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APPLICATION OF RESPONSE SURFACE METHODOLOGY ON SURFACE ROUGHNESS IN GRINDING OF AEROSPACE MATERIALS (6061Al-15Vol%SiC_{25P})

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ABSTRACT

In this paper, the effects and the optimization of machining parameters on surface roughness in the grinding of 6061Al-SiC_{25P} (MMCs) specimen are investigated. In the grinding process, a machining parameter, such as hardness of the specimen, flow rate of the coolant and depth of cut while machining were chosen for evaluation by the response surface methodology. By response surface methodology, a complete realization of the process parameters and their effects were achieved. The variation of surface roughness with machining parameters was mathematically modeled using response surface methodology. Finally, experimentation was carried out to identify the effectiveness of the proposed method.

Keywords: metal matrix composites, response surface methodology, surface roughness, ANOVA.

1. INTRODUCTION

Reinforced metal matrix composites (MMCs) are finding wide application in aeronautics, astronautics, and automobile industries. Reinforced metal matrix composites (MMCs) offer an advantage in applications where good capability to withstand relatively high temperature is needed, besides the requirements of high specific strength and stiffness, which are typical features of composite materials. MMCs are often fabricated with near-net-shape processing techniques both traditional, such as precise casting and forging [1], and innovative, such as a variety of spray techniques [2]. However, a number of secondary machining operations are always necessary.

The main concern when machining MMC is the extremely high tool wears due to the abrasive action of the ceramic fibers or particles. Therefore, materials of very high resistance to abrasive wear, like polycrystalline diamond tipped tools (PCDs), are often recommended [3-8]. Tungsten carbide tools are not effective for the machining of these materials and their use should be limited to cases where diamond tipped tools are not available, such as for twist drills and taps with diameter lower than 3 mm [4]. Recently, a special tool fixturing which minimizes the sliding of the hard particles against the tool faces has been proposed and it has been shown that the wear resistance of tungsten carbide tools can be enhanced up to values comparable to diamond tools [5]. The grinding of MMCs has received little attention. To the authors' knowledge there is one paper ceiling with the grinding of Al_2O_3 short fibre reinforced MMCs [9]: the main results are the independence of the surface finish of the grinding parameters and the superiority of diamond and CBN wheels over conventional abrasives. Another paper focuses on the necessity of using grinding wheels for the removal of gates in MMC castings [10]. The machining guidelines of one producer of MMCs provide some indications on grinding wheels [11]. As is well known, the grinding process does not perform very well for soft materials due to the tendency of the chips to clog the wheel. However, the grinding process plays an important role in secondary machining operations on MMC parts due to the free cutting tendency of these materials [3]. The grinding process might also be possible in heavy-duty grinding operations, where a single grinding process could be economic, which eliminates the need for prior metal cutting processes [12].

In this work an experimental investigation was performed in order to assess some grinding characteristics of MMCs.

2. EXPERIMENTAL

Al-SiC specimens having aluminum alloy 6061 as the matrix and containing 15 vol. % of silicon carbide particles of mean diameter 25µm in the form of cylindrical bars of length 120mm and diameter 20mm. The specimens are manufactured at Vikram Sarbhai Space Centre (VSSC) Trivandrum by Stir casting process with pouring temperature 700-710°C, stirring rate 195rpm. The specimen are further extruded at 457°C, with extrusion ratio 30:1, and direct extrusion speed 6.1m/min to produce Ø20mm cylindrical bars. The extruded specimens were solution treated for 2 hr at a temperature of 540°C in a muffle furnace; Temperatures were accurate to within ±2°C and quench delays in all cases were within 20s. After solution treatment, the samples were water quenched to room temperature, and subsequently aged for six different time span to obtain optimum peakage and over age time and according to macrohardness measurement. A span of 2 h and 24 h were accepted as peak-aging and over-aging time respectively. All aged and solutionized samples were kept in a refrigerator immediately after the heat treatment. In order to observe the effect of matrix hardness on grinding of the composite materials three samples had been selected (Table-1). A cross-section of a 6061 Al MMCs specimen composite material is shown in Figure-1.

ARPN Journal of Engineering and Applied Sciences

The selected experimental material was manufactured by stir casting process. The chemical composition of specimens is given in Table-2. The experimental study carried out in cylindrical grinding machine. Surface condition of machined work piece was observed using JEOL JSM-6380LA; Analytical scanning electron microscope. Surface roughness was measured using Taylor/Hobson surtronoic 3+ surface roughness measuring instrument as shown in Figure-2. Experimental setup of cylindrical grinding process is shown in Figure-3.

Table-1. The heat treatment conditions and hardness results.

Heat treatment	Solution treatment	Quench condition	Aging treatment	Hardness [BHN]
As-Extruded	-	-	Non-aged	68
Aged for 2h (PA)	1h at 540^{0}C	Water quench at 200^{0}C	2h at 220^{0}C	94
Aged for 24h (OA)	1h at 540^{0}C	Water quench at 200^{0}C	24h at 220^{0}C	81

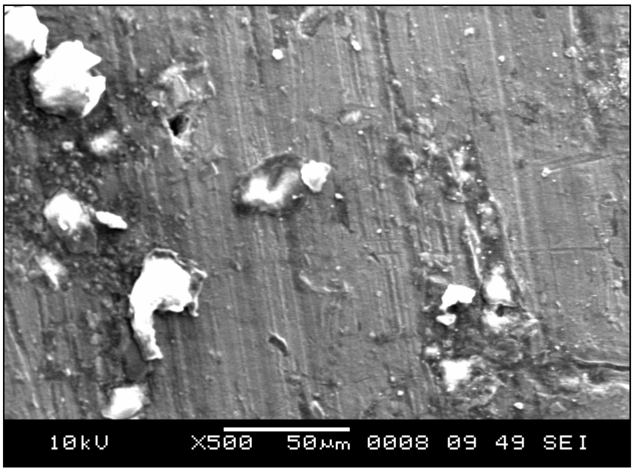

Figure-1. A cross-section of a 6061 Al MMCs specimen.

Table-2. Nominal chemical composition of base metal (6061 Al alloy).

Element	Cu	Mg	Si	Cr	Al
Weight percentage	0.25	1.0	0.6	0.25	Balance

Figure-2. Roughness measurement equipment.

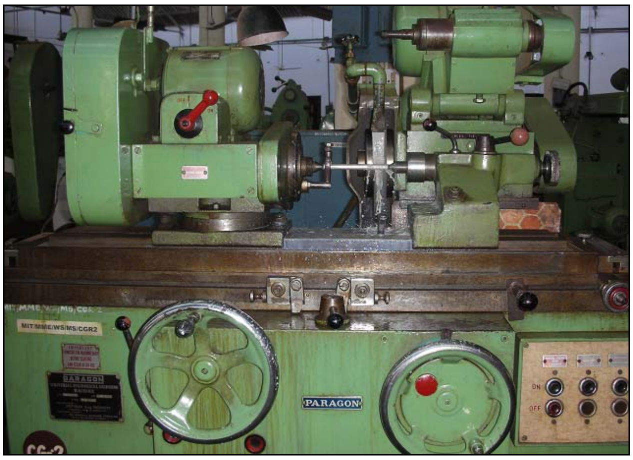

Figure-3. Experimental setup.

2.1 Response surface methodology

The surface finish of machined surface is important in engineering Applications which have considerable effect on wear resistance, light reflection, heat transmission, coating and resisting fatigue of the material. While machining, quality of the parts can be achieved only through proper cutting conditions. In order to know the surface quality and dimensional properties in advance, it is necessary to employ theoretical models making it feasible to do predict the response as a function of operating conditions [13]. Response surface methodology (RSM) is a mixture of mathematical and statistical technique which is useful for modeling and analysing the problems in which a response of interest is influenced by several variables and the objective is to optimize that response [14].

In many engineering fields, there is a relationship between an output variable of interest 'y' and a set of controllable variables $\{x_1, x_2 \ldots x_n\}$. In some systems, the nature of the relationship between y and x values might be known. Then, a model can be written in the form

$$y = f(x_1, x_2, \ldots, x_n) + \varepsilon$$

Where ε represents noise or error observed in the response y. If we denote the expected response be

$$E(y) = f(x_1, x_2, \ldots, x_n) = \hat{y}$$

then the response surface represented by

$$\hat{y} = f(x_1, x_2, \ldots, x_n)$$

In most of the RSM problems, the form of relationship between the response and the independent variable is unknown. Thus the first step in RSM is to find a suitable approximation for the true functional relationship between y and set of independent variables employed. Usually a second order model is utilized in response surface methodology [15-22].

$$\hat{y} = \beta_o + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i} \sum_{j} \beta_{ij} x_i x_j + \varepsilon$$

The β coefficients, used in the above model can be calculated by means of using least square method. The second-order model is normally used when the response function is not known or nonlinear.

3. RESULTS AND DISCUSSIONS

The experiments were conducted with three factors at three levels. L_{27} orthogonal array was used for the elaboration of the plan of experiments, which has 27 rows corresponding to the number of tests (26 degrees of freedom) with 13 columns at three levels. The factors and the interactions are assigned to the columns. The first column was assigned to the Hardness in BHN (A), the second column to Depth of cut in mm (B), the fifth column to the Flow rate in ml/min(C) and remaining were assigned to interactions. The output to be studied was the surface roughness. The selected levels and factors in machining of MMCs are shown in Table-3.

Table-3. Levels and factors.

Levels	(A) **Hardness** (BHN)	(B) **Depth of cut** (mm)	(C) **Flow rate** (ml/min)
1	68	0.04	780
2	81	0.06	1080
3	94	0.08	1380

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3.1 Response surface analysis

The second order response surface representing the surface roughness (Ra) can be expressed as a function of cutting parameters such as (A) Hardness (BHN), (B) Depth of cut (mm), and (C) Flow rate (ml/min). The relationship between the surface roughness and machining parameters has been expressed as follows:

$$\beta_0 + \beta_1(A) + \beta_2(B) + \beta_3(C) + \beta_4[(A]^2) + \beta_5[(B]^2) + \beta_6[(C]^2) + \beta_7(AB) + \beta_8(AC) + \beta_9(BC)$$

From the observed data for surface roughness, the response function has been determined in uncoded units as:

Surface roughness (Ra) = 7.76969- 0.119088A - 7.86757B - 0.00101748C + 0.000513717A^2 -7.95455B^2 - 3.13131X10-07C^2 + 0.0240385AB + 1.37821X10-05AC + 0.00312500BC

Result of ANOVA for the response function as surface roughness is presented in Table-4. This analysis is carried out for a significance level of 5%, i.e., for a confidence level of 95%. From Table-4, it is apparent that, the F (calculated value) is greater than the F-Table value ($F_{0.05, 9, 10}$=3.02) and hence the second order response function developed is quiet adequate.

Table-4. ANOVA table for response function of the surface roughness.

Source	DF	Seq SS	Adj MS	F	P
Regression	9	0.8831	0.098	91.5	0.00
Residual error	10	0.0107	0.001		
Total	19	0.8939			

Contour plot and surface plot of surface roughness at hardness - flow rate planes under different depth of cut are shown in Figures 4 and 5. These response contours can help in the prediction of the surface roughness at any zone of the experimental domain. It is clear from these figures that the surface roughness decreases with the increase of hardness.

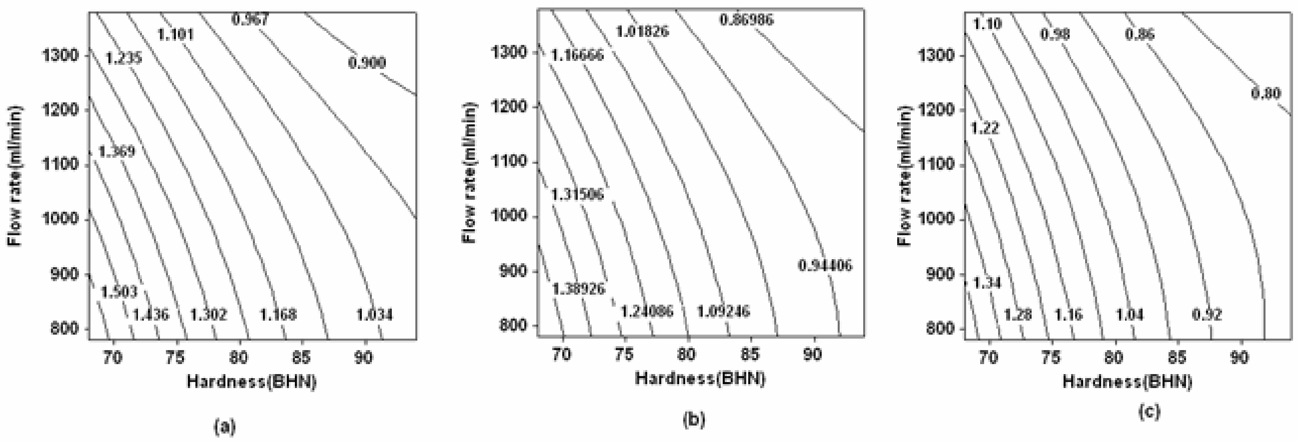

Figure-4. Contour plot of surface roughness at hardness- flow rate planes. At different depth of cut a) 0.08 b) 0.06 c) 0.04.

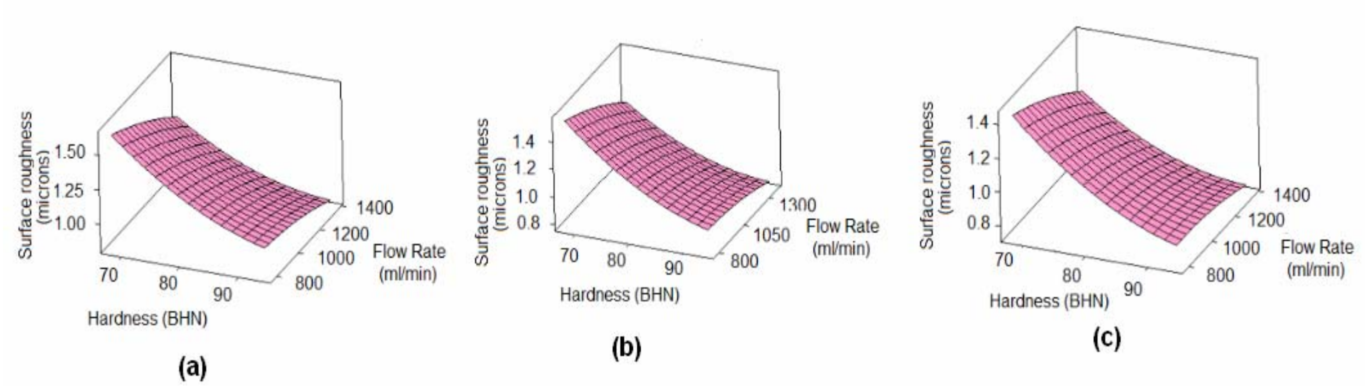

Figure-5. Surface plot of surface roughness at hardness- flow rate planes. At different depth of cut a) 0.08 b) 0.06 c) 0.04.

4. CONCLUSIONS

The surface roughness in the cylindrical grinding process has been measured for machining of MMCs at different cutting conditions on three specimens using response surface methodology. Based on the results, the following conclusions are drawn:

- Increasing the hardness, improves surface finish of MMCs
- Response surface methodology provides a large amount of information with a small amount of experimentation; and
- A second-order response surface model for surface roughness has been developed from the observed data. The predicted and measured values are fairly close, which indicates that the developed model can be effectively used to predict the surface roughness on the machining of MMCs with 95% confidence intervals. Using such model, one can obtain a remarkable savings in time and cost.

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