USE OF FUSED DEPOSITION MODELING PROCESS IN INVESTMENT PRECISION CASTING AND RISK OF USING SELECTIVE LASER SINTERING PROCESS.

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Abstract-Investment Castings (IC) is one of the most economical ways to produce intricate metallic parts when forging, forming and other casting processes tend to fail. However, high tooling cost and long lead time associated with the fabrication of metal moulds for producing IC wax (sacrificial) patterns result in cost justification problems for customized single casting or small-lot production. Generating pattern using rapid prototyping (RP) process may be one of the feasible alternatives. For this purpose present study assessed the suitability of the fused deposition modeling (FDM) process for creating sacrificial IC patterns by studying FDM fabricated part thermal response at various temperatures. A series of experiments with RP patterns are conducted and a set of test castings are also made in steel for establishing feasibility. The build material used is acrylonitrile butadiene styrene (ABS). As an annexe to this work a concurrent attempt is also made to quantify the risk in using Selective Laser Sintering patterns for Investment Castings. Authors hope this work might establish applicability of ABS in IC and also lead the investigations to theoretically tone down the shell cracking tendency with Selective Laser Sintering patterns when Proprietary Duraform is used as the build material.

Keywords*-Investment Castings (IC); Fused Deposition Modeling (FDM);Rapid Tooling (RT);Rapid Prototyping(RP); Acrylonitrile Butadiene Styrene (ABS);Thermal response; Pattern worthiness. Selective Laser Sintering, Dilatometer. Thermal expansion/Percentage thermal linear change.*

1. INTRODUCTION

The cut on delays and cost of intricate tooling in prototype development stage renter any conventional manufacturing process sustain the market[1]. Investment Casting(IC) though synonym with precision castings suffers from both delays and cost[2]. While Rapid Prototyping (RP) process is capable of building part of any imaginable geometry in least possible time without need for any physical tooling [3,4]. It also offers freedom for endless design iterations involved in the development of precision engineering components. But its popularity with producing functional parts is scarce, as RP is better known in the world of prototypes. Hence secondary RP applications are often required to obtain highly durable components from RP process. one of the possibilities is linking of RP with IC and it appears to be an ideal choice to innovate IC and to gain affirm footing in the casting market. Rapid Tooling links RP with IC [5]. This work explores the possibility of linking RP with IC to manufacture full functional engineering components.

Fused deposition modeling (FDM) (Fig. 1) is one of the RP processes and use acrylonitrile butadiene styrene (ABS) as a build material and can be considered as an alternative for conventional wax pattern tooling[6,7,8]. Based on this idea, to explore the suitability of ABS as a pattern material for IC, its pattern worthiness need to be explored which again based on ABS mouldability (ease in making moulds) and de-mouldability (ease of removal from the mould).Present study explores the pattern worthiness of ABS. Rest of this paper is divided as follows,

section 2 will explain the procedure adopted followed by results in section 3. Discussion on the outcome of this study is presented in section 4 and conclusions are presented in section 5.
annex

2. PROCEDURE

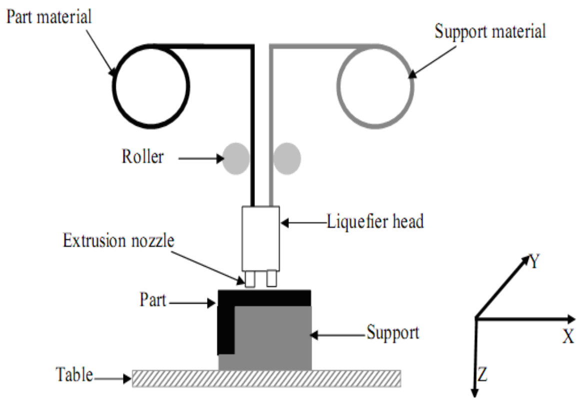

Fig. 1 Schematic description of FDM process

2.1.Pattern Preparation

The 3D (Three dimensional) CAD models are modeled in CATIA™ 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.1 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.

Table1 FDM process parameters

Sl.No	Settings	Value
1	Raster Angle	45 degree
2	Air Gap	0.0 mm
3	Slice Thickness	0.254mm
4	Raster width	0.4064mm
5	Envelop Temperature	80 °C

2.2. Testing Pattern worthiness of ABS
Experiments i to v are carried out.

2.2.1 Expt i (Test for ABS compatibility with molding medium) An electric resistance furnace with temperature controller and heating range of room temperature to 1200°C is used. Moulds are made using ABS patterns Fig2 (a) in commercial foundry Silica sand bonded with sodium silicate hardened by CO2 and tested for any chemical reaction. After firing the mould at 900C patterns are removed leaving its neat replica mould cavity (b) . No sign of spoilage of mould cavity is observed.

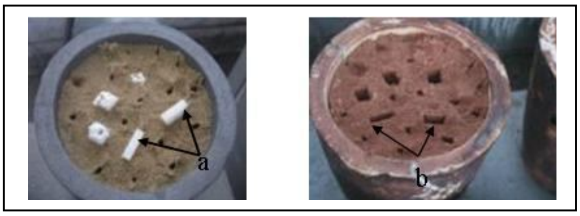

Fig.2 Mold and mold cavity

2.2.2 Expt ii (test for type of ash & burn out)

To understand the type of burn out and ash content, three ABS samples are fired at 900C.as in (Fig. 3) in small crucibles. it is observed that ash content was negligible as indicated in Table 2. Moreover the residue is fragile and non sticky (Fig 3 b& c) and simple to be removed with a mild air blow. This result being encouraging and acceptable following test is planned.

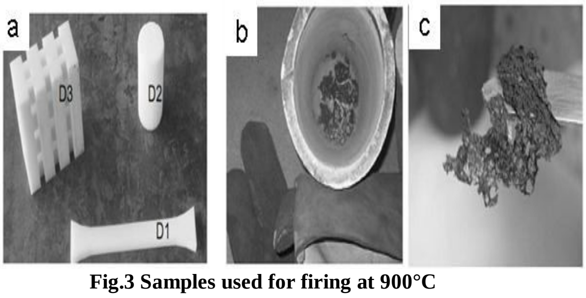

Fig.3 Samples used for firing at 900°C

Table 2 Result of direct firing of three samples

Sample Identification(weight)	Fired in the furnace and ash content is noted	900˚C
D1 (4.g)	In a crucible	Ash .0.0g.Nil
D2 (8.6g)	do	Ash.0.15g
D3 (16g)	do	Ash 0.24g

2.2.3.Expt. iii (Test for the thermal decomposition)

Five samples were tested for detailed observation and the samples were fired in the range of (100-1050ºC), ranging from 100°C,150°C, 200°C, 300°C, 450°C, 570°C, 650°C, 950°C and1050°C and their thermal degradation is tabulated(Table3) and is also represented in the graph. Expt iii simulated various stages of material decompositions that may occur to ABS in a real life mould in the working range of 100 to 1050°C. The fig 4 reports the details .The result being encouraging Expt iv is planned.

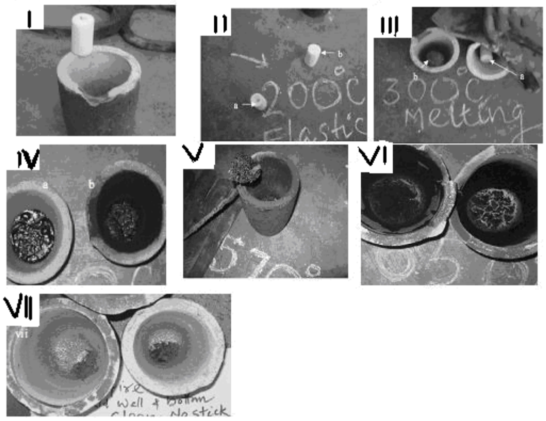

Fig.4 Thermal decomposition of ABS

Fig. 4 (i) no visible softening at 100-150°C, (ii) Sample after firing at 200 °C, a- Sparse sample centre caved in , b- Solid sample started softening, (iii) Sample after firing at 300 °C a- Solid sample bent & begin to melt, b- Sparse Sample became Milky paste, (iv) a-solid sample shows Boiled bubbles, b -sparse sample shows burnt Black Tar at 450 °C, (v) Ash Flakes at 570°C, (vi) Ash and walls with carbon soot at 650°C, (vii) shows Clean walls with easily removable ash residue at 1050ºC.

2.2.4. Expt. iv (Test for replicas of precision patterns)

This Expt. is planned to understand the capability of ABS to produce intricate mould cavities off precision patterns. A test mould (12 * 10 * 7” size) with self setting sand, FeSi as binder is prepared using a set of ABS patterns Fig 5 (i). Fired it at 1050 to remove the patterns. Very good mould cavities are left behind . With absolutely no sticky trace of ash on the cavity. Fig 5 (ii) – mould being fired at 1050C in an electrical resistance furnace. Fig 5(iii & iv) –After firing mould is being cooled off and patterns are completely removed.

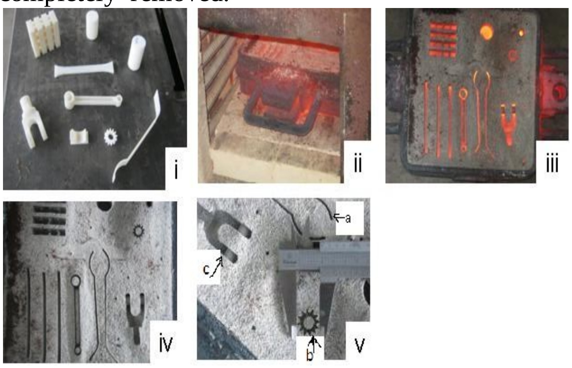

Fig.5 (i-v) Precision Moulds.

Fig 5(v) shows the capability of ABS to replicate intricate shapes in the mould. Fig(V-a) shows a clear mould cavity of a 2mmthick rib. Fig(v-b) shows that of 20$^{\varphi}$ mm pinion and a self core of 10mm Knuckle joint shone in fig 5(v-c). All the above five stages clearly establish the suitability of ABS as a pattern material and hence it is decided to take a set of sample castings in IC route.

2.3. Expt. V (Test castings through IC route.)

Patterns are prepared in ABS Fig 6 (i). Pattern Tree are made-Fig 6 (ii) . Shell is prepared with subsequent dipping and stuccoing. The mould is poured in plane Carbon steel and components are made, un-fettled as shown in fig 6 (iii). The castings are fettled and short and sand blasted and individual component casting are shown with in-gate stubs as in Fig.7

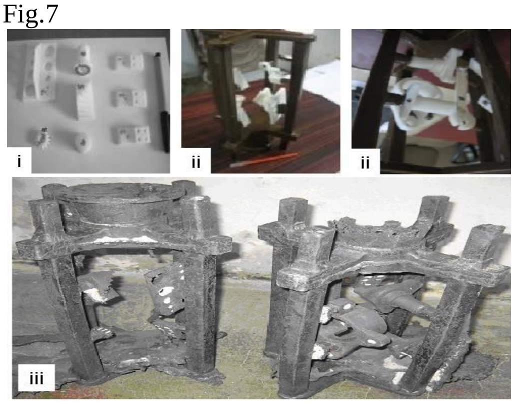

Fig.6; Investment Casting Tree.

Fig.7 Castings after degating

2.4. Expt. vi (Test to compare the criticality of FDM(ABS) and SLS(Duraform) pattern in IC application.).

One of the critical issues with use of RP patterns in investment casting is known to the cracking tendency of the shell during firing. Hence it was decided to determine the thermal expansion of both FDM and SLS samples. For this test pieces of 12 mm cubes were generated on FDM and SLS to test separately on Dilatometer [9,10,]. Dilatometer set up is shown in Fig.8. The percentage Linear Change/The percentage linear thermal expansion for ABS and Duraform are in Fig .9 and Fig.10. respectively. The result speaks up the risk in replacing ABS with SLS patterns.

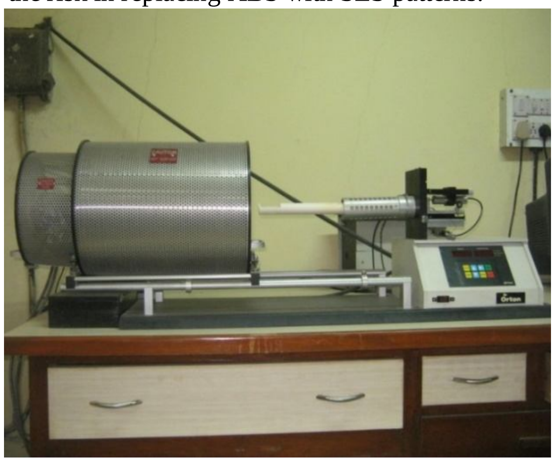

Fig.8 (Dilatometer Setup)

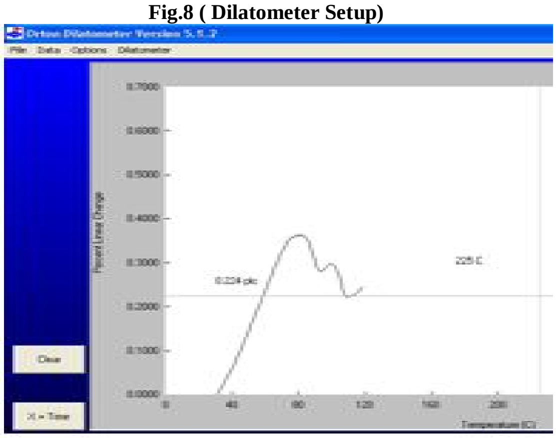

Fig.9(Thermal Expansion for ABS)

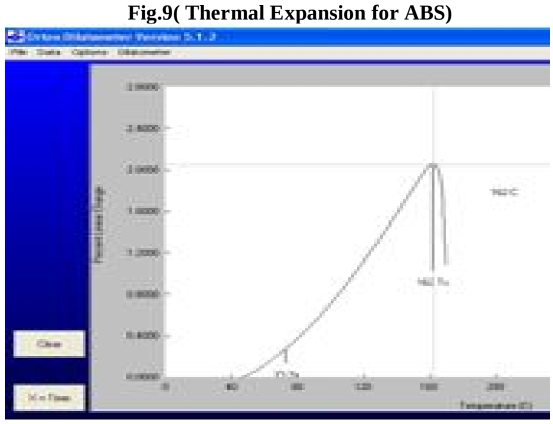

Fig.109(Thermal Expansion for Duraform)

A series of further investigation are also being carried and encouraging results are drawn by the authors in theoretically tone down the shell cracking tendency of Duraform patterns, as a separate piece of research work.

3. RESULTS

The experiment i,ii,iii & iv establish the worthiness of ABS as an IC pattern and experiment v converted prototypes into real life engineering components through IC route(Fig7)

The Table 3 is the result of Expt. iii on ABS. At 100°C and 150°C there is no visible softening (Fig. 4.i) but at 200°C part with sparse interior fill shows inward collapsing tendency (Fig. 4.ii. a) whereas parts with solid fill just start softening (Fig. 4.ii. b).it implies Sparse impart the collapsibility enhancement. At 300°C solid sample

(Fig. 4.iii.a) started melting and begin to bend and sparse become milky paste (Fig. 4.iii.b). At 450°C solid sample melted (Fig. 4.iv. a) and sparse sample melted and became black tar (Fig. 4.iv. b). At 570 °C ash flakes are observed in both solid and sparse samples (Fig. 4.v). At temperature beyond 600°C soft ash residue and carbon soot on the crucible walls are observed (Fig. 4.vi). But at temperature of 1050°C clean crucible walls and soft easily removable ash residues are observed. Fig.11 summarizes the percentage quantity of ash formed from table 2 and 3.

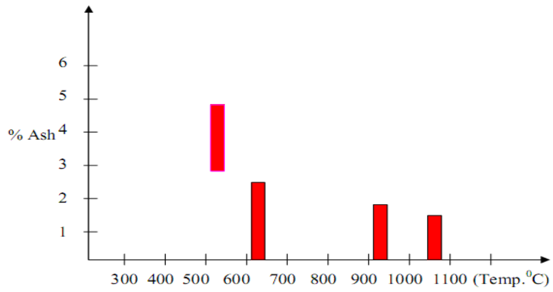

Fig.11.

The Expt. vi gives us the thermal expansion details of FDM ABS and SLS Durafom as 0.350 % and 2.20 % respectively, which quantifies and compares the cracking tendencies of both. It is evident that the use of Durafom is more critical in IC application as its thermal expansion is about 7 to 8 times that of ABS.

Table.3 Thermal decomposition of ABS

Sample Identification	100˚C-150C	200˚C	300˚C	450˚C	570˚C	650˚C	1050˚C
Sample .I 19.915g	No visible Softening	Softening visible	Melting started	Boils& Bubble	Ash 0.570g	Ash ---	Ash 0.315g
Sample .II 19.961g	No visible Softening	Softening Visible	Melting started	Boils& Bubble	Ash ---	Ash 0.530g	Ash 0.155g
Sample .IV 9.385g Sparse	No visible Softening	Softened(Centre Caved in)	Melted (milky paste like)	Burnt (Black Tar)	Ash	Ash 0.0gNil	NA
Sample.VI 7.838g Sparse	No visible Softening	Softened(Centre Caved in)	Melted (milky paste like)	Burnt (Black Tar)	Ash 0.370g	Ash ---	Ash 0.055g
Sample.VII 9.339g Sparse	No visible Softening	Softened(Centre Caved in)	Melted (milky paste like)	Burnt (Black Tar)	Ash ---	Ash 0.110g	Ash 0.057g

4. DISCUSSION

ABS starts softening externally only above 150°C hence it will withstand all possible exothermic reactions during the bond development of sand moulds. hence it is compatible with any sand system. Steam can not wash off ABS patterns like it does with wax in the autoclave, hence no autoclave is done in RP- IC. In the range of 200°C to 300°C it gets softened and become paste. It burns between 300°C to 450°C. This is the range it collapses in the mould as a pattern. Above 570°C ABS turns into ash from hard to non- sticky -soft as temperature shoot to 1050°C. Even at 1050°C firing we may get ash residue.

It is clear from the Fig.11 that 2.8% to 4.8 % is the ash content at 550˚C. 0% to 2.6 % at 650˚C.Ash content at 1050˚C is nil to 1.5% max. Solid and Sparse built patterns also responded differently in the range of temp 150˚C to 500˚C in regard to its collapsibility, favoring Sparse construction. The final ash content varies with its Sp. Gravity , on an average it is around 1.5%. This %ash residue will be of no concern to the Investment Casters as it is non-sticky and can easily be blown out of the shell. Hence after firing the shell at 1050ºC;there could be an additional stage for blowing out the ashes before pouring as a deviation from the normal route.

The solid and Sparse built may become a mere choice of the designer and Caster. Nevertheless it is a trade off between distortion, dimensional tolerance, surface finish, saving of material, speed of manufacture, pattern collapsibility/thermal expansion etc. The authors have observed the difference in dimensional expansion in Z direction in solid and Sparse. Similarly contraction in XY plane too is different for Solid and Sparse built.

Now these contrasts are obviously rich enough to stretch imagination of researchers, however when it comes for commercial production of casting, the above factors will not bother the investment caster much once the shop floor gets tuned to the new development and cast variables. It is also confirmed that the SLS Duraform patterns exhibits greater shell cracking tendency than ABS.

5. CONCLUSION AND SCOPE FOR FURTHER RESEARCH.

The study explored the applicability of FDM and pattern worthiness of ABS in IC. The results indicate that burning ABS generate non-Sticky, loose & brittle- minimal residue around 1.5% and is can be remedied by suitable process variations –post cleaning of the shells. To commercialese the process, continued research will 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 (Ra 5) besides attending to the shell cracking.

Its is known that the pattern worthiness of Duraform (SLS) is excellent as ABS in molding – demolding aspects but its thermal expansion. The result of Expt vi caution the RP users the risk of SLS Duraform pattern in IC as the percentage thermal expansion of Duraform (2.20%) is about 7 to 8 times that of ABS (0.350%). Even ABS with relatively low percentage thermal expansion, it occasionally necessitates minor shell crack repair prior it is put to the pouring bay. Hence one can well guess the severity of shell cracking tendency with Duraform. Continued & concurrent investigations are planned out to tone down the severity of Duraform patterens. It is an urgent need of Precision casthouses to exploit the applicability of both ABS & Duraform patterns as wax based RP machines are being phased out. Now the precision casters – the potential use of RP is said to be in state of flux with its use due to lack of data and guide lines. Hence the Indian RP community including academia need to invest their time and synergy in recording and on mitigating the criticality of RP patterns to commercialize and popularize RT route in precision casting. This only can win the confidence of Indian Precision Casters before we transfer of RT technology to them..

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