available materials with RP machines and unavailability of authentic data required by metal casters. When RP & IC are linked suitably this may lead us to exploit full potential of both besides countering disadvantages. [5,6,7,8,9,10].

But there are four principal issues which the authors have experienced when experimented RP with Investment Casting .

i) Residue deposit after shell firing.
ii) Pattern contraction/ expansion in x, y & z build axes.
iii) Shell Cracking during firing.
iv) Ra. value on pattern to command required Ra. on the casting.

The authors believe above issues are to be addressed well before we offer RP to Investment casters. Though partial, a few researchers[11] claim success, no published work known to the authors has successfully addressed all above problems and authors have taken up the work of resolving these issues to popularize the RP in industry and academia as well. Our previous work [12] reports suitability of ABS pattern for preparing the IC shell. Present work focuses on expending /firing the pattern and issues associated with it. The experiment is done in two parts. First part - a set of acrylonitrile butadiene styrene (ABS) patterns are generated on STRATASYS' fused deposition modeling (FDM) RP machine. The patterns are converted into castings though IC route and shell cracking tendency observed.. In the second part five test patterns of size 12ømm*12mm are generated on FDM machines employing different build styles to minimize the severity of thermal expansion and their respective thermal expansion values are estimated on the Orton Dilatometer model DIL2016.

2. Procedure

Pattern Preparation

The 3D (Three dimensional) CAD models are modeled in CATIA^{TM} software and imported to FDM Vantage SE Machine in STL format. Here the process parameters are set as per the values given in Table 1 and parts are fabricated using ABS as a built material. For material deposition FDM uses two nozzles, one for model material deposition and other for support material deposition. These two nozzles work alternately to each other. Fig. 2 provides the schematic description of FDM machine part fabrication methodology. A few parts are generated with solid (fills the part interior completely) and few parts are generated with sparse (honeycomb type internal structure) interior fill style.

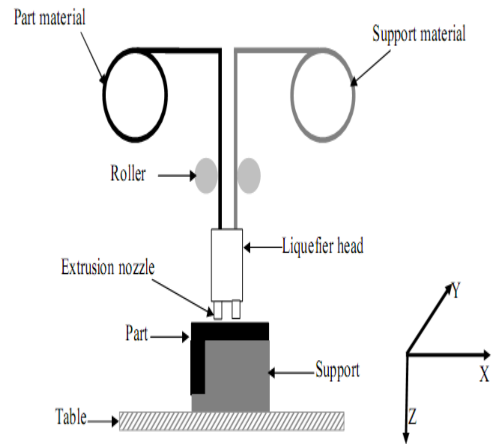


Fig. 2 Schematic description of FDM process

Table.1 FDM process parameters

Sl	Settings	Value
1	Raster Angle	45 degree
2	Air Gap	0.0 mm
3	Slice Thickness	0..4064mm
4	Raster width	0..4064mm
5	Envelop Temperature	80 °C

art I (ABS patterns are generated and converted into castings through IC route.)

Patterns are prepared in ABS Fig.3 (i). Pattern Tree is made Fig.3 (ii & iii) . Shell is prepared Fig.3(iv) with subsequent dipping and stucco and fired. The mould is poured in plane carbon steel and components are made , as - cast as shown in Fig.3 (v)

Fig. 3 (i)

Fig. 3 (ii) Fig.3(iii)

Fig.3(iv) Fig.3(v)

Part II(ABS test samples are generated on FDM and tested on Dilatometer)

Five test samples Fig.4(i&ii) of size (12 ø mm*12mm) are modeled on FDM machine for testing the thermal expansion. Different parameters and build styles are used to generate distinct internal web structure in the sample. A few build parameters are displayed for the information of the enthusiastic readers as in the Table.2.

Orton Dilatometer Fig.5 is a versatile piece of equipment designed to measure the thermal Expansion/Percentage Linear Dimensional Change of any solid material (ceramics,glass, metal,polymers etc)as a function of temperature. Standard Orton Dilatometer [13] is a digital, horizontal, single sample bench top system comprised of a furnace with silicon carbide heating element (1600C), fused quarts sample holder system, thermocouple , sample displacement system (consisting of Probe Rod, Linear Variable Dimensional Transducer and counter -

Table.2

sample	Interior style	slice thickness	Sparse fill air gap	Sparse Solid layers	Perimeter-raster air gap	Raster to raster air gap
R1	solid	0.4064	na	na	0.000	0.000
R2	sparse	0.4064	1.000	3	0.000	0.000
R3	sparse	0.4064	2.000	3	0.000	0.000
R4	solid	0.4064	na	na	0.000	1.600
R5	sparse	0.4064	3.000	3	0.000	0.000

Fig.4(i)

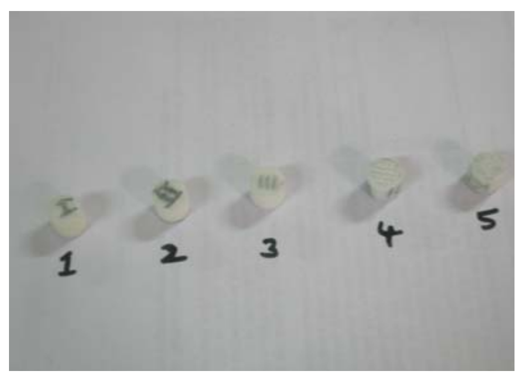


Fig.4(ii)

-weighed pulley.),Control board for furnace and data acquisition with Orton software. Sample in the holder is pushed into furnace and heated from room temperature to 100˚C. the expansion of the sample is probed and transmitted to LVDT, it generates signal corresponding to the change in sample length and continuously sends that signal to the Orton Board Computer along with the thermocouple output.. As a result, the PLC(percentage linear change) Vs.

temperature of the test sample is obtained from the display continuously. The readings against each sample is recorded as shown in the Table.3.

Fig. 5

Table.3

3. Result

Unlike other casting processes IC involves pattern investing (burying) in the ceramics and expending (firing) it out later. These two factors hence decide the suitability of ABS replacing wax. Author's previous work had investigated and reported the first factor and in this work it is found that there are complications in the second factor ie. in firing, in

Sample	Initial Length Lo mm	Start Temp, oC	Softe-ning Temp, oC	%linear Change,PLC =ΔL/Lo *100
R1	12.22	31	81	0.363
R2	12.22	27	71	0.296
R3	12.22	28	69	0.290
R4	12.22	30	70	0.195
R5	12.22	27	69	0.133

which shells are found with cracks.Fig.6. This may be due to the differential thermal expansions of ABS used for the pattern and the ceramic used for the investment shell build up.

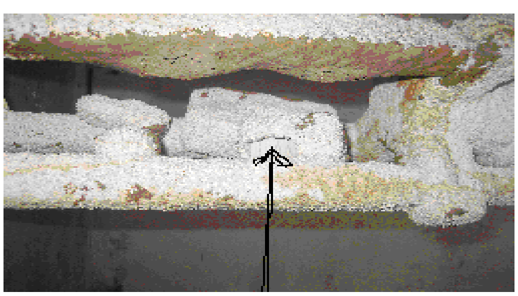
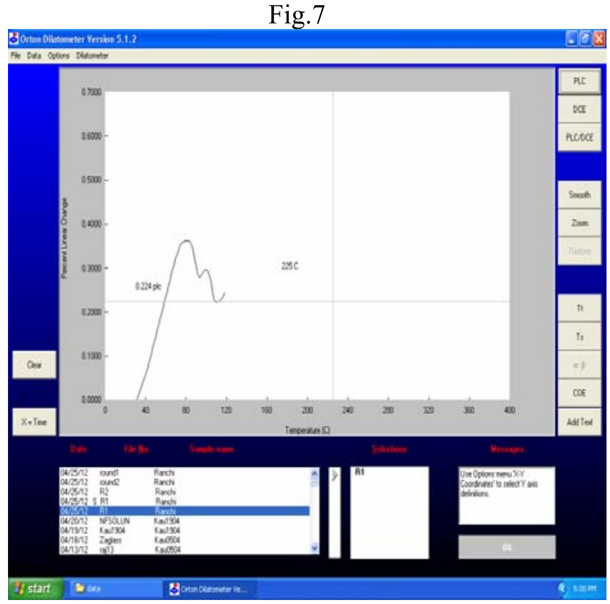


Fig.6

Let us now see the Dilatometer output. Fig.7 is the PLC Vs Temperature graph generated for sample R1. One can read the softening temp and the corresponding percentage linear expansion from the graph as 81˚C & 0.363 respectively. Similar graphs are generated for other four samples. In this context it is important to understand the thermal expansion of the ceramic shell also. The ceramic shell will also expand but the thermal expansion of ceramic shell below the softening temperature of ABS (i.e below 80˚C) is negligible. Hence the expansion of ABS will be the only deciding factor of shell cracking. The result got from the dilatometer for test samples of varied internal web structures indicate that we could attain more than fifty percentage reduction (~ 63%) in thermal expansion from sample solid build R1. to sparse build sample R5.,controlling the sparse air gap, and it is a very encouraging result which might help us to control the shell cracking to nil.

Fig.7



4. **Discussion**

ABS softening starts in the temperature range of 70C to 80C and then collapsing impends. Hence the researchers working on this issue of controlling the shell cracking tendencies, in investment casting, need to bother the thermal properties of the ceramic shell within this range only. It is clear that as the thermal expansion of the ceramic shell is negligible bellow the softening temperature (80C) of ABS, the critical factor to be controlled is the thermal expansion of ABS. Our investigation proves this control is possible through the manipulation of ABS patterns build styles.

5. Conclusion and scope for further research.

The study is a part of our investigation to integrate RP with IC and it explored the applicability of FDM generated ABS pattern suitability for IC . This work focused on thermal cracking tendency of IC shell. The results indicate a means to control the cracking tendency of IC shells. However, before commercialize the process, continued research is required to establish the scale factor for ABS in xyz directions and to establish a suitable post finishing operation on the ABS to deliver the surface qualities, precision casters demand. The ABS used on FDM machine being proprietary there is an urgent need for documenting its coefficient of thermal expansion to win the confidence of Cast Houses before FDM based RT is transferred to its potential users.

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