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Optimization of Machining Parameters on Sugarcane Ash Aluminum Composite for Optimum Power Consumption and Surface Roughness

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Abstract:

In current research industrial waste sugarcane bagasse ash (SCBA) was used as a reinforcement to cast a Metal Matrix composite (MMC).The potential use of waste is explored in this article. AA 6061 is used base alloy of matrix. SCBA Particles of size 0.165µm are used in fabrication of MMC's via double stir casting technique. The effect of low size of reinforcement particles on the dispersion and strength of MMC was observed. The tensile strength and hardness were found to increase by 20% for 2.5% weight addition of SCBA filler. The microstructure showed that the filler particles have been dispersed uniformly. The influence of cutting process parameters speed, feed, depth of cut on surface roughness and power consumption on fabricated SCBA AA6061 MMCs are studied using Taguchi L_9 orthogonal design of experiments. It is observed that feed is most predominant factor that significantly affects the surface roughness and power consumption followed by speed and depth of cut. Taguchi based grey relational analysis combined with entropy method is employed in the current study for optimization of cutting parameters for conflicting objectives in turning process. The speed 125 mm/min, feed 0.5mm/rev and depth of cut 0.5 mm is optimal parameter setting.

Keywords: Aluminum, optimization, MMC, Taguchi, GRA, entropy, surface roughness, power.

I. INTRODUCTION:

Composites and light weight materials are finding wide applications and are driving factors for an economy. Industrial sector has thrown many challenges in economic, environmental front like waste disposal [1]. Many researchers have targeted the utilization of the waste as reinforcement materials in Metal matrix composites (MMC) [2-5]. MMC's find wide applications as their tensile, hardness and wear properties are superior at a low density when compared to pure alloy. They find application in aerospace and automobile, ship industries as connecting rods, piston rings, liners, aircraft forgings. By varying dependant variables like reinforcement type, size, volume, base material, method of fabrication application specific mechanical properties can be obtained [2]. Stir casting method is widely used technique for preparation of MMC's owing to cost advantage when compared to the powder metallurgy and spray techniques [2-4]. Most commonly used matrix materials are aluminum and magnesium for automobile and aerospace applications and titanium for biomedical applications [6]. For past few decades the reinforcements exhaustively reported in research arena and successfully in industry are Silicon carbide (SiC), Alumina (Al_2O_3), Fly Ash, Rice Husk Ash. [2-6]. Though many techniques were adopted to fabricate parts that are almost near the desired shape, but still machining is inevitable to attain the desired quality characteristic [7]. Quality components need has enhanced the focus for better surface finish products. Surface finish depends on cutting factors such as type of cutting tool, depth of cut, work piece material, feed rate, cutting tool material, coolant [8,9]. Machinibilty studies reported in literature showed that in metal matrix composite the micro gaps at particle reinforcement interface minimize the cutting forces [10]. The effect of cutting speed, feed rate, depth of cut, coolant were reported on different MMC's[11-14]. As the filler material size decreases machinibilty property enhances for the MMC's [12]. Taguchi technique is widely used to design controllable parameter settings for desired objectives, where noise factors are minimum[13]. Optimizing the responses productivity and surface finish which are contradictory at minimum cost requires a judicial selection of robust optimization technique. Studies conducted with aid of Taguchi design give one factor effect on the response at a given time. Grey relational analysis (GRA) can be applied to systems with discrete data. GRA technique application overcomes the limitation of Taguchi method. The optimization of multi performance responses problem is converted to single grade, which is used to rank the performance characteristics [14-20]. The significance of quality characteristic can be given by Principal Component Analysis (PCA) [21]. Power consumption is an indispensible factor as it has great influence on production cost nowadays. To reduce surface roughness, enhance the production rate, decrease cutting forces the cutting parameter choice plays an important role to increase efficiency and quality [20]. Polycrystalline diamond inserts are used as cutting tool and the impact of controllable cutting variables on surface quality is studied [23]. Many researchers have used various optimization methods like Response surface Methodology (RSM), PCA based Taguchi method, Grey relational analysis, but few works have been reported using entropy method in conjunction with GRA to optimize controllable cutting parameters for Al based MMC's in turning operation. There is no reported work on machinibilty studies on sugar cane baggase ash (SCBA) (an industrial waste) reinforced aluminum metal matrix. The present study investigates the effect of controllable turning parameters of SCBA reinforced Aluminum MMC using entropy based GRA method of optimization.

A. Methodology Adopted

The research methodology is separated into three parts. The first part includes composite preparation and checking for agglomerations using optical microscope. Minimize the dispersions conglomeration of filler particles by appropriately adjusting the casting parameters and evaluation of mechanical properties. The second part includes machining experimental planning & design and third phase is optimization of controllable parameters for maximum surface finish and minimum power consumption criteria using Taguchi, Entropy based GRA.

Taguchi Optimization Steps. Signal to Noise Ratio: Smaller the better S/N ratio is employed as the quality characteristic is continuous and positive, can take any value between 0 and ∞ .To achieve this we should minimize the quality loss Q = k (mean Square Quality Characteristic) $Q = k\{i/n \sum_{i=i}^{n} Y_i^{2}\}$ Q is quality loss function Or Maximize the S/N Ratio (η) $\eta_{ij} = -10\log_{10}[\frac{1}{n}\sum_{i=1}^{n} y_i^2]$ (1)

Where j corresponds to i^{th} experiment's j^{th} S/N ratio , y_{ij} is the i^{th} experiment at the j^{th} test, and n signifies the total number of tests.Trade of analysis need to be employed where two or more responses are to be optimized simultaneously. As responses are measured using different parameters foremost data has to be preprocessed.

Grey Relational Analysis:

Data Preprocessing is a process where the data is converted to a range of 0 to 1 as to obtain sequence to compare in common units. The responses need to be minimum the lower – the – better criteria for normalization is employed which is given as follows.

$$X_i^*(k) = \frac{\max X_i^0 - X_i^0(k)}{\max X_i^0(k) - \min X_i^0(k)} \quad (2)$$

Where $X_i(k)$ is value after data preprocessing , max $X_i^0(k)$ is the maximum value , min $X_i^0(k)$ is least value of $X_i^0(k)$ and X_0 is the desired value. The Grey Relational Coefficient is calculated by following equation

$$\xi_i(k) = \frac{\Delta_{max} - \omega\Delta_{max}}{\Delta_{oi}(k) - \omega\Delta_{max}} \quad (3)$$

Where $\xi_i(k)$ is grey relational coefficient, $\Delta_{oi}(k)$ is deviation sequence of the reference sequence $X_0*(k)$

$$\Delta_{oi}(k) = ||X_0^*(k) - X_i^*(k)|| \quad (4)$$

$$\Delta_{max} = \max\max ||X_0^*(k) - X_i^*(k)|| \quad (5)$$

$$\Delta_{min} = \min\min ||X_0^*(k) - X_i^*(k)|| \quad (6)$$

Ш ranges from [0, 1] and usually a 0.5 value is employed.The grey relational grade is given as follows

$\gamma_i = \sum_{k=1}^{n} w_k \xi_i (k)$ (7)

Where wk normalized weight value of factor k. If i^{th} sequence influences more than next sequence the grey relational grade for i^{th} sequence will be higher than others.

Entropy Method

Entropy is widely used in thermodynamics and it is measure of quantifying the disorder or randomness. Entropy is applied in this work to measure the weights of the quality characteristic. An attribute with more entropy has more significant influence on responses. [22] Defined entropy as mapping function $f[0,1] \rightarrow [0,1]$ which is monotoic increasing in the range xℇ(0,0.5). The mapping function used for entropy measure is $w_e(x) = xe^{(1-x)} + (1-x)e^{x} - 1$ (8)

At x= 0 the entropy function value is 0.6458 which is maximum. The summation of the grey relational coefficients in all sequences for each quality characteristic is given by $D_j = \sum_{i=0}^{n} \xi_i(j),\ j = 1,2 \ldots p$ (9)

Entropy of each quality parameter $e_j = k \sum_{i=1}^{n} w_e \left(\frac{\xi_i(j)}{D_j}\right), j = 1, \ldots . p$ (10)

Total sum of entropy $E = k \sum_{j=0}^{p} (e_j)$ (11)

Weight of quality characteristic $w_j = \frac{\frac{1}{p} - E[1-e_j]}{\sum_{j=1}^{p} \frac{1}{p} - E[1-e_j]}, j = 1,2 \ldots \ldots p$ (12)

II. EXPERIMENTAL SETUP

Composite Fabrication

The filler material Sugarcane Bagasse Ash (SCBA) which has high content of silica and Alumina is brought from Govada sugar factory located at Visakhapatnam, Andhra Pradesh. The particle size obtained post sieve analysis is 0.165 micrometer. The SCBA particles were heated at 500°C for 2 hours to remove moisture, and burn any unburnt carbon content present in the ash. Al alloy is taken and heated in a graphite crucible above the liquids temperature in furnace to ensure complete melting of the alloy. A small amount of Magnesium is added which enhances the wet ability of matrix and reinforcement. Then preheated SCBA particles are added while stirring and continue stirring for 2 min post addition of filler. Heat the mixture to 800 °C for second term to and stir to ensure complete mixing of particulates in the liquid state and pour liquid in preheated dies. The microstructure as observed from optical microscope is shown in Fig 2. The composite properties and wear behaviour analysed by author [24]. The mechanical properties of the fabricated composite are given in Table 1. The micro structural analysis in Fig 1 shows that the SCBA particles are uniformly distributed in the matrix for 2.5%weight percentage.

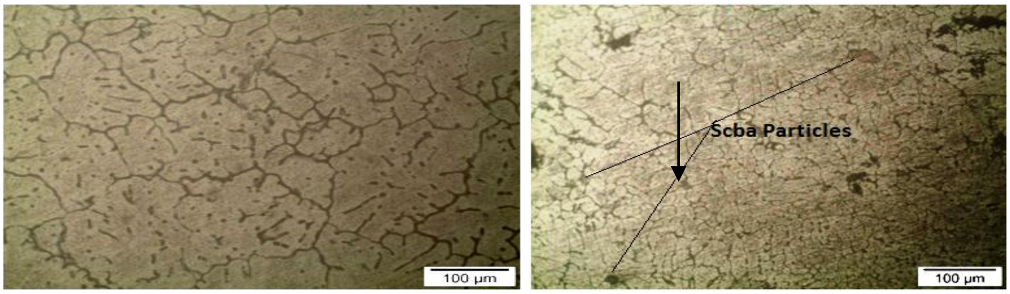

Figure 1: Optical Micrograph of pure Al6061 and Al6061+2.5% weight of SCBA

Machining Procedure

The manufacturing design process involves 3 steps a) Concept design b) Parameter design and c) Tolerance design. The parameter design is important for reducing sensitivity of unit to unit variation to manufacturing variations. Parameter design is selection of the optimum values of the tolerance of control factors to maximize robustness. It can be performed systematically by using orthogonal arrays and signal to noise ratio which is most economic way to improve quality. The experiments are designed based on Taguchi L_9 orthogonal array. Taguchi method of design is used widely in engineering design as it gives optimal experimental runs to obtain data for analysis. As number of experiments is less it is time advantage and also economical method.

The turning experiments were carried out using a centre lathe. The cutting tool used is CNMG 120408NC6110 coated carbide. Cutting forces were measured using Kristler dynamometer which is fixed to lathe tool post. Forces are tracked using software dynoware. Surf test SJ-301 (stylus material diamond tip radius 5µm) is used o measure surface roughness (R_a). An indirect method using cutting forces are used to measure the power consumed as described by [23]. The three components of forces cutting force, feed force and radial force are measured using a kristler dynamometer.

As selection of parameters operating range values is very important for optimization, preliminary experiments were conducted and choice was made. The selection of parameters and operating range is shown in table 2. The responses surface roughness was measured at 4 points and an average value is tabulated in table 3.Cutting forces thrust, radial and axial forces are using dynamometer and power consumed is calculated using the formula P= (depth of cut* feed per revolution*Cutting Speed*Specific cutting force)/60 Watts. The calculated power and measured surface roughness means is shown in table 3. In order to analyze the percentage of influence of parameters (Speed, Feed, and Depth of cut) on power consumption and surface roughness Analysis of Variance ANOVA is used. It is a statistical tool to observe difference of means among experiments. ANOVA gives us the contribution of each parameter variation to overall response variation. Statistical Package MiniTab in used to find out the effect of parameters on responses.

III. EXPERIMENTAL RESULTS AND ANALYSIS

The results of the cutting experiments performed are in table 3. In machining operation a lower value of surface roughness and power consumption is desirable. The Signal to noise ratio of the output characteristics is calculated for lower the better criteria using equation (1). The S/N ratios are normalized using equation (2) and the results are tabulated in table 4. The ANOVA for Surface roughness carried at 95% confidence level is tabulated in Table 5. The factors with p-value less than 0.05 are significant statistically. Hence from table 5 it can be noted that feed is the most significant factor that has highest contribution for response surface roughness. The percent contribution is calculated by equation 13. The feed contributes to almost 80% of variation in surface roughness followed by speed which contributes 18% and DoC the rest in the operating ranges for machining of Al composite.

$$\%\text{Contribution} = \frac{\text{MS}}{\text{MS}_{\text{Total}}} \qquad (13)$$

Table 1. Mechanical Properties

Tensile Strength	136 N/mm^2
Hardness	55 BHN
Micro Hardness	78HV
Modulus of Elasticity	14520.60 MPa

Table 2: Machining parameters and their levels

Machining parameter	Symbol	Levels			Unit
		1	2	3	
Speed	A	93	125	200	(m/min)
Feed	B	0.5	0.75	1	(mm/rev)
Depth of Cut	C	0.5	0.75	1	Mm

From fig 3 it can be observed that as speed increases the surface roughness values decreases which can be due to absence of built up edge (BUE) at higher cutting speed which enhances to surface finish [25]. Since a low value of surface roughness from table 4 experimental run 7 has the minimum value. Hence at higher speed and low values of depth of cut and feed rate the surface quality is optimum. At a speed of 200m/min feed 0.5mm/rev and depth of cut 1 mm the surface quality is optimum. For power consumption the minimum power consumption is at level 1 that is at low speed, feed and depth of cut.

Table 3 Orthogonal L_9 Experimental runs and their Responses

Trail No	Cutting Speed in m/min	Feed in mm/Rev	Depth of Cut in mm	Surface Roughness Ra in μm	Power in Watts
1	1	1	1	3.04	680
2	1	2	2	3.53	770
3	1	3	3	3.98	1060
4	2	1	2	2.74	960
5	2	2	3	3.33	1650
6	2	3	1	3.53	620
7	3	1	3	2.70	1470
8	3	2	1	3.14	780
9	3	3	2	3.56	1690

Table 4 S/N Ratios and Normalized values

Exp. Run	S/N Ra	S/N Power	Normalized S/N	
			R_a	Power
1	-9.65747	-56.6502	0.3057	0.0921
2	-10.9555	-57.7298	0.6908	0.2161
3	-11.9977	-60.5061	1.0000	0.5348
4	-8.75501	-59.6454	0.0379	0.4360
5	-10.4489	-64.3497	0.5405	0.9761
6	-10.9555	-55.8478	0.6908	0.0000
7	-8.62728	-63.3463	0.0000	0.8609
8	-9.93859	-57.8419	0.3891	0.2289
9	-11.029	-64.5577	0.7126	1.0000

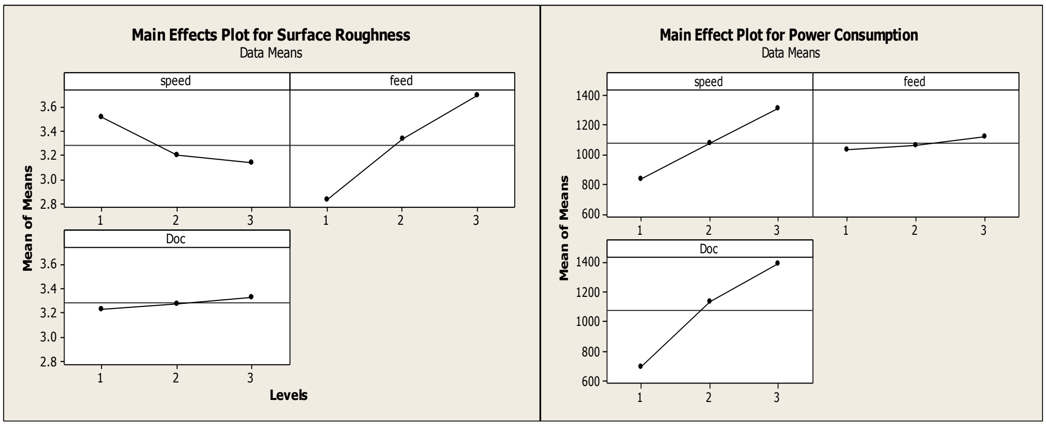

Figure 3: Main Effect plots for Surface Roughness and Power Consumption

Table 5: Anova for Surface Roughness (μm)

Source	DF	SS	MS	F	P	%Contribution	
Speed	2	0.252	0.126	0.66	0.552	18%	
Feed	2	1.1293	0.5646	12.47	0.007	80%	Significant
DoC	2	0.015	0.008	0.03	0.968	1%	
Error	2	0.0047					
Total	8	1.401					

Since the optimum values are at different levels for each response a multi objective optimization is used. The grey relational coefficient for all quality characteristics and its deviation sequence are calculated using equations (3, 4). The grey relational coefficient for each response is tabulated in Table 5. The weight for surface roughness and power are calculated using entropy method equations (10, 11, and 12). The weights thus obtained are 0.49 and 0.498. These weights are further used to calculate the weighted grey relational grade in table 5. The mean response table for weighted grey relational grade and factor levels is shown in table 6 and graphically represented in fig 3. Experimental runs vs Grey relational grade is shown in fig 4. It has been observed from fig 3 and table 5 the sequence close to experiment 5 has the most desired response. Max –Min values in table 6 are the difference in grey relational grades of all the chosen parameters feed, depth of cut and speed. Max-min difference gives the level of influence of parameters on multi performance characteristics. Feed is the most significant factor that contributes 45% to performance characteristics followed by depth of cut and speed, graphical representation in fig 5.

From grey relational grade graph the optimal parameter combination for better performance is determined. The optimal parameter setting is the parameter which has maximum grey relational coefficient as A2-B1-C1 cutting speed (125 mm/min) feed (0.5 mm/rev) and depth of cut (0.5 mm). At low speeds the surface roughness is high and with increase in speed surface roughness decreases till certain speed and further increases. Surface quality increase with speed till certain extent and further increase in speed from level 2 to 3, surface finish decreased. Similar results were observed and reported by others during machining of composites [10, 14].

Table 6 Deviation sequence and Grey relational coefficient

Exp Run	Deviations $\Delta_{oi}(k)$		Grey relational coefficient		Grey relational Grade
			R_a	Power	
1	0.3057	0.0921	0.6206	0.8444	0.721
2	0.6908	0.2161	0.4199	0.6983	0.545
3	1.0000	0.5348	0.3333	0.4832	0.401
4	0.0379	0.4360	0.9295	0.5342	0.751
5	0.5405	0.9761	0.4805	0.3387	0.416
6	0.6908	0.0000	0.4199	1.0000	0.681
7	0.0000	0.8609	1.0000	0.3674	0.715
8	0.3891	0.2289	0.5624	0.6859	0.618
9	0.7126	1.0000	0.4123	0.3333	0.377

Table 7 Response Table for weighted Grey Relational Grade

Levels	Cutting Speed	Feed	Depth of Cut
1	0.56	0.73	0.67
2	0.62	0.53	0.56
3	0.57	0.49	0.51
Max-Min	0.06	0.24	0.16

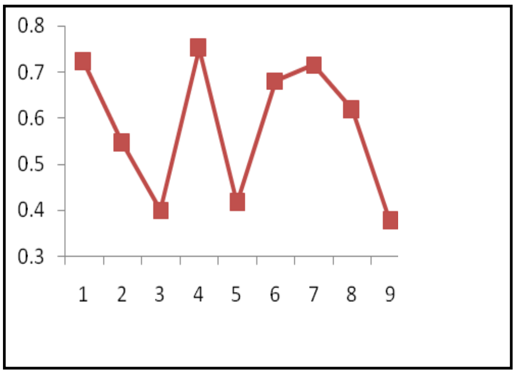

Figure 4: Experimental runs Vs Weighted Grey relational grade

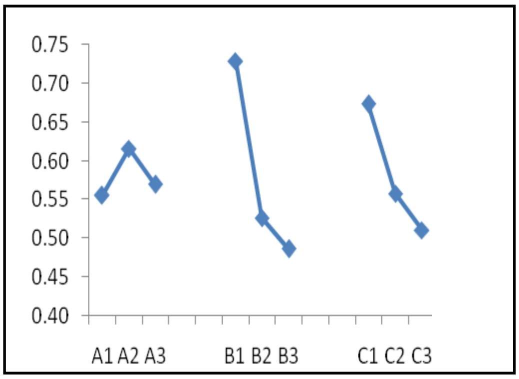

Figure 5: Parameter levels Vs Grey relational Grade

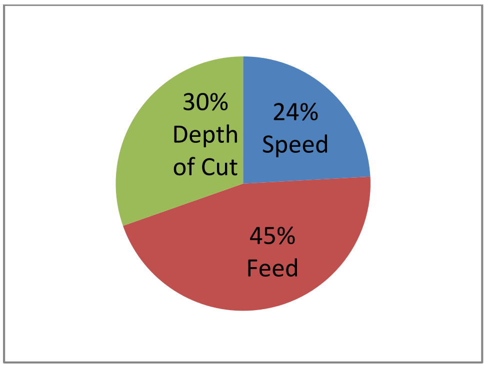

Figure 6: Contribution of cutting factors on performance characteristics (R_a and power consumed)

Confirmation Test

Once the optimal parameters are selected the next step is to predict and verify the responses at the optimal setting. The estimated grade using optimal level us calculated as

$$T_e = T_m + \sum_{i=1}^{p} T_i - T_m \quad (13)$$

T_m = Total mean Grey relational Grade.
T_i is the mean relational grade at optimal setting.
p is the no of cutting parameters that significantly affect the response.
The predicted grey relational grade at the optimal setting is 0.767. The experimental values at the optimal settings are surface roughness 2.712 and power consumption 740 watts. The grade is improved by 1.9%.

IV. CONCLUSIONS

In this study composite of aluminum alloy and SCBA of submicron size was fabricated successfully by carefully selecting the stirring parameters. The reinforcement particles contain hard particles such as SiC , Al_2O_3 which increase the hardness and tensile strength of the composite when compared to base alloy. Taguchi L_9 orthogonal array was used to explore the machining parameters effect on surface roughness and power consumption via cutting forces measurement . The potential application of Grey relational analysis in conjunction with entropy method to optimize the multi performance characteristics is explored. It is inferred that in contrast to published literature that feed and depth of cut are parameters that show dominant impact on surface roughness and power consumption followed by speed. The optimal setting is found to be A2B1C1 .The confirmation experiment at the parameter setting showed that the surface roughness decrease to 2.72μ_m and power decreased from 960 to 740 watts.

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