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Process Capability Analysis of MMC Prepared by Combining FDM, Vacuum Moulding and Stir Casting

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***Abstract* - There has been a critical need for development of cost-effective aluminum (Al) based metal matrix composites (MMCs) for various industrial applications. But hither to no work has been reported for process capability analysis of Al based MMC prepared by combining fused deposition modelling (FDM), vacuum moulding and stir casting process. In the present work an approach to macro-model the hardness of Al based MMC have been proposed and applied for process capability analysis. The relationship between hardness and other input parameters have been deduced by using Taguchi technique L9 orthogonal array. The result of study indicate that value of process capability indices is greater than 1 for the MMC developed by combining FDM, vacuum moulding and stir casting process. Hence the process can be used for commercial batch production activities.**

***Keywords:* Fused deposition modeling, Vacuum moulding, Hardness, Process capability, Stir casting.**

I. Introduction

FDM is one of the RP process which works on the principle of additive method [1]. In FDM process the part is fabricated by deposition of layers. This process is able to quickly fabricate complex-shaped, 3D parts directly from computer-aided design models. A plastic filament or metal wire is unwound from a coil and supplies material to an extrusion nozzle which can turn the flow on and off as shown in Fig.1.

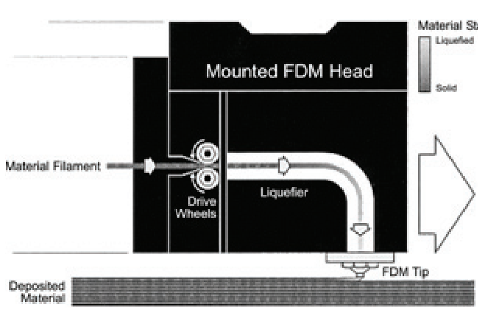

Fig. 1 Schematic of FDM [2]

In vacuum moulding process the pattern made from wood is normally used [3]. This process is different from sand casting as it does not required binder for sand holding. In this process polymer sheet is used to seal the open ends of mould [4]. The term "composite" broadly refers to a material system which is composed of a discrete constituent (the reinforcement) distributed in a continuous phase (the matrix) and which derives its distinguishing characteristics from the properties of its constituents, from the geometry and architecture of the constituents and from the properties of the boundaries (interfaces) between different constituents [5]. Al based MMC are used for manufacturing automotive parts (pistons, pushrods, brake components), brake rotors for high speed trains, bicycles, electronic substrates, cores for high voltage electrical cables [6]. For developing MMC, stir casting is one of the simplest and the most cost effective method of liquid state fabrication [7]. A dispersed phase (ceramic particles, short fibers) is mixed with a molten matrix metal by means of mechanical stirring. Liquid state composite material is then cast by conventional casting methods and may also be processed by conventional metal forming technologies [8]. The literature review reveals that lot of research work has been reported independently on development of MMC by stir casting, process, optimization of FDM and vacuum moulding process. But hitherto very less work has been reported on combining of FDM, vacuum moulding and stir casting for development of the MMC. So in the present work it is proposed to study process capability of MMC prepared by combining of FDM, vacuum moulding and stir casting process. Following are the objectives of study:-

- Process capability analysis of combined FDM, vacuum moulding and stir casting process.
- To develop a model for hardness of MMC based upon Taguchi approach.

II. Design of Experiments

Before going for the final experimentation, pilot experiments were conducted in order to analyze the contributing parameters and their levels. For the present study different sizes of ‘ABS’ patterns were made on FDM. The input parameters of the pilot experiment were the vacuum conditions (which were with vacuum pressure 0.04 N/mm^2 and 0.06 N/mm^2, sand grain size 50 and 70, and compositions (Al-5%SiC, Al-10% SiC).The parameters like molten metal temperature, plastic film thickness were kept constant for the components. The output parameter of the study was micro hardness of MMC. Table1 shows observations of pilot experimentation.

Table 1 Pilot Experiment Observations

S. No.	Composition	Grain size (AFS No.)	Vacuum pressure (N/mm^2)	Micro hardness (HV)
1	Al-5% SiC	50	0.04	70
2	Al-10% SiC	70	0.06	43
3	Al-5% SiC	50	0.04	57
4	Al-10% SiC	70	0.06	50
5	Al-5% SiC	50	0.04	57
6	Al-10% SiC	70	0.06	41

After conducting the pilot experimentation it has been observed that input parameters like vacuum pressure, grain size and composition have some significant effect on the HV of the MMC. For the optimization of process, design of final experiments was made according to Taguchi’s L9 orthogonal Table II shows control log for final experimentation.

Table II Control Log for Experimentation

S. No.	Composition	Grain size (AFS No.)	Vacuum pressure (N/mm^2)
1	Al-5%SiC	50	0.04
2	Al-7.5%SiC	60	0.05
3	Al-10%SiC	70	0.06
4	Al-5%SiC	50	0.04
5	Al-7.5%SiC	60	0.05
6	Al-10%SiC	70	0.06
7	Al-5%SiC	50	0.04
8	Al-7.5%SiC	60	0.05
9	Al-10%SiC	70	0.06

III. RESULTS AND DISCUSSION

Based upon Table II, three repetitions of experiment were made as R1, R2 and R3 for measurement of HV (Ref. Table III). Based upon Table III, Table IV shows sum of squares and signal to noise (S/N) ratio for present set of experiments.

Table III Observations of Final Experimentation for HV

S. No.	HV		
	R1	R2	R3
1	69.33	69.32	68.98
2	56.67	55.76	56.77
3	56.67	56.7	55.88
4	47.86	48.01	47.88
5	52.77	53.01	52.78
6	54.45	54.47	54.43
7	42.82	42.79	41.87
8	49.15	48.97	49.1
9	40.92	41.02	40.94

Table IV S/N Ratio For HV

S.No.	Sum squar	S/N ratio	Average
1	0.000209	36.8033	69.21
2	0.000314	35.02473	56.4
3	0.000314	35.02755	56.41667
4	0.000436	33.60971	47.91667
5	0.000358	34.46139	52.85333
6	0.000337	34.71996	54.45
7	0.000554	32.565	42.49333
8	0.000415	33.81688	49.07333
9	0.000596	32.24718	40.96

Based upon Table IV, Fig.2 - 4 shows the highest value of the S/N ratio and HV w. r. t. to composition, grain size, and vacuum pressure and Fig 5 shows pie chart for percentage contribution of input parameters for HV.

Further based upon Fig. 2-4, final experimentation have been carried out at optimized settings suggested by Taguchi design (that is composition Al-5%SiC, grain size 60 (AFS No.), vacuum pressure 0.04 N/mm^2) and six set of observations have been recorded (Ref. Table V). Based upon Table V, Fig.6, 7 respectively shows histogram and normal curve for HV and Table VI shows Cp and Cpk values for HV.

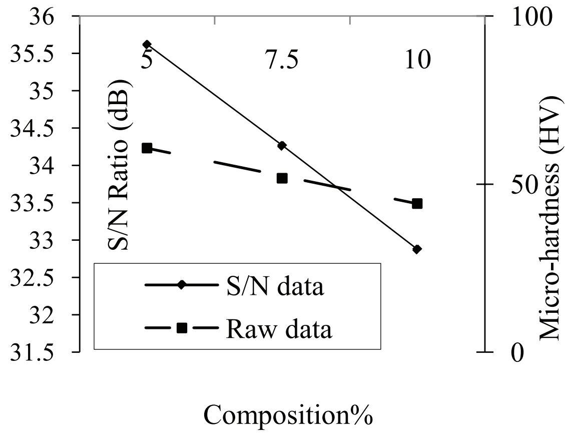

Fig. 2 S/N ratio and HV w. r. t. to composition

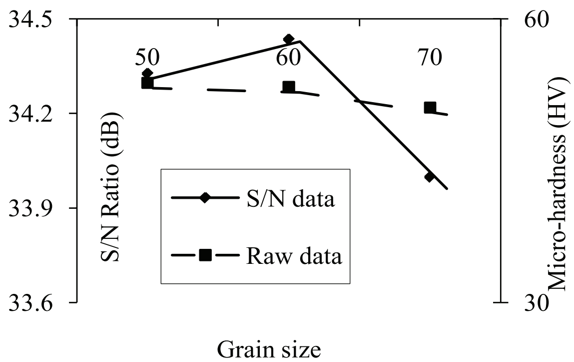

Fig. 3 S/N ratio and HV w. r. t. to grain size

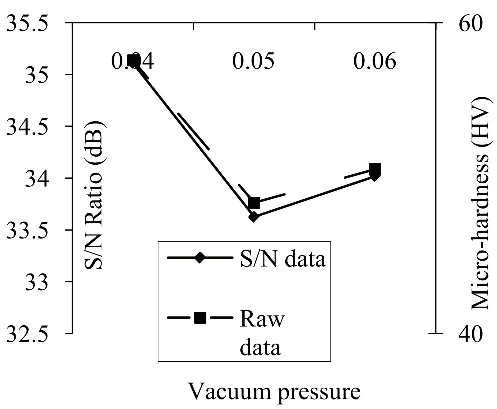

Fig. 4 S/N ratio and HV w. r. t. to vacuum pressure

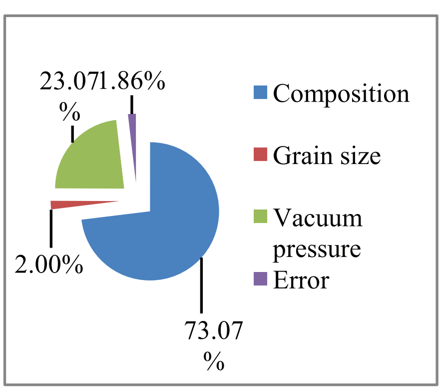

Fig.5 Pie Chart for contribution of HV

TABLE V OBSERVED HV AT OPTIMIZED SETTINGS

S. No.	Observed HV
1	54.00
2	54.32
3	54.64
4	54.55
5	54.32
6	54.21

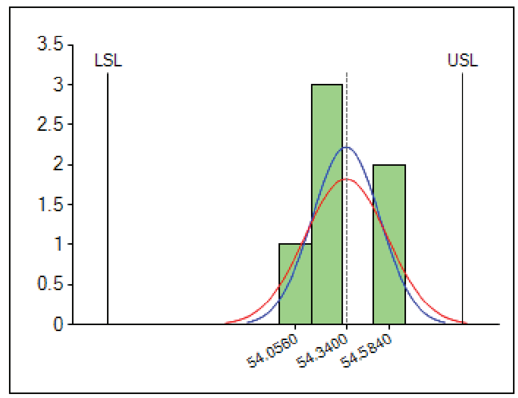

Fig. 6 Histogram for observed values of HV at optimized settings

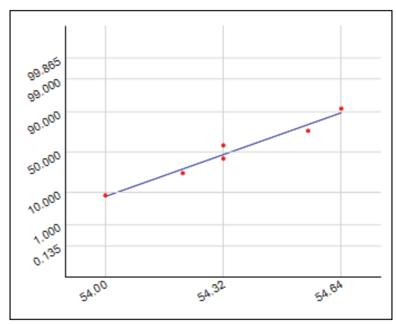

Fig. 7 Normal probability curve for observed values of HV at optimized settings

TABLE VI CP AND CPK VALUES FOR HV AT OPTIMIZED SETTINGS

Readings	6	Potential Capability	
Tolerance Range		Std. Deviation	0.189716
USL	55	Cp	1.757
Target	54	Cpu	1.160
LSL	53	Cpl	2.354
Tolerance	2	Cpk	1.160
Normality Test		CR	0.569
Cpm	0.811	PPM	251.8

These results are valid for 95% confidence level and results are in line with the observations made by other investigators [7-10].

IV. Conclusions

The contribution of input parameters to HV of casting is: composition73.06%, grain size 2.00%, and vacuum pressure 23.06%. Optimized setting of input parameters for the maximum HV is composition Al-5% SiC, vacuum pressure 0.04 N/mm^2, and grain size 60. The results of study suggests that value of process capability indices is greater than 1 for the MMC developed by combining FDM, vacuum moulding and stir casting process. Hence the process can be used for commercial batch production activities.

Acknowledgement

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