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Some Investigations on Surface Quality of Aluminium Matrix Composite Developed Using Modifi ed FDM Pattern Based Rapid Investment Casting

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Abstract - The prototypes prepared by using fused deposition modelling (FDM) usually have highly rough surface due to staircase effect. This is the main obstacle in rapid investment casting (RIC) where FDM based replicas are employed as master pattern. Present research work is focused to improve the surface finish of aluminium matrix composite (AMC) by altering the levels of process variables (like: dimension of master pattern, density of master pattern and number of slurry layers) using Taguchi L9 OA. FDM filament with 60%nylon-30%Al-10%Al_2O_3 proportion has been used for preparation of master pattern. AMC was developed using Al6063 alloy through RIC route at recommended parameters. Results indicated that input parameters significantly affected the roughness of AMCs prepared.

Keywords: Aluminium Matrix Composite, Fused Deposition Modelling, Investment Casting, Surface Roughness.

I. INTRODUCTION

Today, metal matrix composites (MMCs) are classified as one of the most popular category of materials used for engineering applications. Aluminum based composites have caught all the attractions because of their potential advantages, such as flexibility, light weight, high wear resistance, high thermal conductivity, improved modulus of elasticity and strength [Lui *et al*, 1999, Kaczmar *et al*, 2000].

Lot of researches has been focused on the development and characterization of aluminium matrix composites (AMCs) during last two decades [Miracle, 2005]. A wide variety of techniques like; vapor state methods, liquid phase methods and solid state methods have been explored for AMCs development [Harrigan, 1998, Degischer, 1997]. Particle reinforced AMC based on liquid processing route (casting route) have received particular preponderance of researchers [Lloyd, 1994, Surappa, 2003]. Further, considering the factors including poor machinability and workability of components in AMCs, investment casting (IC) process could be a valuable option for producing complex geometrical products [Ralph et al, 1997]. IC method is a precision casting process, capable of producing highly accurate and intricately detailed casting. This process involves wax patterns coated with refractory material to make shell mould. Wax is then drained out and molten metal is poured into resulting cavity once autoclaved.

Despite of various advantageous of IC process in foundries, conventional IC process suffered badly from high tooling costs and lengthy lead times associated with the fabrication of metal moulds required for producing the sacrificial wax patterns used in IC [Sachs et al, 1992]. Assistance of rapid prototyping techniques (RPT) in conventional IC process have proved for significant reduction in cycle time and production cost as patterns and moulds can be rapidly fabricated using RPTs [Chakradeo and Kulkarni, 2002, Rooks, 2012, Wang et al, 2010].

Fused deposition modelling (FDM) is one of the commercially available RPTs that work on principle of additive manufacturing by employing a heated nozzle to melt and extrude Acrylonitrile-butadiene-styrene (ABS) filament on platform. FDM assisted IC process enjoys advantages like: low maintenance costs, quick production of thin parts, clean burnout, robustness and dimensional stability [Chua et al, 1999, Dickens et al, 1995, Pal et al, 2002]. The schematic of FDM machine is shown in Figure 1.

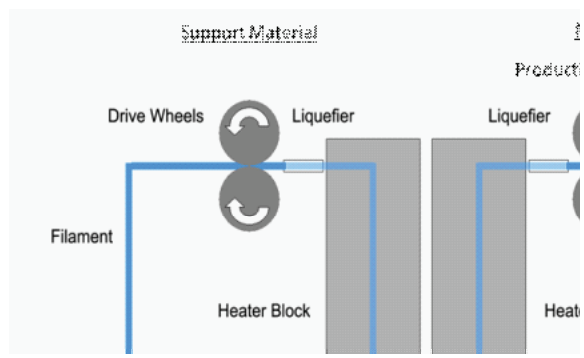

Fig. 1 Schematic of FDM

Apart from ABS, researches have been carried out for the development of alternative feedstock FDM filament at various universities and institutions around the world to increase its applications [Masood 1996, Zhong et al, 2001, Masood and Song, 2004, Nikzad et al. 2007].

In present research work, an alternative route has been selected for the development of AMC by using reinforced (abrasive) FDM filament [Patent File No. 2847/DEL/2013]. Taguchi L9 orthogonal array has been used for the optimization of the surface roughness of AMCs developed and to study the affect of process parameters; volume of pattern (V_P), density of FDM pattern (P_D) and number of IC layers (L) on surface roughness. Cubical geometry was selected as benchmark (pictorial view shown in Figure 2).

Fig. 2 Pictorial view of benchmark

II. EXPERIMENTATION

The first step in this research work was to match the melt flow index (MFI) of proportions of nylon, Al_2O_3 and Al mixture with commercially used ABS filament on melt flow tester shown in Figure 3. It has been observed that MFI of 60%nylon, 30%Al and 10%Al_2O_3 proportions matched the MFI of ABS. Selected proportions was fabricated on single screw extruder as shown in Figure 4 and used to fabricate cubical shaped pattern with three different volumes i.e. 17576mm^3, 27000mm^3 and 390304mm^3 at three densities of FDM system i.e. low density (L.D), high density (H.D) and solid (S). Pattern developed thus attached with riser and IC tree is stucco coated and moulds were prepared by varying number of IC layers to 7, 8 and 9. Al-6063 alloy was poured into cavity obtained after autoclaving of mould at 1100°C. Finally casted AMC specimens are shown in Figure 5. Table I shows the category of input parameters selected and their levels. Taguchi L9 orthogonal array has been used to design final control log of experimentation (refer Table II).

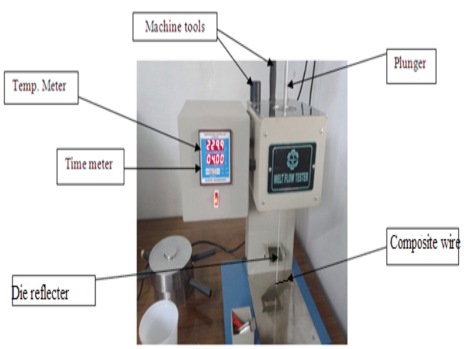

Fig. 3 Melt flow tester

TABLE I INPUT PARAMETERS

Parameter 1	V_P (mm^3)	L1	17576
		L2	27000
		L3	39304
Parameter 2	P_D	L1	L.D
		L2	H.D
		L3	S
Parameter 3	L	L1	7
		L2	8
		L3	9

TABLE II CONTROL LOG FOR EXPERIMENTATION

S. No.	V_P (mm^3)	P_D	L
1	17576	L.D	7
2	17576	H.D	8
3	17576	S	9
4	27000	L.D	8
5	27000	H.D	9
6	27000	S	7
7	39304	L.D	9
8	39304	H.D	7
9	39304	S	8

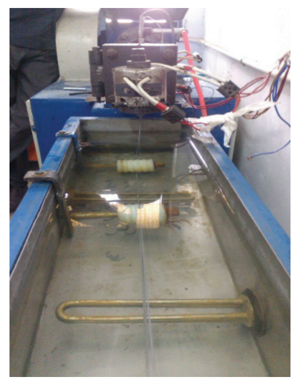

Fig. 4 Single Screw Extruder

Fig. 5 Casted AMC

III.RESULTS AND DISCUSSION

The surface roughness of casted AMCs was tested using Mitutoyo SJ-210 surface tester. Based on control log of experimentation (refer Table II), three sets of experiments were made under three repetitions (R1, R2 and R3) are shown in Table III.

S/N response for surface roughness was plotted using Minitab-16 using "smaller the better" condition as shown in

Figure 6. Where A, B and C represents the V_P, D_P and L respectively. Average values of surface roughness in Table III were used to calculate percentage contribution of input parameters in Design-Expert 6.0.8 version software. Table IV shows the percentage contribution of input parameters.

In case of parameter 'V_P', it has been found that surface roughness of casted AMCs was produced best, when cubical volume of 17576mm^3 was used. It has been observed from Figure 6 that as volume of cubical pattern increased from 17576mm^3 surface roughness became poor. It may be due to FDM staircase affect in manufacturing which increased with pattern volume. As slicing step in FDM prototyping is an approximation of the original (computer aided) model depending upon geometry and produces a physical object. Larger the volume of geometry more will be the impact of staircase affect and hence the roughness of the FDM parts. Further in case of parameter 'D_P', it has been seen that increase in density affected the roughness of the castings. Generally, pattern density was an option available in FDM system that affects the part weight. This is due to the fact that patterns fabricated at 'S' option of FDM were having maximum quantity of Al_2O_3 particles hence rough casting surfaces were produced.

Similarly, in case of 'L' it has been found that surface roughness of the castings was produced best at 9 numbers of layers. Heat transfer rate of the matrix metal at this particular level of 'L' was decreased due to thicker shell mould resulted into smaller sized grains.

TABLE III OBSERVA.TIONS OF SURFACE ROUGHNESS

S. No.	Surface roughness (μm)			
	R1	R2	R3	Avg.
1	4.417	5.303	5.632	5.117
2	5.676	4.136	4.86	4.890
3	4.954	5.148	5.279	5.127
4	4.71	4.64	5.028	4.792
5	4.985	5.176	5.149	5.103
6	5.249	5.875	4.968	5.364
7	4.929	4.865	4.662	4.818
8	5.124	5.291	6.104	5.506
9	5.702	5.414	4.989	5.368

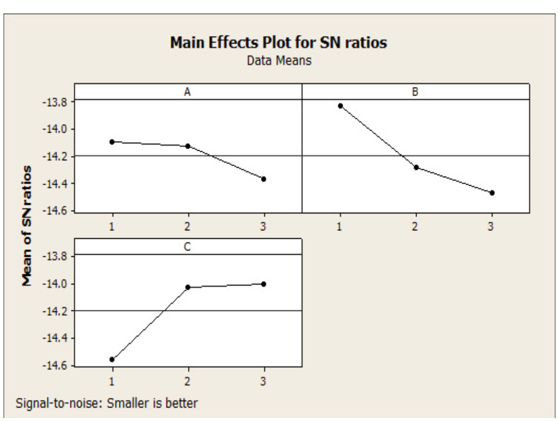

Fig. 6 S/N ratio for surface roughness

TABLE IV PERCENTAGE CONTRIBUTION FOR SURFACE ROUGHNESS

Parameter	V_P (mm^3)	P_D	L	Interaction of V_P and P_D
Percentage contribution (%)	10.14	43.36	37.21	9.29

IV.CONCLUSIONS

From present research work following conclusions may be drawn:

1. AMCs have been successfully developed using reinforced FDM based pattern in IC process.
2. As the volume of FDM based pattern increased surface roughness of final casting also increased due to staircase affect involved in FDM manufacturing. Pattern manufactured at solid density option of FDM machine consisted of higher quantity of Al_2O_3 particles. So high surface roughness obtained at this particular level. Heat transfer rate of the matrix metal is affected by mould wall thickness. It has been concluded that at 9 number of layers heat transfer rate was poor and solidification occurred at self cooling rate which resulted into small sized grains.
3. According to Taguchi L9 array surface roughness of AMCs was obtained best at; V_P-17576mm^3, D_P-L.D and L-9. Confirmatory experiment was performed at proposed parametric setting highlighted 6.79% improvement in surface roughness.
4. Further the results of present study highlights that the percentage contribution of input parameters for surface roughness is: V_P-10.14%, D_P-43.36% and L-37.21%. Whereas, parameter V_P and D_P have interaction of 9.29%.
5. The study may be further carried out with more number of input parameters and their levels.

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