International Journal of ChemTech Research
CODEN (USA): IJCRGG, ISSN: 0974-4290, ISSN(Online):2455-9555
Vol.11 No.05, pp 73-77, 2018

Influence of Solid Lubricant Particles on Surface Roughness in Turning Hybrid Metal Matrix Composites

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Abstract : The current study presents an experimental examination on surface roughness in turning Al6061/10B_4C, Al6061/10B_4C/2%MoS_2,Al6061/10B_4C/4%$MoS_2$and Al6061/10B_4C/6 % MoS_2 composites. The novel composite is fabricated through stir casting composite by reinforcing constant amount of boron carbide ceramic particles (10% in weight) and varying weight percentage of MoS_2solid lubricant (0, 2, 4 and 6). Turning experiments were conducted based on the Taguchi L16 orthogonal array experimental design with carbide tool. The results reveals that the increase in weight percentage of MoS_2leads to increased surface roughness values. The ANOVA results indicated that feed has highest influence on surface roughness followed by MoS_2content, depth of cut and speed. Increase in MoS_2content in the composite results in discontinuous chip formation which indicates the ease of machining.
Key words : Hybrid MMC, Solid lubricant, ANOVA, Surface roughness.

1. Introduction

Metal matrix composites (MMC) are gaining wider attention in modern industry applications due to their enhanced and tailored properties [1]. Aluminium based particle reinforced MMC are an important class of materials among the MMCs with higher strength to weight ratio, higher wear resistance and easy availability. Additionally, the trend of adding two or more reinforcements with aluminium to fabricate hybrid MMC is increased nowadays since they posses well improved properties than the single type of particle reinforced MMCs. Among that, addition of soft solid lubricant as secondary reinforcement with primary hard ceramic reinforcement is highly increasing. These added solid lubricants increases the wear properties of the composites by reducing the friction between parts. Even though these hybrid MMC are possessing well improved basic and functional properties, their machinability is an important aspect that hinder their wider applications [2, 3]. The added reinforcements reduce the machinability of the MMC even if the base material has good machining behaviour. But, current manufacturing circumstancesis extremely competitive and thus to compete, it is necessary for high productivity without compromising quality [4].

Machining of MMC is very different from alloy machining due to the presence of abrasive reinforcements. The tool wear rate is found increasing with increase in the alumina ceramic reinforcement content while machining Al/Alumina composite [5]. The MMC surface roughness was directed by particle fracture or pull-out at lower feeds but in the case of highfeeds surface roughness was directed by feed.

International Journal of ChemTech Research, 2018,11(05): 73-77.

DOI= http://dx.doi.org/10.20902/IJCTR.2018.110508

Conversely, roughness of the machined non-reinforced alloy surface was chiefly influenced by feed [6].Surface roughness and tool wear is found increasing with increase in the volume fraction of SiC in aluminium matrix. Further it was reported that the surface roughness of the MMC increases with increase in feed while increase in speed decreases the surface roughness [7].Further, it was reported in literatures that the addition of graphite solid lubricant reduces the surface roughness in turning Al MMC. So it can be stated that the addition of solid lubricant with hard to machine MMC will results in improved surface finish. Hence, the current study aims to identify the effect of solid lubricant weight percentage while turning Al/B_4C MMC.

2. Materials and Methods

Al6061 alloy is selected as selected as base material to produce the aluminium MMC due to its easy availability and castability. Aluminium 6061 alloy is directly purchased from the market and its chemical composition analysis is given in table 1. Hard B_4C ceramic particle is selected as primary reinforcement whereas MoS_2solid lubricant is elected as secondary reinforcement. MoS_2solid lubricant is preferred over Gr due to its better thermal and electrical properties. Further, the MoS_2has the ability to expose its solid lubricant nature in all environments like vacuum whereas Gr cannot be used in vacuum environment. Initially, Al6061 base alloy is heated in graphite crucible using an electrical furnace to 700^{o}C and preheated B_4C and MoS_2particles were added to the molten base alloy. Then the mechanical stirring was performed at 300rpm for 10mins and mixed slurry was poured into cylindrical die to get the desired composite. Weight percentage of B_4C is fixed as 10% and MoS_2 weight percentage is varied in the order of 0, 2, 4 and 6.

Table 1. Chemical composition of Al6061

Element	**Fe**	**Si**	**Cr**	**Mn**	**Mg**	**Zn**	**Cu**	**Ti**	**Al**
Weight %	0.5	0.72	0.1	0.4	0.9	0.25	0.9	0.1	Balance

MMC specimens with 40mm diameter and 180mm length was attained from the stir casting is roughly turned initially to remove the defects and unwanted materials in the surface before machining study. Turing operation is performed in a CNC turning centre by varying speed, feed and depth of cut each at four levels as indicated in table 2.

Table 2.Parameters with respective levels

	Unit	**LEVEL I**	**LEVEL II**	**LEVEL III**	**LEVEL IV**
MoS_2 content	%	0	2	4	6
Speed	m/min	50	70	90	110
Feed	mm/rev	0.05	0.075	0.1	0.125
Depth of cut	mm	0.2	0.4	0.6	0.8

Based on the parameters and their levels L16 orthogonal array is designed with the help of MINITAB statistical software to perform the experiments and is given in table 3. This type of experimental designs compresses the number of experimental trials to analyze the process which tends to reduce the cost and time. All the experiments were conducted at no lubrication conditions and roughness of the machined surface is measured through Mitutoyo SJ210 surface roughness tester. Roughness is measured at the direction parallel to the feed at three different places and average value is taken for analysis.

3. Result and Discussion

3.1. Effect of parameters on surface roughness

The surface roughness value obtained from the turning experimentation is given in table 3. In Taguchi method, the experimental values are initially converted into Signal to Noise (SN) ratio and analyzedfurther. Among the different type of criteria to calculate SN ratio, smaller the better quality characteristics is followed for SN ratio calculation since the aim is to reduce the surface roughness. The calculated SN ratio is given in table 3 and main effect plots were plotted using these SN ratio values to identify the effect of input parameters on surface roughness.

Table 3.Experimental design with surface roughness and SN ratio

Trial No.	MoS_2 content	Speed	Feed	Depth of cut	Surface Roughness	SN ratio
	Weight %	m/min	mm/rev	mm	µm	-
1.	0	50	0.050	0.2	1.482	-3.41696
2.	0	70	0.075	0.4	1.523	-3.654
3.	0	90	0.100	0.6	1.692	-4.56801
4.	0	110	0.125	0.8	1.867	-5.42289
5.	2	50	0.075	0.6	1.492	-3.47538
6.	2	70	0.050	0.8	1.343	-2.56152
7.	2	90	0.125	0.2	1.525	-3.6654
8.	2	110	0.100	0.4	1.317	-2.39172
9.	4	50	0.100	0.8	2.149	-6.64473
10.	4	70	0.125	0.6	2.140	-6.60828
11.	4	90	0.050	0.4	1.732	-4.77096
12.	4	110	0.075	0.2	1.439	-3.16122
13.	6	50	0.125	0.4	2.278	-7.15107
14.	6	70	0.100	0.2	1.963	-5.85841
15.	6	90	0.075	0.8	1.892	-5.53842
16.	6	110	0.050	0.6	1.693	-4.57314

The main effect plot for surface roughness given in figure 2 confirms that the surface roughness of the composite decreases initially for 2% MoS_2 addition whereas further increase in solid lubricant content results increased roughness. Lubricant nature of the MoS_2 reduces the friction between the tool and work material that outcomes in better machining results. But higher addition of the same causes rougher surface due to smearing and detachment/removal of soft MoS_2 reinforcement from the material surface. This removal of reinforcement results in formation of cavities in the materials surface and that causes higher surface roughness. Increase in the cutting speed decreases the roughness of the machined surface [8]. Increase in speed decreases the size of built up edge which results in decreased surface roughness at high speed. Increase in feed and depth of cut decreases the surface roughness as shown in figure 2. Increase in feed increases the temperature at the cutting zone that reduces the bonding between base and reinforcement materials which results in detachment of reinforcement from the base matrix [9]. This detached particles forms cavities in the surface machined and increases the surface roughness.

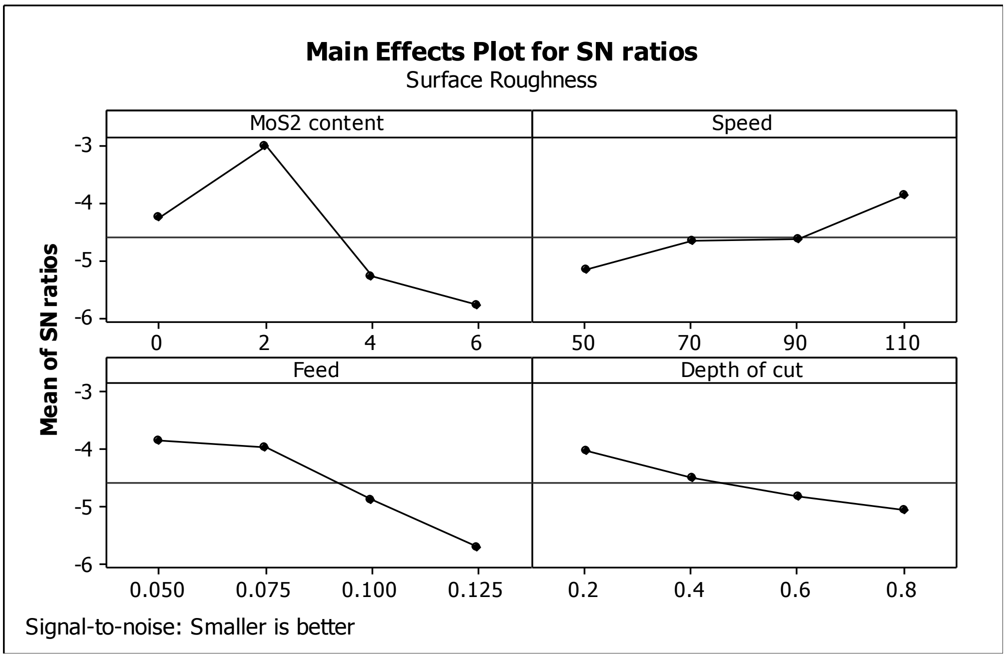

Figure 2. Effect of input parameters on surface roughness

Table 4. Response table for surface roughness

Level	MoS_2 content	Speed	Feed	Depth of cut
1	-4.265	-5.172	**-3.831**	**-4.025**
2	**-3.024**	-4.671	-3.957	-4.492
3	-5.296	-4.636	-4.866	-4.806
4	-5.780	**-3.887**	-5.712	-5.042
Delta	2.757	1.285	1.881	1.016
Rank	1	3	2	4

The level of parameter that has highest mean SN ratio value is considered as optimum as bold marked in table 4. From the main effect plot and response table for surface roughness the optimum condition for improved surface roughness is identified as 2% MoS_2content, 110 m/min speed, 0.05mm/rev feed and 0.2 mm depth of cut.

3.2. ANOVA

ANOVA results tabulated in table 5 confirmed that the addition of MoS_2 solid lubricant has highest influence over surface roughness of the aluminium MMC reinforced with B_4C. Among the turning parameters, feed has highest influence over the surface roughness followed by speed and depth of cut. The highest R square and adjusted R square values with minimal difference confirmed the higher significance of ANOVA.

Table 5. Analysis of Variance for surface roughness

Source	DF	Seq SS	Adj SS	Adj MS	F	P	%C
MoS_2 content	3	0.69459	0.69459	0.23153	56.53	0.004	51.35
Speed	3	0.14974	0.14974	0.04991	12.19	0.035	11.07
Feed	3	0.40126	0.40126	0.13375	32.66	0.009	29.66
Depth of cut	3	0.09478	0.09478	0.03159	7.71	0.064	7.01
Error	3	0.01229	0.01229	0.0041			0.91
Total	15	1.35266					100
R-Sq = 99.09% R-Sq(adj) = 95.46%							

3.3. Mathematical Modeling

General regression model is developed based on the experimental results to predict the roughness of the surface in turning Al MMC reinforced with B_4C and MoS_2. The developed mathematical model is as follows

Surface Roughness = 1.20427 + 0.0696125 MoS_2 content - 0.00422875 Speed + 5.455 Feed +0.336625 Depth of cut

The confirmation experiments results conducted for checking prediction ability of the developed model shows that the developed model predicts the response variable with minimal error(<7%). So the developed model can be further used to predict the surface roughness in turning $Al/B_4C/MoS_2$ MMC.

4. Conclusion

The novel hybrid aluminium MMC reinforced with B_4C and MoS_2 was successfully fabricated through stir casting and its machinability is analyzed in turning based on the surface roughness. From the study, the following conclusions were made

- Addition of MoS_2 decreases the surface roughness during turning up to 2 wt. % and further addition of MoS_2results in increased roughness values.
- ANOVA results confirmed the higher influence of MoS_2over surface roughness when compared to other parameters namely feed, speed and depth of cut.
- Feed has higher effect over surface roughness than the other tuning parameters considered.
- Minimal MoS_2content, feed, depth of cut and maximum speed is recommended for lower surface roughness i.e. higher surface finish.
- The developed mathematical model predicts the response variable with minimal error.

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