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Parametric Optimization of Surface Roughness and MRR on HPMMC using Taguchi Method in CNC Turning Process

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Abstract: ***The presence of the graphite in ceramic (SiC_p) reinforced Aluminum Metal Matrix Composites gives the better machining performance on machining process. Due to formation of the Tribologicallayers it will tends to improvements in the machining normally. In the manufacturing fields they need most précised machining operations which lead to produce good quality products at optimal conditions. The applications of the composites are increasing rapidly day to day in the field of engineering with their specific features, and these composites are required most precise machining operations due to their processing cost and applications. This paper presents that the fabrication of the Hybrid Particulate Aluminum Metal Matrix Composite (HPMMC) in the Sand Casting Process and the results of experimental study on Machinability properties of Hybrid Particulate Metal Matrix Composite (Al-SiC_p-Gr). The influence of reinforced ratios of 10 & 15 weight percentage of (SiC_p and Gr) Silicon Carbide and Graphite particles was examined. The effect of control factors of turning process like Speed, Feed rate, and Depth of Cut on resultant surface roughness and Material Removal Rate of work pieces was studied. The resulted output values were analyzed and optimized through the Taguchi; ANOVA and S/N ratio techniques. It was observed that the increment of graphite reinforcement with addition of SiC_P will improves the MRR with good surface finish. The surface roughness is depended on the Speed and Feed rates of cutting process majorly. The MRR is majorly depended on the Speed and DOC of Cutting process.***

Keywords: HPMMCs, Fabrication, Sand Casting process, Turning, Surface roughness, MRR, Optimization, Taguchi, S/N ratio, and ANOVA.

1. Introduction

The applications of the Aluminum Metal Matrix Composites (AMCs) are increasing day to day rapidly by their good machinability and strength to weight ratio, especially in automotive and aerospace activities (Surappa, 2003). By adding the ceramic reinforcements (B_4C, Al_2O_3, or SiC_p) to the AMCs it will shows the increment in both wear resistance and Mechanical Strength. These types of AMCs are called as Particulate Metal Matrix Composites (PMMCs). But these are having poor machinability property due to presence of ceramic components. And they required high strength cutting tools like High Carbon Steels (HCS tools) or Polycrystalline Diamond Coated tools (PCD tools) and special machining conditions for machining process of PMMCs. In 2008 Mr. Jinfeng Leng et al deliberate that the machinability of the PMMCs which contains the Graphite with combination of hard ceramic particles.

The presence of soft material like Graphite in compound of PMMCs reduces the cutting forces, why because the graphite is worked as the solid lubricant at time of machining processes with tribological property of graphite. At the time of Al-Gr composites machining it gives discontinues chips and prevents the more power consumption and high tool wear rates, here graphite works as a chip breaker. Hocheng et al (1997); Songmene et al (1999) were stated that, Due to self-lubrication property (peculiar properties) of Al-Gr Composites are used for fabrication material of pistons, bearings etc. the Al-Gr composites are having features like low wear rate, Low friction, and also prevents that seizing for the period of inadequate liquid lubrication condition by this life time is increases, reduces the cost and weight of components. The weight or volume percentage of reinforcements like Graphite and Ceramics such as SiC_p, Al_2O_3, or B_4C in AMCs is limited up to certain limit of range beyond that which is not beneficial of adding the Graphite or Ceramics respectively to AMCs. Suresha and Sridhara in 2010 studied about the hybrid composites and their tribological properties which having the multiple reinforcements in their compound over single element reinforced composites. At the time of 2007 Basavarajappa determined that the Al-2219/15SiC composites subsurface are deformed up to maximum of 150μm under the machined surface, but in the case of 15SiC&3Gr /Al-2219fusioncomplexes, due to low friction between tool and work piece with presence of Graphite Particles. In 1998 Iulianoa determined most of the composites are formed or molded or fabricated with precise dimensions and they mandatory often machining for tolerance and surface integrity control of final shape.

The aim of the present work is to explore the impact factor ofcontrol factors like as spindle speed, feed, depth of cut and equivalent weight fraction of SiC_p-Gr particulates on the performance characteristic of surface roughness and material removal rate (MRR) while turning of Al-SiC_p-Gr hybrid particulate metal matrix composites.

2. Experimental Procedure

2.1Materials

Aluminum alloy 6061 was used as matrix material, which has wide range of applications in the field of both aerospace and automotive fields. Here Al-SiC_p-Gr hybrid composites were fabricated from Al-6061 alloy with 10 and 15% of combined reinforcement of SiC_p and Graphite in the form of particulates.The average particle size of reinforcements SiC_p and Graphite was 35μm and 5μm respectively.

Table 1: Chemical composition of Al-6061

Elements	*Contribution (%)*
Silicon (Si)	0.40-0.80
Ferrous (Fe)	0.70
Copper (Cu)	0.15-0.40
Manganese (Mn)	0.15
Magnesium (Mg)	0.8- 1.2
Chromium (Cr)	0.04- 0.35
Zinc (Zn)	0.25
Titanium (Ti)	0.15
Others (each element)	0.05 each
Others Total	0.15 Over-all
Leftovers Aluminum	95.85-98.56

2.2Fabrication of Hybrid Particulate Metal Matrix Composites

The Graphite and Silicon Carbide particles were kept in muffle and pre heated up to 900^0c separately for 90mins. At preheating process Silicon Carbide reacted with atmospheric Oxygen and formed oxidation layer around it's, which prevents the formation of Al_4C_3 after mixing with Al, but the Graphite with stand up to 2350^0c. The Al-6061 was kept in a graphite crucible and heated up to its semisolid state and mix-up with the preheated reinforcements and then stirred manual for formation of homogenous mixture and increase the temperature of mixture to form in to liquid form of Al-6061 and kept at 850^0c for 30mins and melt was degassed and cleaned. The final molten slurry was poured in to sand mold cavity and allowed to solidify.

2.3Experimental set-up

Al-SiC_p-Gr composite rod of 30 mm diameter and 50 mm length is used as testing specimens and Polycrystalline Diamond coated (PCD) tool CCMT040808 as the cutting tool insert. The spindle speed in rpm (A), feed rate in mm/rev (B), and depth of cut in mm (C) are considered as control factors and surface roughness and MRR as output responses for turning process. The selected factors and their levels are presented in Table 2. The surface roughness (Ra) was measured by MITUTOYO surf tester (SJ-210 type)with cutoff length of 0.8 mm and transverse length of 5 mm. The surface roughness R_a is the arithmetic average of the absolute value of the heights of roughness irregularities from the mean value measured. The responses were kept in Table 3 with respect to their control factors for each specimen's ('X', 'Y') turning process.

Table 2: Levels and Factors of machining parameters

S.No.		FACTORS		
		Speed (rpm)	Feed (mm/rev)	DOC (mm)
Levels	01	1000	0.025	0.50
	02	1500	0.050	0.75
	03	2000	0.075	1.00

2.4 Calculation of Material Removal Rate

MRR was calculated through the difference of volume of work pieces before and after test by following formulae.

$$MRR = \frac{Intial\ \ volume\ \ -final\ \ volume}{Machining\ \ time} mm^3/min \qquad (1)$$

3. Results and Discussions

Tests were conducted as per predesigned Orthogonal Array (L_9 Array), to know the impact of control factors Feed, Speed, and DOC on corresponding machining responses Material Removal ate (MRR) and Surface Roughness (R_a). The test results like as MRR and Surface Roughness were tableted in following below table.Work piece "X" refers to composite of Al6061 & 10% (SiC_p + Gr) and Work piece "Y" refers to composite of Al6061 & 15% (SiC_p + Gr) respectively.

3.1 Experimental results MRR and Surface Roughness (R_a) for both Work pieces "X" & "Y"

Table 3: Experimental Results with Surface Roughness and Material Removal Rate (MRR) Response Factors with corresponding Control factors of turning operation

S.No.	*Speed (rpm)*	*Feed (mm/rev)*	*DOC (mm)*	*Work piece "X" Al6061 & 10% (SiC_p + Gr)*		*Work piece "Y" Al6061 & 15% (SiC_p + Gr)*	
				MRR (mm^3/min)	*Surface Roughness (Microns) (R_a)*	*MRR (mm^3/min)*	*Surface Roughness (Microns)(R_a)*
01	1000	0.025	0.5	874.08	0.341	640.56	0.426
02	1000	0.05	0.75	1714.92	0.425	2008.44	0.470
03	1000	0.075	1	1734.36	0.453	3637.2	0.438
04	1500	0.025	0.75	2707.32	0.634	1791.72	0.490
05	1500	0.05	1	3588.18	0.560	2395.8	0.530
06	1500	0.075	0.5	2649.18	0.512	2324.82	0.570
07	2000	0.025	1	2256.48	0.765	4379.16	0.620
08	2000	0.05	0.5	1726.2	0.609	2501.22	0.602
09	2000	0.075	0.75	4481.34	0.592	3411.72	0.670

Taguchi technique is a most effective tool, which is majorly adopted by industrial engineers to approach the high qualitative productivity at possible optimal cost and time. The factors which are affecting the response are arranged in the form of Lattice Square model, this model is called as Orthogonal Array. Forming and selection of the Orthogonal

Array and the Factors for conducting experiments are the main criteria in the Taguchi Process. In Taguchi method, Signal to Noise Ratio (S/N Ratio) is the Statistical measuring process for predict the optimum factors to respected Responses. The smaller the better, the higher the better, and the nominal the better (Ross, 1996) are three sorts for the S/N Ratio for examine the Factor's enactment.

Table 4: Sorts with formulae of S/N Ratio

S. No.	*Sort*	*Formulae*
01	Smaller the Better	$S/N = -10\log_{10} \sum_{i=1}^{n} (1/n)\,({Y^2}_i)$(or) $S/N = -10\log_{10} Y^2$
02	Nominal the Better	$S/N = -10\log_{10}(\bar{Y}^2/S^2)$, $S/N = -10\log_{10}(S^2)$
03	Bigger the Better	$S/N = -10\log_{10} \sum_{i=1}^{n} (\frac{1}{N})(1/$ $Y2i$(or)$SN=-10\log 101Y2$

In this present work we are adopted that the Smaller the Better Sort for Surface Roughness and Bigger theBetter Sort for MRR response values in S/N Ratio process. Surface roughness (SR) and Material Removal Rate (MRR) of machined objects are playing vital role inthe industrial production rate and cost. The main object of the machining operations is to maximize the MRR and minimize the surface roughness to improve productivity and machinability by controlling the machining factors. Low surface roughness helps to improve the machined object life time and appearance. High MRR gives good industrial productivity in period time.

But the ANOVA is gives the impact of the Factors with respect to their Responses normally.

3.1.1Work piece "X"

Table 5: Analysis of Variance for SN ratios of Surface roughness (R-Sq = 91.9%)

Source	*DF*	*Seq. SS*	*MS*	*F*	*P*
Speed (rpm)	2	27.4218	13.7109	9.55	0.095
Feed(mm/rev)	2	0.4608	0.2304	0.16	0.862
DOC (mm)	2	4.7361	2.3681	1.65	0.378
Residual Error	2	2.8725	1.4362		
Total	8	35.4912			

Table 6: Analysis of Variance for SN ratios of MRR (R-Sq = 97.3%)

Source	*DF*	*Seq. SS*	*MS*	*F*	*P*
Speed (rpm)	2	75.713	37.857	19.73	0.049
Feed(mm/rev)	2	22.907	11.453	5.97	0.143
DOC (mm)	2	37.343	18.671	9.73	0.093
Residual Error	2	3.837	1.919		
Total	8	139.800			

Table 7: Response Table for Signal to Noise Ratios Smaller is better (Surface Roughness)

Level	*Speed (rpm)*	*Feed(mm/rev)*	*DOC (mm)*
1	7.885	5.210	6.489
2	4.936	5.592	5.315
3	3.729	5.749	4.747
Delta	4.156	0.539	1.742
Rank	1	3	2

Table 8: Response Table for Signal to Noise Ratios Larger is better (MRR)

Level	*Speed (rpm)*	*Feed(mm/rev)*	*DOC (mm)*
1	62.77	64.85	64.01
2	69.40	66.84	68.79
3	68.28	68.76	67.65
Delta	6.64	3.91	4.78
Rank	1	3	2

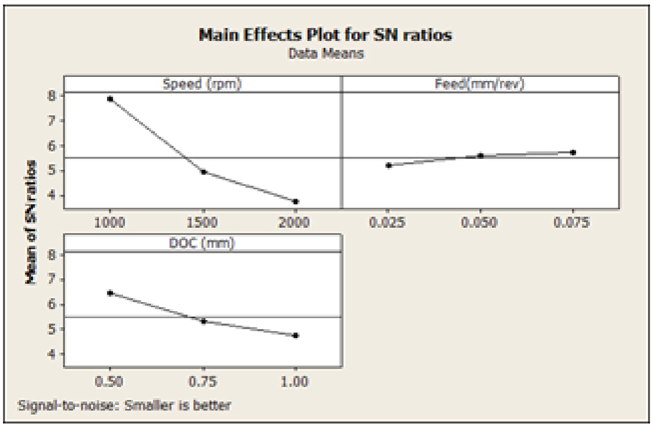

Figure 1: Main Effects plots for SN ratios (Surface roughness)

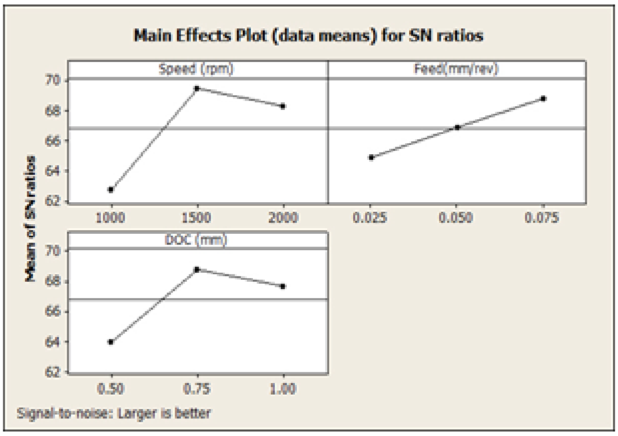

Figure 2: Main Effects plots for SN ratios (MRR)

3.1.2Work piece "Y"

Table 9: Analysis of Variance for SN ratios of Surface roughness (R-Sq =94.8%)

Source	*DF*	*Seq. SS*	*MS*	*F*	*P*
Speed (rpm)	2	13.8066	6.90330	17.03	0.055
Feed(mm/rev)	2	0.8338	0.41689	1.03	0.493
DOC (mm)	2	0.0671	0.03357	0.08	0.924
Residual Error	2	0.8108	0.40539		
Total	8	15.5183			

Table 10: Analysis of Variance for SN ratios of MRR (R-Sq =85.8%)

Source	*DF*	*Seq. SS*	*MS*	*F*	*P*
Speed (rpm)	2	55.61	27.80	2.07	0.325
Feed(mm/rev)	2	38.40	19.20	1.43	0.411
DOC (mm)	2	68.09	34.04	2.54	0.282
Residual Error	2	26.80	13.40		
Total	8	188.90			

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Table11: Response Table for Signal to Noise Ratios Smaller is better (Surface Roughness)

Level	*Speed (rpm)*	*Feed(mm/rev)*	*DOC (mm)*
1	7.047	5.920	5.567
2	5.531	5.494	5.411
3	4.013	5.177	5.612
Delta	3.034	0.743	0.202
Rank	1	2	3

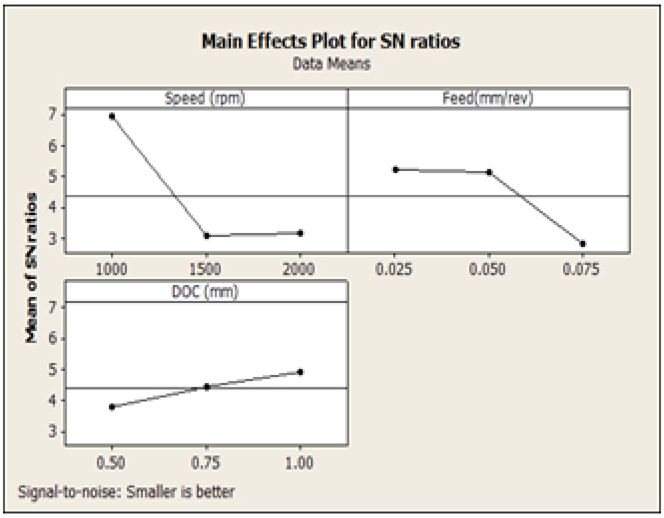

Figure 3: Main Effects plots for SN ratios (Surface roughness)

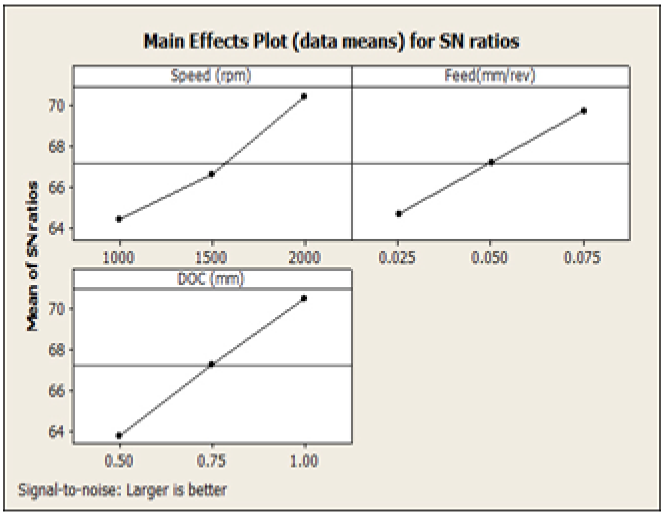

Figure 4: Main Effects plots for SN ratios (MRR)

4. Conclusion

1) In sand casting process we were successfully prepared 10, 15% SiC_p& Gr/Al-6061 Hybrid Particulate Metal Matrix Composite specimens by varying weight fractions of SiC_p and Gr equally.
2) Minitab17 used for to know the impact factor of control factors such as speed, feed, and depth of cut on the turning process's responses factors like as surface roughness and Material removal rate, through the S/N ratio, and ANOVA analysis.
3) While machining the work piece-X and work piece-Y (10, 15% SiC_p& Gr/Al-6061) Speed and Feed were playing more impact on result of surface Roughness, similarly Depth of Cut and Speed were playing more significant on result of Material Removal Rate.

Table 12: Response Table for Signal to Noise Ratios Larger is better (MRR)

Level	*Speed (rpm)*	*Feed(mm/rev)*	*DOC (mm)*
1	64.47	64.67	63.81
2	66.66	67.20	67.26
3	70.48	69.73	70.54
Delta	6.02	5.06	6.74
Rank	2	3	1

4) The optimal level of control factors forminimum valued result factor surface roughness of turning on both 10, 15% SiC_p& Gr/Al-6061 work pieces is $A_1B_1C_1$ (1000rpm, 0.025mm/rev, 0.50mm).
5) Similarly the optimal level of control factors for maximum MRR (4481.34mm^3/min) result of turning on Al-6061/10 SiC_p& Gr work piece-"X" is $A_3B_3C_2$(2000rpm, 0.075mm/rev, 0.75mm), and for Al-6061 /15 SiC_p& Gr work piece-"Y"maximum MRR(4379.16mm^3/min) at level of $A_3B_1C_3$(2000rpm, 0.025mm/rev, 1.0mm).
6) From the table 3 Work piece-X is having lesser Surface roughness value (0.341Microns) and higher MRR value (4481.34mm^3/min) than the Work piece-Y.
7) The work piece-X is having better response factor values than the work piece-Y.
8) Finally we concluded that the Al-6061/10SiC_P&Gr shows better machinability features than Al-6061/15 SiC_P&Gr.
9) The low feed rate, Depth of cut and high speed values of machining process will tends to good surface finish of final objects, similarly high depth of cut and speed values of machining will tends to high material removal rates normally.
10)This present study reveals that proper utilization of Taguchi's plan of experiments to attainoptimal form with lowermost cost at least possible number of trail runs and Industrial Engineers can use this method.

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