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CASE STUDY

Process Capability Analysis of Vacuum Moulding for Development of Al-Al_2O_3 MMC

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Abstract The purpose of the present study is to investigate process capability of vacuum moulding (VM) for development of Al-Al_2O_3 metal matrix composite (MMC). Starting from the identification of component, prototypes were prepared (with three different input parameters namely: vacuum pressure; component volume and sand grit size to give output in form of dimensional accuracy). Measurements on the coordinate measuring machine helped in calculating the dimensional tolerances of the Al-Al_2O_3 MMC prepared. Some important mechanical properties were also compared to verify the suitability of the components. Final components produced are acceptable as per ISO standard UNI EN 20286-I (1995). The results of study suggest that VM process lies in ±4.5 sigma (σ) limit as regard to dimensional accuracy of Al-Al_2O_3 MMC is concerned. This process ensures rapid production of pre-series technological prototypes and proof of concept at less production cost and time.

Keywords Al-Al_2O_3 MMC · Process capability · Vacuum moulding

Introduction

VM process is distinctly different from other sand casting processes as the process requires no binders for holding the sand grains together in the mould [1]. The vacuum inside the mould results in a net pressure pushing in, holding the sand rigidly in the shape of the pattern, even after the pattern is removed. In this process sand thermal conductivity is lower and metal fluidity is improved [2]. However solidification time is slower. Fine surface finish and excellent dimensional accuracy, no moisture related defects, no cost for binders, excellent sand permeability, and no toxic fumes from burning the binders are key advantages of VM [3, 4]. The literature review reveals that lot of work has been reported on optimization of VM process [5, 6]. Some researchers have highlighted development of MMC by VM [7, 8]. But hitherto very less has been reported on process capability analysis of Al-Al_2O_3 based MMC with VM. So, in the present work effort has been made to understand the process capability of VM process for development of Al-Al_2O_3 based MMC. Singh [8] outlined a Taguchi based model for development of Al-5 %Al_2O_3 based MMC. In the present work, this model has been used further for process capability analysis of VM. Figures 1 and 2 shows schematic and 3D view of VM machine used for present study.

For preparation of MMC commercially pure Al (≥99 %) was melted in a silicon-graphite crucible by an induction furnace. The composition of Al with Al_2O_3 was fixed as Al-5 %Al_2O_3. Al was preheated up to a temperature of 450 °C and particles of Al_2O_3 up to a temperature of 1,100 °C in core drying oven. Crucible used for pouring of composite slurry in the mould was also heated up to 760 °C. The stir caster was mounted on the furnace with the help of four legs. Mild steel was chosen as stirrer and impeller material. It has been used to obtain an output of 600 rpm.

Table 1 shows input parameters and their levels (based upon Taguchi L9 OA) for process capability analysis of VM process.

Based upon Table 1, Fig. 3 and Table 2 respectively shows contribution of input parameters on dimensional

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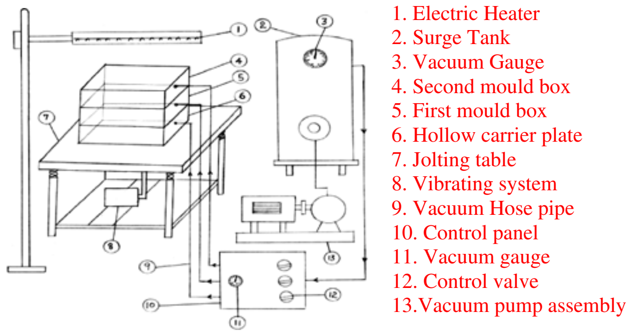


Fig. 1 Schematic of VM machine [8]

Fig. 2 3D view of VM machine [8]

Table 1 Input parameter and their levels [8]

S. no.	Vacuum (kPa)	Volume (mm^3)	AFS No.
1	40	42,411.50	70
2	54	42,411.50	60
3	68	42,411.50	50
4	40	57,726.76	60
5	54	57,726.76	50
6	68	57,726.76	70
7	40	75,398.22	50
8	54	75,398.22	70
9	68	75,398.22	60

accuracy and macro model of dimensional accuracy for Al-5 %Al_2O_3 MMC in VM.

These optimized settings (Ref. Table 2) has been used for process capability analysis. There are three sections in this paper. Following this introduction section, process capability analysis has been highlighted. Conclusions are drawn in last section followed by references.

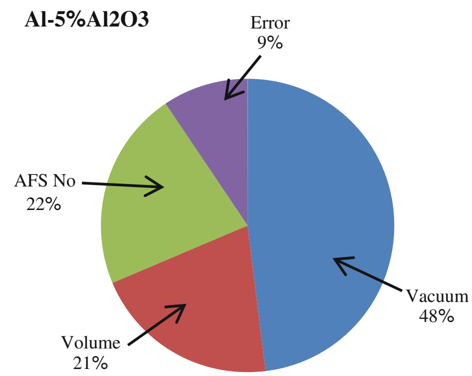


Fig. 3 Contribution of various input parameters for dimensional accuracy of MMC in VM

Table 2 Macro model of dimensional accuracy for Al-5 % Al_2O_3 MMC in VM [8]

S. no.	Name of parameter	Optimized setting
1	Vacuum	54 kPa
2	Volume	42,411.50 mm^3
3	AFS No.	70

Process Capability Analysis

Figure 4 shows dimensions of benchmark used for study. The input parameters were kept constant based upon Table 2. The CMM machine was used to measure the critical dimensions of the specimens. Table 3 shows measured dimension for critical dimensions 15, 60, 70 and 80 mm.

The result of the dimensional measurement have been used to evaluate the tolerance unit 'n' that drives starting from the standard tolerance factor 'i', defined in standard UNI EN 20286-I(1995). The standard value of tolerance was evaluated by considering the standard tolerance factor **i** (μm) as: $i = 0.45 \times D^{1/3} \pm 0.001 \times D$, Where 'D' is the geometric mean of the range of nominal size in mm. In fact, the standard tolerance are not evaluated separately for each nominal size, but for a range of nominal size, for the generic nominal dimension D_{JN}, the number of tolerance unit n is evaluated as follows: $n = 1{,}000\ (D_{JN} - D_{JM})/i$, Where D_{JM} is the measured dimension. Tolerance is expressed as a multiple of 'i'. Table 4 shows the classification of different IT grade according to UNI EN 20286-I (1995) for $D1_=60.00$ mm. Similarly IT grades for D2, D3 and D4 were calculated, which are consistent according to ISO standard UNI EN 20286-I (1995).

The data collected for the nominal dimensions D1, D2, D3 and D4 shown in Table 2 has been used for process capability analysis. Figures 5, 6, 7 shows R chart, X chart and process capability histogram for nominal dimension

Fig. 4 Benchmark dimension

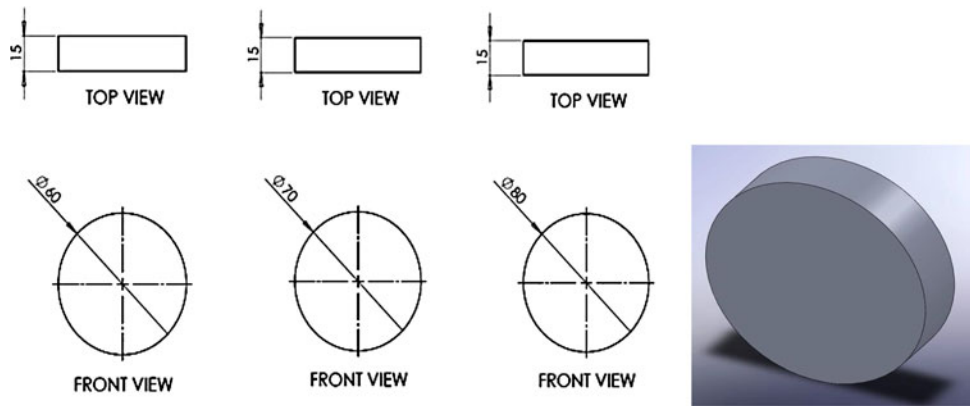


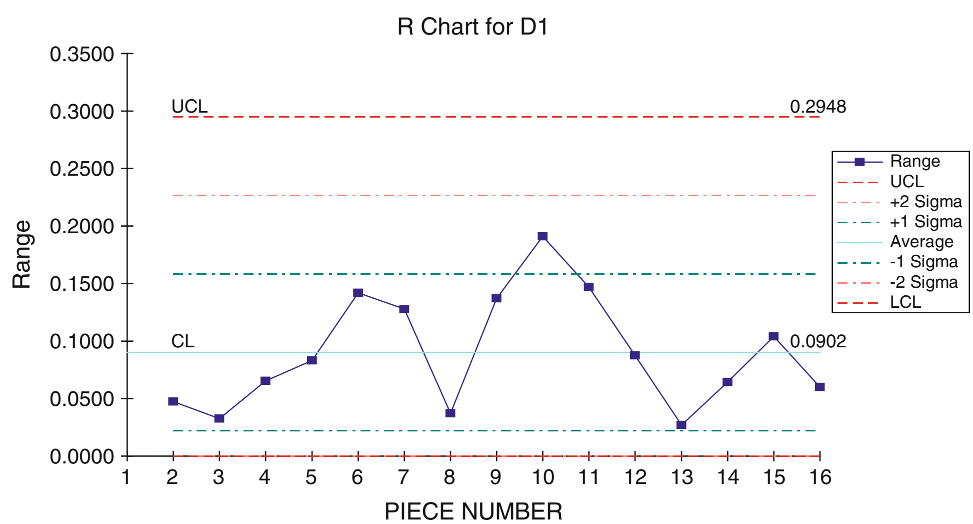
Table 3 Measured dimensions for final experimentation

Sample no.	D1 = 60 mm	D2 = 70 mm	D3 = 80 mm	D4 = 15 mm
1	59.8100	70.0203	79.9216	15.7129
2	59.8575	69.9710	79.9506	15.7534
3	59.8901	70.0508	80.0791	15.6734
4	59.8248	70.0510	80.0335	15.5921
5	59.9080	69.9559	79.9713	15.6939
6	60.0500	70.0754	79.9689	15.6578
7	59.9222	70.0102	80.0276	15.6718
8	59.8851	70.0247	80.0738	15.5934
9	60.0223	70.0300	80.0324	15.6820
10	59.8313	70.0503	79.9470	15.5977
11	59.9782	69.9776	80.0279	15.6119
12	59.8908	70.0152	80.0113	15.6988
13	59.9178	70.0318	80.0228	15.6366
14	59.8534	69.9812	79.9813	15.6191
15	59.9575	70.0777	80.0332	15.6225
16	59.8974	70.0258	79.9786	15.6811

Table 4 IT grades for D1 = 60 mm

Sample no.	D_{JM}	n	IT grades
1	59.8100	104.39	IT10
2	59.8575	78.29	IT10
3	59.8901	60.38	IT9
4	59.8248	96.26	IT10
5	59.9080	51.64	IT9
6	60.0500	27.47	IT7
7	59.9222	42.74	IT8
8	59.8851	63.13	IT9
9	60.0223	12.52	IT5
10	59.8313	92.69	IT10
11	59.9782	11.99	IT5
12	59.8908	60.00	IT9
13	59.9178	45.16	IT9
14	59.8534	80.54	IT10
15	59.9575	23.35	IT7
16	59.8974	56.37	IT9

Fig. 5 R chart for the dimension nominal dimension D1



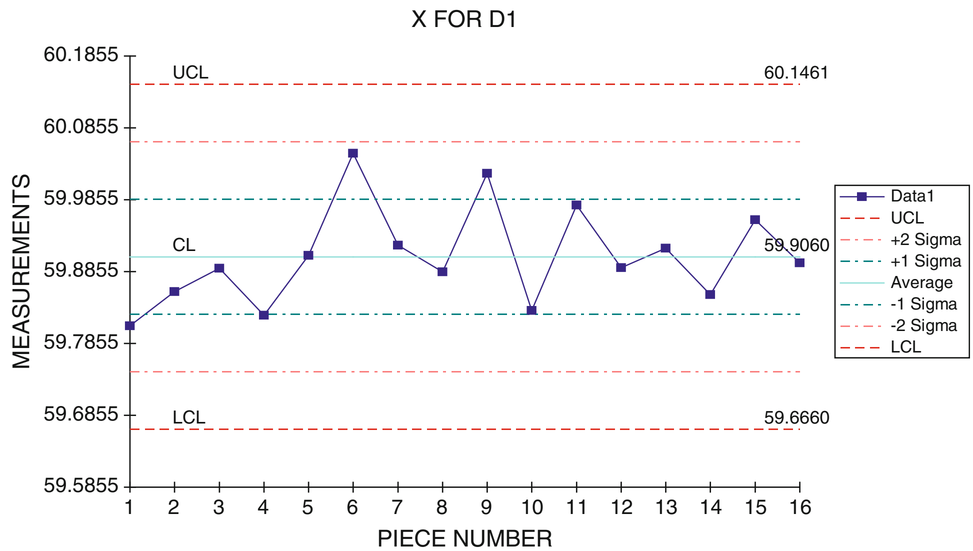


Fig. 6 X chart for nominal dimension D1

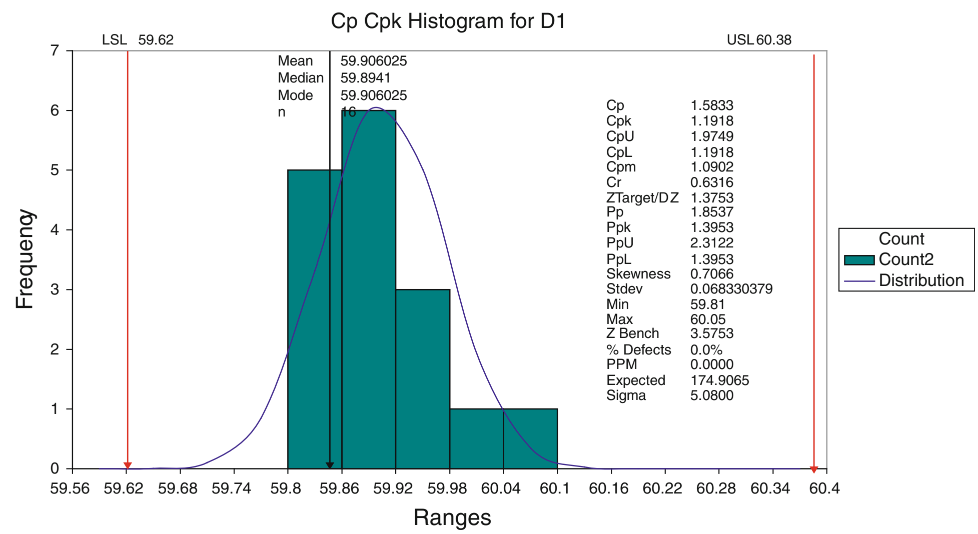


Fig. 7 Process capability study histogram for nominal dimension D1

Table 5 statistical analysis for nominal dimension D1

Cp	1.5833
Cpk	1.1918
Mean of data	59.906
LSL	59.62
USL	60.38
Minimum value	59.81
Maximum value	60.05
SD	0.068
Range	0.24
Target dimension	60

D1. Table 5 shows values of Cp, Cpk and other data for nominal dimension D1. For Cpk value of 1.5, the area under normal curve is 0.999993198 and non conforming ppm is 6.8016. Similarly Cp and Cpk values for other dimensions (D2, D3 and D4) were calculated. The value of Cpk for all critical dimensions is >1.33. The results of study suggest that VM process lies in ±4.5 sigma (σ) limits as per as dimensional accuracy of MMC is concerned.

Conclusions

The result of study suggests that VM is a highly capable process. It is observed that the value of Cpk for all the four critical dimensions were >1.33. As Cpk values of 1.33 or greater are considered to be industry benchmarks, so this process will produce conforming products as long as it remains in statistical control.

The tolerance grades of the MMC produced are consistent with the permissible range of tolerance grades (IT grades) as per ISO standard UNI EN 20286-I (1995). So it is concluded that the parts produced by VM are acceptable in terms of accuracy as per industrial requirements.

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