ABSTRACT

Aluminum Metal Matrix composites (AMMC) refer to a relatively recent class of aluminum alloy-based composites having an emphasis on lightweight and high performance. Compared to other MMC composites, AMMC has advantages like improved strength, higher stiffness, high-temperature properties, wear resistance, increased damping capacity coupled with a reduction in density. Applications of AMMC encompass a wide range of industrial components for automobile, aerospace, nuclear and electronic industries due to their above mentioned attractive properties. In this context, reinforcing the AMMC with suitable particulate materials such as chromium carbide (Cr_3C_2), an abrasive and graphite (Gr), a soft lubricant, can be advantageous over reinforced aluminum alloy due to their improved property combination, particularly high specific strength and elastic modulus coupled with good machinability, enhanced hardness and wear resistance. Hence, an attempt has been made in the present investigation to fabricate LM4/Cr_3C_2/Gr hybrid aluminum composites and to study their microstructure, hardness and machining characteristics.

Al LM4 alloy reinforced with Cr_3C_2 / Gr particles were fabricated using the stir casting method since it is an economical and well-tested fabricating technique for particulate matrix composites. LM4 alloy was selected as the matrix material and reinforced with Cr_3C_2 in varying amounts (3, 6, 9 and 12 wt. %) along with constant 3 wt. % Gr to produce hybrid composites. Optical Microscopy (OM) studies of the hybrid LM4 composites revealed the uniform distribution of Cr_3C_2 and Gr in the matrix. Measured densities of aluminum, Cr_3C_2, and Gr respectively were 2.70, 6.68 and 2.26 g/cm^3, the overall density of composites increased with increasing Cr_3C_2

addition to the aluminum alloy matrix. The lowest density of the aluminum matrix composites was observed for LM4+3wt% Cr_3C_2+3wt% Gr composite.

Machining of composites with good surface finish and minimum Cylindricity is essential for good product quality. Hence a conventional technique, namely drilling was used to study the machinability of the material with respect to Surface Roughness and Cylindricity. WEDM, a non-traditional technique was used to assess the MRR and Surface Roughness of the machined composite.

The main objective of this research work is to carry out machining process following Central Composite Design method (CCD) to study the Surface Roughness and Cylindricity using uncoated carbide drilling tool and uncoated high-speed steel drilling tool, through Burr Height and Burr Thickness measurement as well as the nature of chip formed. Wire Electrical Discharge Machining (WEDM) of composites was carried out and MRR and Surface Roughness were analyzed. With reference to the drilling process, process parameter optimization was carried out taking into account the influence of the cutting parameters and the drill geometry. Optimization was performed to achieve minimum Surface Roughness (SR), Cylindricity (CY), Burr Height (BH) and Burr Thickness (BT) using process parameters including spindle speed, wt% of Cr_3C_2, feed rate and depth of cut. A detailed experimental plan based on the Design of Experiments (DOE) was adopted to minimize the number of experiments as well as reduce the cost and time of experimentation. Drilling experiments were performed as per the design matrix and corresponding Surface Roughness and Cylindricity values were obtained.

The experimental values were analyzed Minitab 17 software using ANOVA (Two-level factorial design) techniques, mathematical models, Response Surface Methodology (RSM), response optimization and composite desirability functions. Mathematical models were developed for Surface Roughness, Cylindricity, Burr Height and Burr Thickness using Response Surface Methodology (RSM).

WEDM is one of the best machining methods for composite specimens because of its accuracy. ANOVA was used to identify the parameters having a significant influence on the chosen responses. The selection of optimum machining parameter combinations for obtaining desired MRR, Surface Roughness, and higher dimensional accuracy is a challenging task in WEDM due to the involvement of a large number of process variables. Hence, there is a need for research to establish a systematic approach to find out the optimum parameter combinations to achieve desired characteristics.

This work attempts to develop an appropriate machining strategy for the WEDM machining of LM4 composites. The four important process parameters, pulse-on time (T-on), pulse-off time (T-off), peak current (A) and spark gap voltage (SV) were taken as input parameters while MRR and Surface Roughness were taken as the responses. Design of Experiments using Central Composite Design was employed for WEDM studies. Machined surface characteristics were analyzed by Scanning Electron Microscope (SEM) to get a better understanding of the machining characteristics of LM4 hybrid composites on machining using uncoated high-speed steel drilling tool, carbide drilling tool, and WEDM.

WEDM machining process achieved the maximization of MRR and minimization of Surface Roughness of the fabricated aluminum hybrid composites. The response optimization and composite desirability function were employed to analyze the machining process to obtain optimum response value. The optimize parameter of process response was fit with the multi-response prediction of machining process conditions.

Hybrid AMMC was successfully cast with a different combination of hard Cr_3C_2 and constant 3wt%Gr using the stir casting technique. Optical microscopy showed a uniform distribution of the reinforcement. The hardness of the aluminum composite varied with the weight percentages of Cr_3C_2. The hybrid composite showed higher hardness due to the presence of hard carbide particles.

ANOVA results showed that an uncoated high-speed steel drilling tool can be used to achieve minimization of Surface Roughness, which is mostly affected by feed rate as the major factor influencing the Surface Roughness (53.622 %), while carbide content and spindle speed (20.248%), wt% Cr_3C_2 (12.941%) also influenced Surface Roughness. The depth of cut contributed least (5.016 %) to the Surface Roughness. Feed rate was the major factor affecting the Cylindricity (52.94%). Other parameters which influence on Cylindricity were spindle speed = 4.91 % and wt% Cr_3C_2= 9.28%, depth of cut = 16.54%.

The optimum level of input parameters for minimization of Surface Roughness and Cylindricity were spindle speed of 1200 rpm, a feed rate of 240 mm/min and depth of cut of 12 mm. Composite desirability optimum value was found to be 0.7130, Surface Roughness to be 1.6145 µm and Cylindricity to be 0.007µm. Predicted values process responses were Surface Roughness 1.37µm and Cylindricity value of 0.0179 µm. Surface

Roughness and Cylindricity as uncoated high-speed steel drilling tool machined surfaces were confirmed by Scanning Electron Microscopy.

The results of drilling experiments using an uncoated carbide drilling tool were analyzed by ANOVA, which showed that the machining process parameters such as feed rate and spindle speed were major factors affecting the Surface Roughness (32.36%) with a contribution of (28.54%) respectively. The lowest contribution was by wt% Cr_3C_2 = 7.87% and depth of cut = 8.59%. Depth of cut is a major factor affecting the Cylindricity (18.98%) while wt% Cr_3C_2 (8.21%) showed a limited influence. Other parameters having a limited influence on Cylindricity were: spindle speed is (4.53%) and feed rate (7.65%).

An optimum level of input parameters for achieving minimum Surface Roughness and Cylindricity were spindle speed 1000 rpm, feed rate 125 mm/min, depth of cut of 12 mm. Using these parameters, the best fit for minimization of Surface Roughness (0.999 μm) Cylindricity (0.0147 μm) and composite desirability for optimal design (0.6636) was obtained. The optimum level of predicted values of Surface Roughness and Cylindricity was 1.3 μm as 0.016 μm respectively. Scanning Electron Microscope was used to confirm the minimum Surface Roughness and Cylindricity of uncoated carbide drilling tool machined surfaces.

ANOVA analysis showed that with uncoated HSS drilling tool (Minimum Burr Height and Burr Thickness) among the various machining process parameters, the feed rate was the major factor affecting the Burr Height (49.32 %) followed by the depth of cut (21.92%) and spindle speed (8.09%). The influence of wt % of Cr_3C_2 is almost nil (1.01%). Feed rate is a major factor affecting the Burr Thickness (29.43 %.) and the contribution of spindle speed is 22.48%, wt% Cr_3C_2 (9.33%) and depth of cut (28.7%).

Minimum Burr Height and Burr Thickness of the hybrid composite were obtained at a spindle speed at 1200 rpm, the feed rate as 240 mm/min and depth of cut as 9 mm respectively. The composite desirability function value was 0.7083. The minimum value of Burr Height was 0.103 mm and Burr Thickness was 0.0183 mm, while the predicted value of Burr Height was 0.102 mm and Burr Thickness was 0.018 mm.

ANOVA analysis showed that the major factor affecting the MRR with a percentage contribution of the machining parameters pulse-on time = 5.02%, pulse off time=7.87%, peak current = 11.4% and spark gap voltage =31.07%. The percentage contributions of the machining parameters for Surface Roughness were pulse-on time = 1.53%, pulse off time=60.04%, peak current = 0.74 % and spark gap voltage = 5.7%. Multivariable optimization of the WEDM process of hybrid aluminum alloy composites predicted values from 0.5474 g /min for MRR and 1.9534 μm for Surface Roughness. The composite desirability function value for both MRR and Surface Roughness (optimal design) was 0.7050. Scanning Electron Microscopy studies confirmed the various features of WEDM machining surfaces.