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Evaluation of MRR Properties by HSS and Carbide Tool on Aluminum (AA6063) Alloy with SiC and TiO_2 Novel Reinforcement Using CNC Drilling Operation

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Abstract

The central focus of this study was to assess the efficacy of the material removal rate (MRR) with respect to high-speed steel (HSS) and carbide cutting tools utilized in CNC (Computed numerical control) drilling operations of AA6063 with SiC (Silicon carbide) and TiO_2 (Titanium dioxide) alloys. In this investigation, AA6063 was selected as the base material. The reinforcement materials are SiC (5%, 10%, and 15%) and TiO_2 (5%). Two groups were used for this statistical analysis: one is experimental group performed using carbide tool and the second is control group preferably HSS tool. The SPSS (Statistical Package for the Social Sciences) software statistical analysis was performed for statistical analysis. Stir-casting methods have been used to fabricate hybrid metal matrix composites (MMCs). The total sample size of 40 was calculated by keeping the alpha value 0.05 and G-power at 80%. The study's results indicate that the maximum MRR of 2800 mm^3/min was attained under specific cutting conditions, namely feed rate of 0.06 mm/rev, spindle speed of 2800 rpm, and 10% SiC reinforcement. Furthermore, statistical analysis revealed that the carbide tool outperformed the HSS tool in terms of MRR with a 95% confidence level and a two-tailed significance value of p = 0.000, which is below the threshold of 0.05. A substantial significance between the two groups is evident from the results. Furthermore, it was observed that the average value of MRR from the drilled hole exhibited an upward trend for carbide tools while a downward trend was observed for HSS tools with an increase in the particle content. Notably, in terms of MRR, carbide drill tools surpassed all other tools tested and were the most efficient.

Keywords

Material removal rate, CNC drilling, High-speed steel, Carbide tool, AA5083, Sustainable production

Introduction

Composite materials are commonly utilized as replacements to traditional materials due to its superior lightweight, higher resistance to wear, increased durability, lower thermal expansion, and reduced weight characteristics. Furthermore, they may be manufactured to fit the required dimensions and widths at an affordable price while maintaining a high level [1]. The addition of B_4C has recently received attention because to its high melting point of 2450 °C, high stiffness of 445 GPa, low density of 2.51 g/cm^3, exceptional mechanical characteristics ranging from 3800 - 4200 Hv, and thermal flexibility [2]. MMC composites are manufactured using a number of processes, including stir casting and powder metallurgy. Stir casting has several advantages, including its simplicity, affordable processing, and ability to produce materials with virtually unlimited shapes

[3]. The production is highly dependent on the selection and combination of suitable reinforcements and matrix specifications for sustainable production. However, machining MMCs to the required accuracy and surface integrity is challenging because the hard ceramic particles severely erode the cutting tools during the machining process [4]. The cutting forces and surface quality of these materials during drilling are influenced by various parameters, including feed rate, cutting speed, tool dimension, and particulate structure. Optimum drilling conditions are essential to increase drilling productivity, reduce drilling costs, and improve the appearance of the drilled surface [5]. Drilling materials and particle weight percentage are important factors that greatly affect pressure distribution; polycrystalline diamond tools provide low stress [6]. Compared to uncoated (solid) carbide, drill drills made of coated carbide generate less force during cooling through the tool [7]. According to previous research on drilling sustainable MMCs, the machined surface of the drilled hole decreases with increased cutting conditions and increases with higher feed rates. However, other findings contradict the recent results. According to most researches, in terms of sustainable production, feed rate has a bigger influence on surface roughness than cutting speed. Limited research has found the relative effectiveness of HSS and carbide tools in increasing material removal rates on AA6063 aluminum hybrid composites reinforced with SiC and TiO_2 particles, and statistical analysis is not often reported [8]. The objective of the investigation is to explicate the application of grey correlation analysis for determining the most suitable drilling conditions with regard to a multitude of performance measures, including feed rate, spindle speed, and percentage of reinforcement. Drilling of MMCs reinforced with three different weight percentages of SiC and TiO_2, and AA6063 alloys alloy is done for this purpose. CNC-drilling parameters of statistical significance were determined using SPSS statistical method. During the drilling operations using HSS, and carbide drills, MRR phenomena were investigated. Furthermore, the independent t-test is executed on the process parameters in order to bolster the durability of hybrid composites and thereby enhance sustainable production.

Materials and Method

The study was executed at CNC industries located at Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Chennai (Tamil Nadu, India). The production of the hybrid MMCs was accomplished through the utilization of stir-casting techniques. The AA6083 was selected as the base material of the experiment, whereas SiC and TiO_2 were used as reinforcement materials. The SiC particles had a size of 63 µm, while the typical size of the TiO_2 particles was 45 µm. The volume fraction of TiO_2 was held constant at 5%, while the weight percentage of SiC was altered between 5%, 10%, and 15%. Stir casting was utilized to produce various composite specimens with dimensions of 130 mm x 100 mm and 50 mm, ensuring uniform distribution of the reinforcement (Figure 1). An electric furnace was used to melt the composite material in a crucible. A SiC and aluminum mixture was heated to 900 °C before adding the aluminum matrix alloy at 750 °C. For five minutes, 600-rpm mixing was applied. It is poured into a continuous metal mold to give the workpiece a suitable size and shape for sustainable production.

Figure 1: Schematic representation of stir casting setup used to fabricate hybrid MMCs for plate dimensions 150 x150 x10 mm.

In the present investigation, pair of groupings was executed. Hence, a total of 40 specimens were employed for both the HSS and carbide end milling tools. Two groups were selected, each comprising 20 samples, bringing the ultimate sample size to 40 with a G-power of 80% and a statistical significance of confidence interval (CI) is 95% [9].

The first group in this study is the control group, which has been supplemented with the HSS drilling operation on the aluminum (AA6063) alloy, reinforced with the SiC and TiO_2 hybrid MMCs produced via the stir-casting process. In this experiment, the dimensions of 150 x 150 x 10 mm were analyzed prior to the machining of the hybrid composite plate.

Group 2 is an improved experimental cohort that uses carbide tool drilling motion on aluminum (AA6063) alloy made by stir-casting with SiC and TiO_2-reinforced hybrid MMC. Before the machining procedure in this investigation, the dimensions of the composite plate dimension, 150 x 150 x 10 mm, were adhered to using a rectangular die [10].

MRR for all prepared samples (AA6063 and 5% TiO_2 + 5% SiC, 5% TiO_2 + 10% SiC, and 5% TiO_2 + 15% SiC) were studied. The model was fixed to a piezoelectric-based KISTLER multi-component dynamometer. Tool inserts are installed on the workpiece, marking TE90AX 220-09-L. The workpiece is 20 mm in size and 170 mm in length. The orientation in which the final machining process was carried out was determined by the width of the specimen (100 mm). The determination of the MRR was carried out through the computation of the mean value of three measurements, which were taken at three distinct locations on the final drilling depth, and repeated three to four times.

Statistical analysis

Following a series of experiments, the MRR was subsequently computed. By using statistical software SPSS, mean value, sample variance, and CI were calculated. A statistically significant difference is assessed when p is < 0.05. The three variables being analyzed are the spindle speed, feed rate, and percentage of SiC reinforcement. To examine the impact of machining parameters on MRR and to produce statistically

significant results, an independent t-test was employed to analyze the data [6].

Results

The characteristics pertaining to the mechanical and chemical attributes of the reinforcing agents

AA6083 have been meticulously depicted in table 1 and table 2. A comprehensive representation of the thermal and mechanical properties of SiC has been elaborated in table 3. Table 4 presents an exhaustive analysis of the MRR of aluminum hybrid composites. Table 5 displays the group statistics acquired for the MRR of HSS (Group 1) and carbide tool (Group 2), as the maximal MRR is necessary for achieving the optimal production rate. Table 6 presents the statistical analysis of the MRR of HSS (Group 1) and carbide (Group 2) using Levine's test for equality of variance and the independent sample test statistics.

Table 1: Chemical properties of AA6063 alloy.

Elements	Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Al
%	0.3 - 0.69	0.35	0.2	0.25	0.6 - 0.9	0.15	0.14	0.05	Bal

Table 2: Mechanical properties of AA6063 alloy.

Material properties	Value
Tensile strength	220 MPa
Elongation	5%
Proof stress	190 MPa

Table 3: Mechanical and thermal properties of SiC.

Material name	Value
Melting point	2730 °C
Thermal conductivity	120 W/m-K
Poisson's ratio	0.35
Density	3.22 g/cm^3
Modulus of elasticity	90 GPa
Yield strength	21 GPa
Tensile strength	0.1379 GPa

The effect of machining operations on MRR on aluminum alloy machining parameters was studied while the CNC drilling. Figure 2 illustrates the experimental setup of the drilling operation in a CNC machine. The visual representations of the HSS and carbide tools can be observed in figure 3. To demonstrate the impact of these tools on AA6063 with SiC and TiO_2-reinforced hybrid MMCs. Figure 4 displays the corresponding MRR values. Figure 5 MRR comparison between experimental and control groups.

Table 4: Results of MRR for HSS (Group 1) and carbide (Group 2) tool on (AA6063/SiC/TiO_2) hybrid composites.

S. No.	MRR of AA6063/SiC/TiO_2 '(mm^3/min)'	
	HSS	Carbide
1	595.16	854.78
2	735.62	866.32
3	745.85	886.69
4	756.34	898.25
5	766.32	912.63
6	774.21	935.26
7	780.32	956.83
8	795.62	976.52
9	810.23	988.48
10	825.63	1012.25
11	838.52	1025.58
12	842.35	1058.56
13	866.32	1112.25
14	879.52	1135.27
15	895.36	1148.95
16	912.32	115628
17	925.45	1202.34
18	935.62	1250.65
19	945.28	1368.59
20	955.45	1468.59

Table 5: Group statistics obtained for the MRR of HSS (Group 1) and carbide tool (Group 2).

	Group	N	Mean	Std. deviation	Std. error mean
MRR	HSS	20	829.0745	89.47610	20.00746
	Carbide tool	20	1060.753	169.1534	37.82395

Discussion

The research involved a set of machining tests to examine the effect of machining performance on key factors, including impact energy, surface roughness, and chip deposition. The variables under scrutiny included drill material, spindle speed, and feed rate, wt.% of fraction. The increase in material potency was discovered to be proportional to the increase in the weight fraction of SiC and TiO_2 in AA6063 composites. This resulted in a stronger connection between the tool surface and the material's ceramic particles, significantly increasing thrust force and drilling torque.

Table 6: Levene's test for equality of variance and independent sample test statistics obtained for the MRR of HSS (Group 1) and carbide (Group 2).

		Levene's test for equality of variances		T-test for equality of means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean difference	Std. error difference	95% CI of the difference	
									Lower	Upper
MRR	Equal variance assumed	7.073	0.011	-5.414	38	0.000	-231.67900	42.78960	-318.30201	-145.055
	Equal variance not assumed			-5.414	28.860	0.00	-231.67900	42.78960	-319.21193	-144.14607

Figure 2. Vertical milling machine for machining a slot in the aluminium composites (AA6063/SiC/TiO_2) hybrid MMCs using HSS and carbide tool.

Figure 3: Schematic representation of HSS and carbide tool for evaluating MRR.

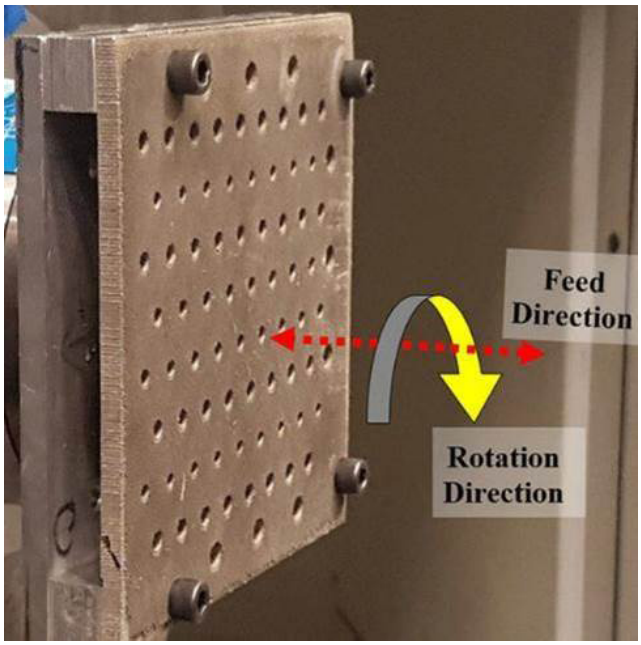

Figure 4: Effect of HSS and carbide tool MRR on AA6063 with SiC and TiO_2 reinforced hybrid MMCs.

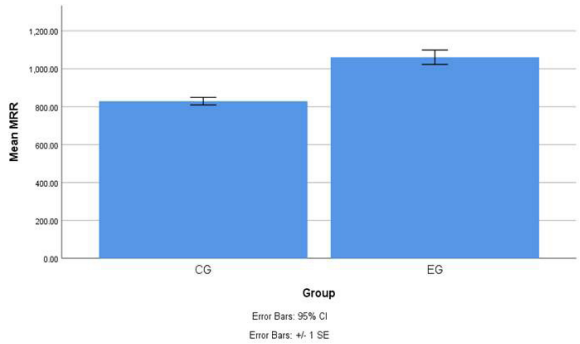

Figure 5: MRR comparison between experimental and control groups. Compared to the samples of the experimental group of the innovative hard carbide tool insert, the samples of the control group of machining parameters using carbide have a higher mean MRR value (1468.59 mm^3/min) than the HSS tool (595.16 mm^3/min) and a lower standard deviation. X-axis: HSS (Control group) and carbide (Experimental group) Y-axis: mean MRR with error +/-1 standard deviation.

Accordingly, the model constructed for connected and prospective purposes is more appropriate. A scientifically significant correlation between independent and dependent variables on cutting parameters (Feed rate, percentage of reinforcement, and spindle speed) on the response (MRR) is considered a p-value less than 0.05. The obtained p-value of statistical analysis is 0.000 ($p < 0.05$) shows the significance of the mathematical model [6]. Therefore, there is statistical significance between the two groups. According to the results, the cutting parameters had a significant effect on the MRR as opposed to the depth of the cut, which had a minor effect. A similar trend was observed in the previous experimental studies [11] using CNC drilling and machining operations.

Assuming a fixed depth size of 2 mm for the process parameters, an improvement in cutting speed leads to an increase in MRR and vice versa. Research has shown that MMRs have improved as feed rates are increased. The optimum value of the MRR is 1553.89 mm^3/min, which is determined at a feed rate of 0.06 mm/rev. The results indicate that there is an impact of the lubricant on the MRR. The results demonstrate that an increase in spindle speed leads to a corresponding increase in MRR, as reported by Javidikia et al. [12], indicating a clear relationship between the two variables. The best ranges of process characteristics for the required performance characteristics are determined by identifying the most critical factor. Based on the Analysis of Variance results, it can be inferred that the MRR is primarily influenced by the feed rate and spindle speed, whereas the depth of cut seems to have the least impact [13].

Conclusion

Utilizing SPSS analysis, it was observed that the carbide tool demonstrated a noteworthy MRR as compared to the HSS. The experimental data indicated that the applied load

escalated with an increase in the ratio of SiC to TiO_2 and feed rate. However, it exhibited a decline as the spindle speed escalated. Moreover, the disparity between the two clusters of estimated values was 0.000 ($p < 0.05$), which was less than 0.05, thus showing the difference between the groups.

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Conflict of Interest

None.

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