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Machinability analysis of rice husk ash and copper reinforced aluminium matrix composite

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Abstract
Recent developments in the manufacturing industry have fueled the demand for materials having higher strength, hardness and toughness. These materials pose a problem while machining with conventional machines available. The new materials available are lightweight combined with greater hardness and toughness. In this experimental work, rice husk ash and copper based aluminium matrix composite was fabricated using stir casting route. The machinability of the cast composite is analysed in form of material removal rate and overcut. During experimentation, Flushing Pressure, Peak Current, Pulse on Time, Pulse off Time, Wire Feed Rate, and Wire Tension were selected as input parameters and experiments were performed on wire-cut electric discharge machining. The scanning electron microscopy and energy dispersive spectroscopy was also performed on the composite casting. ANOVA result reveals that for maximum material removal rate, peak current is the most significant parameter, which contributes 64.61% followed by pulse on time (10.73%) and wire tension (10.64%), while other parameters are insignificant. for minimum overcut, the pulse on time is the most significant parameter which contributes 31% followed by flushing pressure (19.37%), peak current (18.82%) and pulse off time (13.84%).the other parameters are insignificant to achieve maximum dimensional accuracy. The nonlinear regression model for material removal rate and overcut are also presented, which reflects the dependency of the responses on the input variables.

Keywords: wire-EDM, stir casting, kerosene ANOVA, taguchi method

Introduction

Composites consist of one or phases that are more discontinuous fused into a continuous phase. In general, the phase of discontinuity is harder and heavier than the phase of continuity. The continuous phase called the 'matrix' and discontinuous phase called the 'reinforcement'. The word composite means combination, hence it should be compound consisting of two or more component material with substantially different physical or chemical properties, which remains separate and the finished structure is distinct on a macroscopic level. This will also mean that this category contains the majority of natural and synthetic materials and alloys. As composite material composed of two or more components may be tested, where at least one of them is solid, attaining properties which cannot be given separately or not by their basic sum by either of the components. The properties of composites are accomplished by the individual stage called the synergistic effects through collaboration. A composite material consists mainly of a matrix or continuous layer, followed by a reinforcement that is usually the discontinuity layer. Researchers in the area of materials science are continuously developing materials having higher strength, hardness, toughness and other tri bological properties. Metal Matrix Composites (MMCs) have emerged as a class of materials suitable for structural, aerospace, automotive, electronic, thermal, and wear applications owing to their advantages over the conventional materials. Hybrid composites are becoming better substitutes for the conventional alloys because of characteristics like high stiffness, high strength and low density. Aluminium hybrid composites are a new generation of metal matrix composites that have the potentials of satisfying the recent demands of advanced engineering applications. These demands are met due to improved mechanical properties, amenability to conventional processing technique and possibility of reducing production cost of aluminium hybrid composites. The performance of these materials is mostly dependent on selecting the right combination of reinforcing materials since some of the processing parameters are associated with the reinforcing particulates. The different reinforcing materials used in the development of Aluminium matrix hybrid composites are synthetic ceramic particulates, industrial wastes and agro waste derivatives. It has been also observed that increasing number of reinforcements in MMCs can improve some mechanical properties, depends upon the nature of reinforcement or sometimes it reduces cost without altering the properties significantly. The different countries have target to get composites by consideration the industrial and agro wastes as reinforcement material and subsequently reducing the cost and improvement in performance level. On the other side, the reinforcement materials such as Silicon Carbide and alumina have relatively high cost due to its procurement from abroad. Fly ash, silica, and graphite are a few examples of industrial/inorganic materials that have been used as reinforcement in Aluminium hybrid composites. Rice hush ash, bagasse ash, and coconut shell ash are few agro waste products which have also been tested as potential reinforcing material. Karthikeyan *et al.* [1] introduced EDM's statistical molding of particulate composites with aluminum-silicon carbide. The impact of tool wear rate (TWR), material removal rate (MRR) and surface roughness (SR) with processing parameters considered were pulse length, current and Silicon carbide percent vol. (25 μ size). Full factorial architecture of three rates was used. The ANOVA method was eventually used to verify the interpretation of the models. The MRR was found to decrease with an increase in the percent volume of silicon carbide, while the TWR and surface roughness rise with an increase in the volume of silicon carbide. Yan *et al*. [2] conducted a study of EDM process development using standard EDM machine assisted by magnetic force. The consequences of magnetic force on features of EDM machining are determined. In this research paper, a Taguchi method based L18 OA is used to execute a series of experiments, and ANOVA is used to analyze the experimental data statistically. The key processing parameters such as machining polarity, peak current, pulse length, auxiliary high-voltage speed, no-load voltage, and servo reference voltage selected to evaluate the MRR and Ra in EDM. This concluded that EDM aided by magnetic force has a higher MRR, a lower relative EWR and Ra compared to normal EDM. Often calculated are the important machining parameters and the optimum combination rate of both MRR and Ra machining parameters associated with them. Vamsi Krishna *et al*. [3] carried out a report on Ti alloy machining (Ti6Al4V) in WEDM. Taguchi Parameter Model was used to research the behavior of eight control parameters such as ignition pulse current, short pulse length, time between two pulses, servo velocity, servo reference voltage, injection pressure, wire velocity and surface tension. For the development of a mathematical model, a linear regression analysis is used which determines the relationship between control parameters and surface finish. Muthu Kumar *et al*. [4] conducted a study of Incoloy 800's multi-response characteristics within the WEDM. Grey relational analysis (GRA) is used to determine optimal levels of process parameters and ANOVA is used to determine relatively important parameters. The Ra shows a decreased value of 3.31 to 3.10μm, the MRR shows an increased value of 0.05351 to 0.05765g / min, and the Kerf width shows a reduced value of 0.324 mm to 0.296 mm, respectively. The analysis found that the Grey-Taguchi method is ideal for parametric optimization of the WEDM process when using Incoloy 800’s multiple performance features for machining. Jangra *et al* [5] studied WC-5.3 percent Co composite sophisticated machining on WEDM. Taguchi's DoE was used to continue investigating processing parameters for four machining features namely material removal rate (MRR), Ra, angular error, and radial overcut. In order to simultaneously standardize the four mechanical parameters, ANOVA shows on identified machining parameters that the three parameters of the process, namely taper angle, pulse on time and pulse off time, are most important factors determining the MRR and Ra. In the case of radial overcut, the parameters such as taper angle, peak current and pulse on time are the most important parameters, while in the case of angular error, the most significant parameters such as taper angle, peak current and dielectric flow rate were observed. Yanzhen *et al*. [6] analyzed the behaviour of three dielectric types at different configurations of EDM parameters satisfactory for the generation of porosity. The attributes of porosity formation in the recast layer formed by Water / Oil (W / O) emulsification are analyzed by referencing them with those present in the recast layer formed by kerosene and deionized dielectric water. It is found that when machining is done in a W/O emulsion, the quantity of both the internally and externally holes in the recast layer is greater than the quantity of kerosene and deionized water, and the porous structures that have modified the morphology of the machined surface. It is also reported that the total amount of micro-pores with a diameter less than 2μm is smallest when machining performs in kerosene. It is indicated that the machined surface gets worse when machining is performed in the W / O emulsion. Rajesha *et al*. [7] used Taguchi technique to optimize process parameters so as to minimize the Ra of the resolidified layer of Al 7075 MMCs in WEDM. The minimum recast layer Ra in this study is found with gap current 15A, pulse on time 10μs, and pulse off time 6μs. The current 15A, 15μs pulse on time and 6μs pulse off time are uses for nearly the entire case. It is found from the roughness profiles that the minimum Ra and Rz value is found at run 4. Velmurugan *et al*. [8] conducted a study to investigate the effect on metal removal rate (MRR), tool wear rate (TWR) and surface roughness (SR) and the parameters are Current, Voltage, Pulse on time, and Flushing pressure. The work materials were composites of hybrid metal matrix Al6061 reinforced with 10 percent SiC and 4 percent graphite particles. Stir casting procedure used to produce the Composite Metal Matrix. The experiment was carried out using a rotatable, central composite design. The software MINITAB R14 was used to develop Mathematical Models. The technique of least squares was used to calculate the coefficients of regression. The significance of the built models was tested using the Variance Analysis (ANOVA) technique. Analysis of the Scanning Electron Microscope (SEM) was performed to research the surface characteristics of the machined specimens and to correspond with the development of the models. Lai *et al*. [9] Investigated a study to interrogate the intercellular reactions between B4C and liquid Al at 7300C when the B4C plate is engaged in Scandium (Sc), Zirconium (Zr) and Ti alloyed liquid Al. Using a Scanning Electron Microscopy (SEM) and a Transmission Electron Microscopy (TEM), the influence of alloying elements on the interfacial microstructure and reaction products in terms of individual and combined additions is evaluated. The study results revealed that the three components react with B4C and form interfacial layers, which act as a diffusion barrier to limit the B4C in liquid Al decomposition. It suggests that the simultaneous addition of Sc, Zr, and Ti enriches most of the Ti at the interface, which not only provides adequate B4C protection but also reduces Zr and Sc expenditure at the operating system. In this experimental work, rice husk ash and copper based aluminium matrix composite was fabricated using stir casting route. The machinability of the cast composite is analysed in form of material removal rate and overcut. During experimentation, Flushing Pressure, Peak Current, Pulse on Time, Pulse off Time, Wire Feed Rate, and Wire Tension were selected as input parameters and experiments were performed on wire-cut electric discharge machining.

Experimental Details

For the experiment Al 6061 is used as matrix material and of 10% Rice Husk Ash (RHA), and 3% Copper (Cu) by weight was chosen as reinforcements. Using stir-casting process, rice husk ash used to prepare the reinforcing step with alloy Al 6061 as matrix. To increase the wettability between the Al matrix and reinforcements, the 1wt. percent of Mg was also introduced in the molten metal. Rice husk washed with water in today's analysis to remove its dust and other unwanted items, and dried at room temperature.

The rice husk was further put into the crucible of graphite and heated for one an hour up to 200°C, and extracts its moisture and organic matter for spectacular results. The colour of the rice husk s changed from yellowish to black due to the presence of organic matter during this heating process. When the rice husk heats up to 200°C heats it again for 6 hours up to 600°C±30°C. In this process, the rice husk was completely burnt due to the presence of oxygen. The ash was further heated in the electric furnace at 750°C for 12 hours to obtain desired properties. Once this operation was done and at room temperature, a colour of the ash shifted thoroughly from black to gray or slightly greyish-white. There is use of two-step stir casting technique in this composition for its processing. Around a temperature of 250°C, the RHA and copper particles are initially pre-heated differently to eliminate moisture and increase its wettability with molten alloy Al. The Al alloy charged in graphite crucible and melted its temperature by electric furnace to around 750°C. The liquid material melted to a semi-solid state at about 630°C in the furnace. Preheated rice husk ash (RHA) and copper (Cu) particles charged to the semi-solid melt at this temperature about 630°C and sequentially stirred up to 20 min. 1wt percent of magnesium is added to enhance the wettability between the matrix and reinforcement. The semi-solid hybrid composite combination heated to around 900°C temperature and stirred at 300 for 10 min by means of an automated mechanical stirrer. Ultimately, for casting reason the molten plastic mixture poured into the mould cavity. The composite exhibits harness of 58.3 HRB, tensile strength 98.7 MPa, impact strength 2.47 joule, when tested using standard testing techniques. The scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) image of the novel composite is shown in Figure 1 and Figure 2.

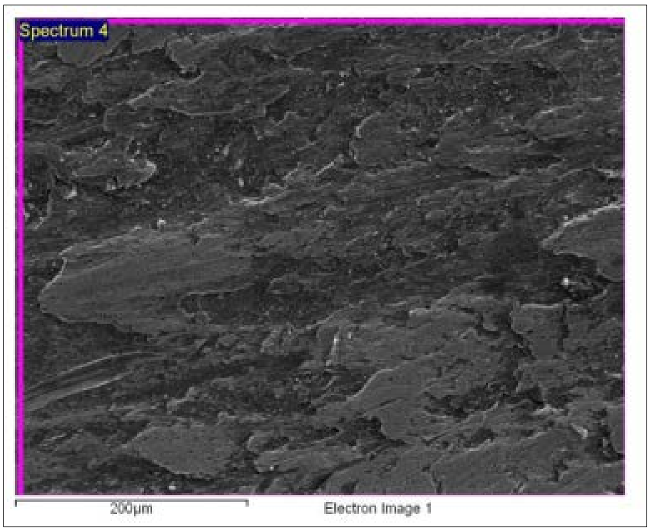

Fig 1: SEM Images of Al/Cu/RHA hybrid composite work piece

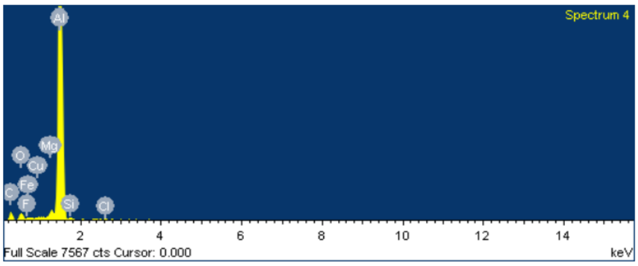

Fig 2: EDS Image of of Al/Cu/RHA hybrid composite workpiece

In Taguchi experimental design different levels of process parameters are chosen as per literature survey and pilot study. The experiment conducted based on the degree of freedom (DOF) approach using L_{18}OA. Machining characteristics of the hybrid composite is evaluates based on the output responses such as material removal rate (MRR) and overcut. For the present experimental work, six input parameters were chosen and their levels are listed in table1.

Table 1: Process Parameters and their Levels

Symbol	Process Parameters	Units	Level 1	Level 2	Level 3
A	Flushing Pressure(W_P)	Pascal	H	L	-
B	Peak Current(I_P)	Amp	100	160	220
C	Pulse on Time(T_{On})	µs	120	125	130
D	Pulse off Time(T_{Off})	µs	32	40	48
E	Wire Feed Rate(W_f)	m/sec	4	8	12
F	Wire Tension(W_t)	G	4	8	12

Calculated material removal rate (MRR) from the observational data collected at the time of experimentation. Workpiece weight collected using a digital weighing machine with accuracy of 0.0001 g before and after machining. The workpiece adequately washed and disinfected before weighing for safety from dust particles. The weight difference before and after machining gives the workpiece weight loss during the machining process. MRR is expressed as the ratio of the workpiece's difference in weight to the machining time before and after machining.

$$MRR = \frac{w_b - w_a}{t}$$

Where, before and after machining w_b and w_a are weights of the workpiece and t is the machining time.

The overcut measured after wire-EDM indicated the dimensional accuracy of the process. The cut gap was measured after each cut using instrumental profile projector and the overcut was calculated as per given below:

Overcut = measured of cut gap after machining - actual diameter of wire.

Table 2 represents the control log experiments and corresponding response parameters.

Table 2: Control log of Experiment and corresponding responses

S. No.	Flushing Pressure (H/L)	Peak Current (A)	Pulse on Time (µs)	Pulse off Time (µs)	Wire feed rate (m/sec)	Wire Tension (g)	MRR (mg/min)	Overcut (mm)
1	L	100	120	32	4	4	63.8	0.085
2	L	100	125	40	8	8	61.8	0.083
3	L	100	130	48	12	12	63.4	0.088
4	L	160	120	32	8	8	63.5	0.088
5	L	160	125	40	12	12	63	0.085
6	L	160	130	48	4	4	62.5	0.09

7	L	220	120	40	4	12	65.2	0.094
8	L	220	125	48	8	4	65.5	0.087
9	L	220	130	32	12	8	65.1	0.095
10	H	100	120	48	12	8	63.7	0.092
11	H	100	125	32	4	12	61.7	0.089
12	H	100	130	40	8	4	63.6	0.097
13	H	160	120	40	12	4	61.7	0.101
14	H	160	125	48	4	8	62.1	0.088
15	H	160	130	32	8	12	61.8	0.094
16	H	220	120	48	8	12	64.8	0.097
17	H	220	125	32	12	4	65.6	0.088
18	H	220	130	40	4	8	65.3	0.103

The signal to noise ratio of the Taguchi is the logarithmic function of the desired output. S/N is the ratio of mean and standard deviation. Here mean refers to signal and the standard deviation refers to noise. The ratio is depending on the product/process/procedure quality characteristics to be optimized.

Larger the Better (LB):
$S/N = -10 * \log (\Sigma (1/Y^2)/n)$

Results and Discussion

Analysis of variance (ANOVA) for material removal rate is shown in table 3.

Table 3: Analysis of Variance for S/N ratios for MRR

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Flushing Pressure (H/L)	1	2.0806	0.6806	0.43	0.526	6.06%
Peak Current (A)	1	22.1875	15.1875	9.59	0.01	64.61%
Pulse on Time (µs)	1	3.6833	0.0833	0.05	0.823	10.73%
Pulse off Time (µs)	1	1.0208	0.0208	0.01	0.911	2.97%
Wire feed rate (m/sec)	1	1.3008	0.3008	0.19	0.671	3.79%
Wire Tension (g)	1	3.6533	0.6533	0.41	0.534	10.64%
Error	11	0.4164	1.5833			1.21%
Total	17	34.3428				100.00%

The response table for signal to noise ratios larger is better for material removal rate (MRR) is given in table 4.

Table 4: Response Table for Signal to Noise Ratios Larger the better for MRR

Leve	Flushing Pressure (H/L)	Peak Current (A)	Pulse on Time (µs)	Pulse off Time (µs)	Wire feed rate (m/sec)	Wire Tension (g)
1	36.09	35.99	36.09	36.06	36.04	36.09
2	36.03	35.91	36.02	36.04	36.05	36.06
3		36.29	36.07	36.08	36.09	36.03
Delta	0.05	0.38	0.07	0.03	0.04	0.06
Rank	4	1	2	6	5	3

The main effects plot for signal to noise (S/N) ratio for material removal rate (MRR) is given in the figure 3.

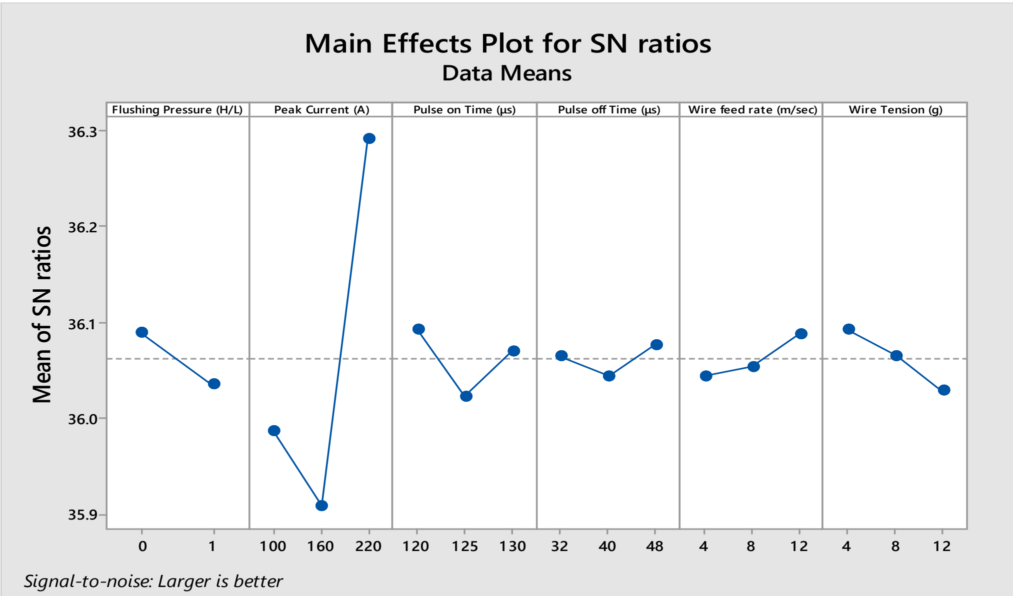

Fig 3: Main effects plot for S/N ratios for MRR

Table 5: Analysis of Variance for S/N ratios for overcut

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Flushing Pressure (H/L)	1	0.000105	0.000162	6.02	0.032	19.37%
Peak Current (A)	1	0.000102	0.000075	2.79	0.123	18.82%
Pulse on Time (µs)	1	0.000168	0.000008	0.31	0.589	31.00%
Pulse off Time (µs)	1	0.000075	0.000001	0.03	0.87	13.84%
Wire feed rate (m/sec)	1	0.00005	0	0	1	9.23%
Wire Tension (g)	1	0.00004	0	0	0.957	7.38%
Error	11	0.000006	0.000027			1.11%
Total	17	0.000542				100.00%

The response table for signal to noise (S/N) ratios smaller is better for overcut is given in table 6.

Table 6: Response Table for Signal to Noise Ratios Smaller is better for overcut

Level	Flushing Pressure (H/L)	Peak Current (A)	Pulse on Time (µs)	Pulse off Time (µs)	Wire feed rate (m/sec)	Wire Tension (g)
1	21.09	21.02	20.66	20.94	20.79	20.80
2	20.52	20.83	21.25	20.58	20.83	20.79
3		20.55	20.50	20.89	20.79	20.81
Delta	0.57	0.47	0.74	0.36	0.05	0.02
Rank	2	3	1	4	5	6

The main effects plot for signal to noise (S/N) ratio for overcut is given in the figure 4.

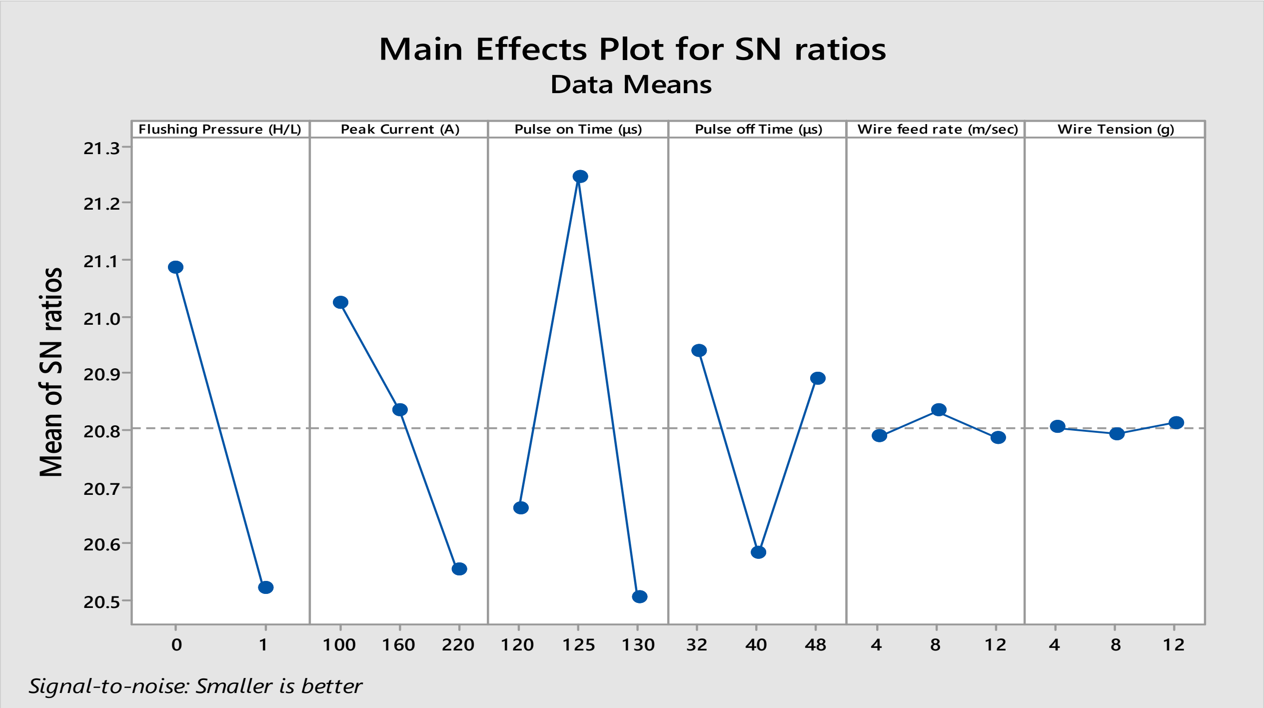

Fig 4: Main Effect Plot for SN Ratio for Overcut

Confirmation Experimentation

After the application of Taguchi analysis, best settings for each response parameter are obtained and the conformation experiments have been performed accordingly. The results of confirmation experiments shows significant improvements in the material removal rate with the marginal reduction in dimensional inaccuracy with percentage improvement in material removal rate and reduction in overcut is 4.46% and 1.25% respectively.

After performing the confirmation tests, SEM images of machined surfaces (obtained from tests as per best setting maximum MRR and minimum overcut) are taken to analyse the pattern of machined surfaces, and compare it with the un-machined surface. From the images, the improvement in the surfaces textures is observed.

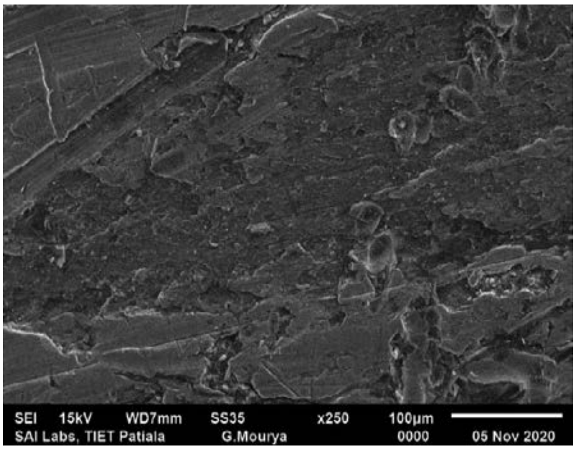

Fig 5: SEM image of Un-machined surface

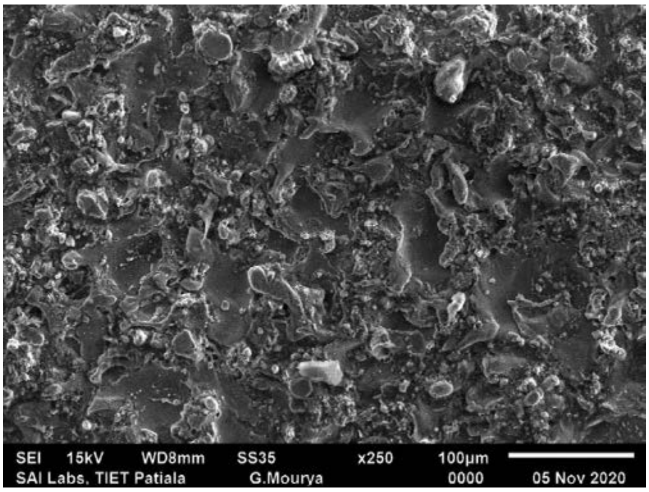

Fig 6: SEM Image of machined surface as per best setting for maximum MRR

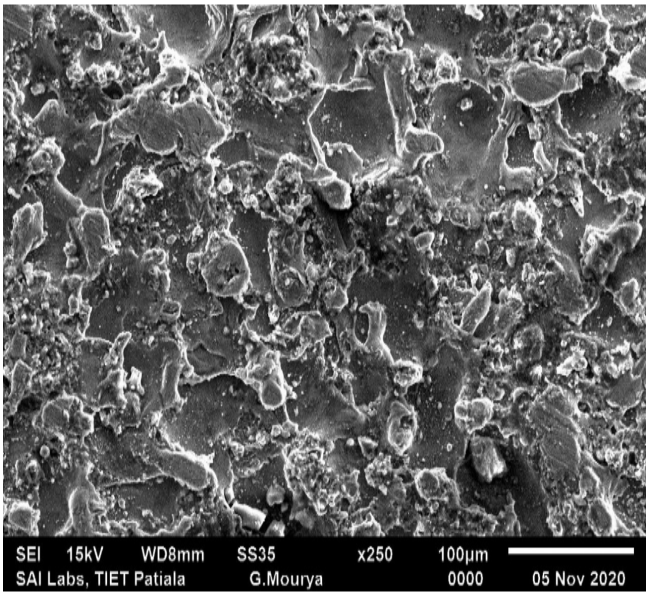

Fig 7: SEM Image of machined surface as per best setting for minimum overcut

Conclusions

On the basis of experimental observations made on fabrication and evaluation of machining behaviour of novel Al-RHA-Cu hybrid composite, the following conclusions can be drawn:

- Stir casting method can be successfully adopted for the fabrication of Al-RHA-Cu hybrid composites.
- For maximum material removal rate, peak current is the most significant parameter, which contributes 64.61% followed by pulse on time (10.73%) and wire tension (10.64%). Other parameters have not shown significant effect on the material removal rate. Optimized setting of input parameters for the maximum material removal rate is low flushing pressure (4 - 5 N/m^2), peak current of 220A, Pulse on time of 120 µs, pulse off time of 48 µs, wire tension of 4g and wire feed rate of 12 m/s.
- Similarly, for minimum overcut, the pulse on time is the most significant parameter which contributes 31% followed by flushing pressure (19.37%), peak current (18.82%) and pulse off time (13.84%).the other parameters are insignificant to achieve maximum dimensional accuracy. Optimized setting of input parameters for the maximum dimensional accuracy (i.e. minimum overcut) is low flushing pressure (4 - 5 N/m2), peak current of 100A, pulse on time of 125 µs, pulse off time of 32 µs, wire tension of 12g and wire feed rate of 8 m/s.
- The nonlinear regression model for material removal rate and overcut are also presented, which reflects the dependency of the responses on the input variables. The analysis of signal to noise ratio for each response is performed and the input parameters for each responses are ranked accordingly.
- The confirmatory experiments are performed and result of study shows percentage improvement in material removal rate and reduction in overcut is 4.46% and 1.25% respectively.

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