Surface roughness and tool wear analysis while turning Al/SiCp metal matrix composites

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ABSTRACT

KEYWORDS

Al/SiCp MMC,
Design of Experiments,
Surface Roughness,
Tool Wear.

Al/SiCp is special types of metal matrixes composite which shows excellent mechanical properties and have wide range of application. This paper represents optimum process parameters on Al/SiCp metal matrix composites. For experimental investigation 2024-Al alloy has been used as matrix material and reinforcement as silicon carbide powder (SiCp). A stir casting process was used to developed Al/SiCp metal matrix composite in which 20% weight fraction of SiCp reinforcement has been chosen having 220 mesh size (65μm). The experiment involves turning operation in which cutting tool used as carbide insert having TiN coating. The three process parameter with three levels is considered for experimentation i.e. speed 150 to 250 m/min, feed rate 0.05 to 0.1 mm/rev and DOC 0.5 to 1 mm are under dry state condition. Taguchi L_9 orthogonal array methodology was done to decide the optimum process parameter using SN ratio. To identify machinability of Al/SiCp MMC study focused on surface roughness and tool wear response variables. The experimental study showed that the speed is the utmost substantial factor as compared to DOC and feed in case of surface roughness while for tool wear the speed is the most important factor than feed rate and DOC. The signal-to-noise ratio gives optimum conditions as speed of 200 m/min, the feed 0.07 mm/rev, and DOC 0.5 mm for the surface roughness and for tool wear optimum conditions as speed of 150 m/min, the feed 0.07 mm/rev, and DOC 0.75 mm.

1. Introduction

Metal Matrix Composites (MMCs) are leading engineering material in recent years of industrial applications because due to its superiority in properties. Metal matrix composites comprises of high mechanical properties such as strength, stiffness, heat resistance, wear resistance, corrosion resistance, low weight and superior mechanical properties for numerous industrial uses. [1] In recent days MMCs have been commonly used in automobile and aerospace parts manufacturing organisations. They also widely used in recreation services, shipyards, wind power, sports, racing car bodies, military and medical application etc. High speed sports cars for example manufactured at Porshe they used silicon carbide and carbon fibre for rotor to get high thermal properties. So metal matrix composites (MMCs) offers excellent mechanical properties over the conventional material but MMCs tend to be more expensive because the difficult to fabricate and machining.

Generally aluminium, magnesium, titanium alloy has been used as matrix phase and for hardening these alloy phase aluminium oxide and silicon carbide in the form of particulate and fibre are used as reinforced material. In aluminium metal matrix composite (MMC) aluminium is matrix material while Al_2O_3, SiC, and B_4 etc. can be used as reinforcing material. The machining of Al MMC are challenging because it has different values of properties with different axis, non-homogenous and unbreakable reinforcement. Aluminium metal matrix composite material are very hard for machining and this machining difficulty lead towards limited manufacturing of Aluminium metal matrix composite component in industries and due to this expensive machining cost and short cutting tool life. However strength, hardness, toughness of Al MMC can still maintained and

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machining can be done by selecting appropriate process parameters.

Surface finish is one of the major feature required for aluminium metal matrix composite because it obstructs several causes in machining. Life of mechanical component can considerably decide by surface finish which disturbs numerous properties like corrosion, wear, fatigue and friction. Tool wear is another important parameter to be studied. Hence dominance of surface finish and tool wear stands important hence proper process parameters must selected for optimum results.

2. Literature Review

U. A. Dabade and M. R. Jadhav [2] carried out experiments on Al composites of two varieties particle size if silicon carbide reinforcement (15µ and 65µ) using taguchi method. The analysis of variance results shows that feed, DOC, and preheating temp. have major effect on surface finish. M. R. Jadhav and U. A. Dabade [3] optimisation was carried out by using grey relational analysis. Results showed optimum machining parameters are feed 0.05 mm per rev, DOC 0.4 mm, preheat temp. 60 °C for both materials only speed was 50 and 25 m/min respectively. M. R. Jadhav and U. A. Dabade [4] they carried out FEA and experimental work on two Al composites. Author found that close agreement between finite element simulation results and experimental results of forces. U. A. Dabade et al. [5] observed that feed influenced the machined surface finish and with use of wiper insert, surface defects on machined surface highly reduced. While machining of 10% reinforcement composite with high speed and 30% composite at lower speed shows better surface finish. U. A. Dabade [6] observed that surface finish is more sensitive to variation in size than variation in volume fraction. The analysis carried out by them using GRA which showed that optimum machining condition as wiper insert with nose radius 0.8 mm, feed 0.05 mm per rev, speed 40 m per min and DOC 0.2 mm to improve surface integrity. Senthilkumar D et al. [7] Conducted an experimental work on Al metal matrix composites. They concluded that better surface finish values obtained at higher speed and DOC. While machining force and power consumption shows higher values as feed values are more Seyed Ali Niknam [8] author used Titanium metal matrix composite as a composite material for analysis. Author used Mazak Nexus100-II M as with different lubrication modes and process parameters. The uncoated carbide insert was used in the test. The bio-lubricant with 100-300 ml/min flow was applied. Author concluded that larger values of cutting forces were observed under semi-dry modes rapid tool wear occurs for dry mode at cutting speed 50 m/min also they observed that when the flow rate of coolant is a higher than a lower number of concentration of ultrafine particle rate was occur and they also found that with the cutting tool progress in the semi-dry test they got higher values of surface roughness under high cutting speed. Suhasini Gururaja et al. [9] Author reviewed of machining of MMC study through focus on Al MMC with two different cutting tools. They concluded that lower cutting speeds, high feed rate, and deeper depths of cut causes BUE on the tool edge. This increases tool life as stable BUE eliminate abrasion because of prevention of relative motion between tool and workpiece. S. H. Tomadia [10] This research work put light on effect of machining conditions on surface roughness and linear model equation developed for the same by using design expert software. Uncoated and coated carbide tools are used for experimentation under dry machining environment. A comparative result shows that better surface finish obtained for uncoated cutting tool between them. Optimum machining condition obtain from S/N ratio and validation of the same also carried out by author. N Senthilkumar and T Tamizharasan [11] They carried out experimentation by varying cutting tool geometry and analyse temperature at tool interface as well as wear. Author found that nose radius has more significant impact as compared to other tool geometry parameters on cutting zone temperature whereas for wear, insert shape. M Asad and F Girardin, et al. [12] This paper presents the dry cutting study of an aluminium alloy through numerical and experimental approach. The process parameters are considered as speed & feed with constant cutting depth. Numerical approach regarding cutting force and segmentation frequency are compared to experimental approach.

3. Experimental Works

3.1. Work material

The experimentation was carried on ø 30mm round bar of Al/SiC$_p$ MMC made from stir casting route. The 2024 Al alloy used as matrix material and 20% weight fraction of Silicon Carbide Powder (SiC$_p$) with 220 mesh size (65µm) had been used for the reinforcement.

3.2. Design of experiments

L_9 experiments were carried out using DOE method for Al/SiC$_p$ MMC. Experimental work process parameters are used tabulated as shown in Table 1.

3.3. Experimental setup and procedure

MTAB CNC turning center as shown in fig. 1 with cutting insert sandvik make QM 1105, TiN PVD coated with good mechanical properties are used. Every turning operation experiment was performed by using new edge of cutting inserts for proper study and differentiation. Taylor Hobson surface roughness tester was used to measure surface roughness at three separate 120° angle location and its average value was recorded. Mititutyo microscope was used to measure flank wear.

Table 1
Process parameters and their levels.

Process Parameters	Unit	Levels		
		1	2	3
Cutting speed	m/min	150	200	250
Feed	mm/rev	0.05	0.07	0.10
Depth of cut	mm	0.5	0.75	1.00

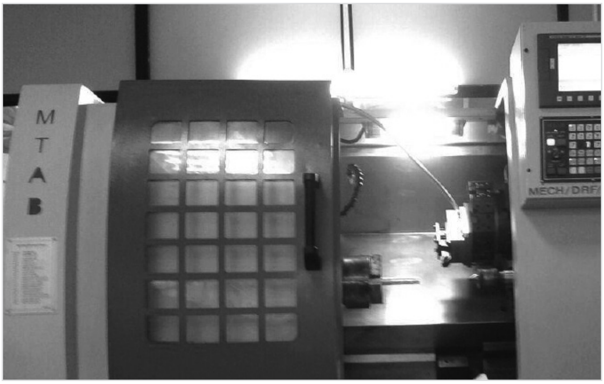

Fig. 1. Experimental setup.

4. Result and Discussion

Minitab-16 software was used for statistical analysis to study the most important factor influence surface finish and tool wear and also SN ratio for optimum machining parameters. A linear regression technique was used to develop numerical model of the surface roughness and flank wear.

4.1 Analysis of surface roughness

From the ANOVA table we found that 89.80% is contribution by cutting speed and the inference can be drawn that cutting speed has more impact on surface roughness. From AOM plot as shown in fig. 2 it is observed that up to 200 m/min surface finish value lowered and further increased with increase in speed. As it clear from classical relation

From Figure 1 which represents the AOM plot of surface roughness. As it is clear from classical relation $Ra = f^2 / 32r$. Feed is directly proportional to surface finish, same is observed from experimental work. It is also observed that depth of cut directly proportional to surface roughness.

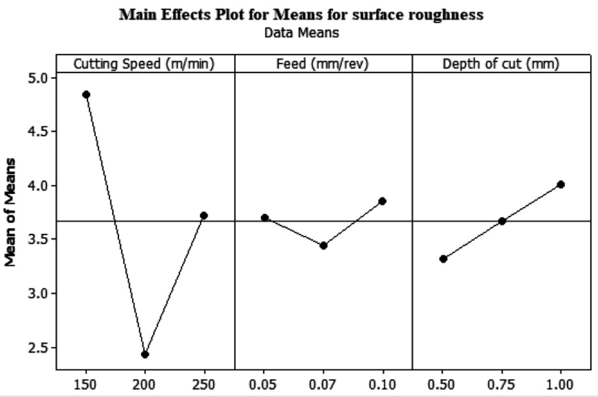

Fig. 2. Main effect plot for means of surface roughness.

Table 2
ANOVA (P and F values) for surface roughness.

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**	**% contribution**
Cutting Speed (m/min)	2	8.7266	8.7266	4.3633	6889.42	0.000	89.80
Feed (mm/rev)	2	0.2613	0.2613	0.1306	206.26	0.005	2.68
Depth of cut (mm)	2	0.7281	0.7281	0.3640	574.79	0.002	7.49
Error	2	0.0013	0.0013	0.0006			0.013
Total	8	9.7172					100

4.2 Optimization of process parameters for surface roughness

Taguchi methodology is used for optimization of machining parameters. In Taguchi methodology S/N ratio approach is utilised for optimization of machining conditions. In any machining operation cutting parameters are selected to minimize the surface roughness. To carry out optimization for surface roughness smaller-the-better methodology of S/N ratio is considered. For better performance of process high value of S/N ratio is preferred. The highest S/R corresponds to optimized parameters. Referring fig. 3 it can be seen that optimized cutting parameters are speed 200 m/min, feed 0.07 mm per rev and DOC 0.5 mm.

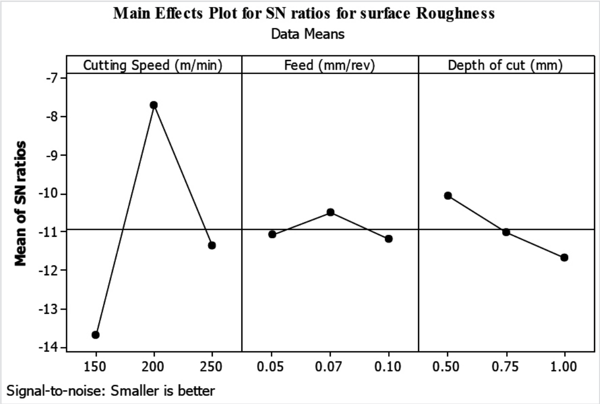

Fig. 3. Mean effect plot for SN ratio for surface roughness.

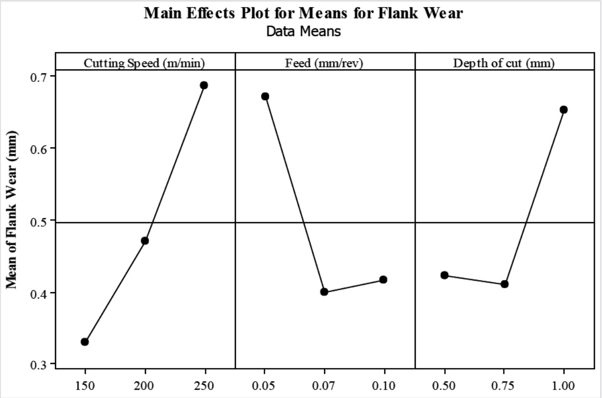

Fig. 4. Main effect plot for means for flank wear.

4.3 Analysis of tool wear

ANOVA results indicate that the cutting speed is the major contributing factor for flank wear and then feed rate and depth of cut. It found that cutting speed has 28.47% contribution to the value of flank wear as shown in Table 3.

From Fig. 4 which represents the AOM plot of Flank wear it is clear that Flank wear is directly proportional to cutting speed from 150 to 250 m/min. At high cutting speed the temperature at tool chip interface increases which leads to flank wear due to softening of insert edge. As feed rate are increases 0.05 to 0.10 mm/ rev flank wear decreases. It is clear from AOM plot shown in Fig. 4 that tool wear increases with increase in depth of cut which is a general trend found in turning operation. Flank wears directly proportional to DOC. This can be contributed to increase cross sectional area due to increase in DOC. This increases the cutting force which in turn increases the flank wear.

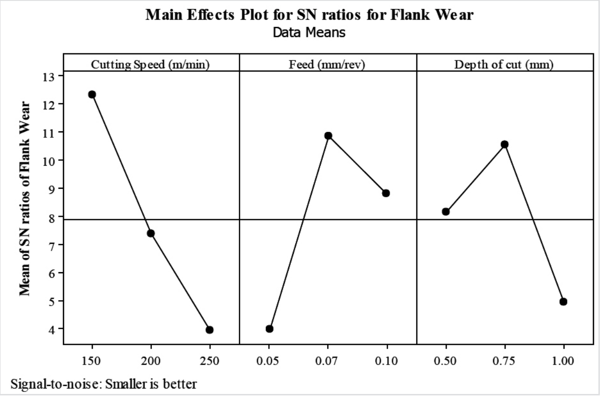

Fig. 5. Main effect plot for SN ratio for flank wear.

Table 3
ANOVA (P and F values) for flank wear.

Source	DF	C	Adj SS	Adj MS	F	P	% contribution
Cutting Speed (m/min)	2	0.1936	0.1936	0.0968	0.83	0.546	28.47
Feed (mm/rev)	2	0.1408	0.1408	0.0704	0.60	0.623	20.71
Depth of cut (mm)	2	0.1122	0.1122	0.0561	0.48	0.675	16.50
Error	2	0.2331	0.2331	0.1166			34.28
Total	8	0.6798	0.6798				100

4.4 Optimization of process parameters for tool wear

Taguchi methodology is used for optimization in which S/N ratio approach is used. In any machining operation input parameters are choosen to minimize the tool wear. To carry out optimization for tool wear smaller-the- better methodology of S/N ratio is considered. For better performance of process high value of S/N ratio is preferred. The highest value of S/R corresponds to optimized parameters. Referring table it can be seen that optimized cutting parameters are speed 150 m/min, feed 0.07 mm/rev, and DOC of 0.75 mm.

4.5 Mathematical modeling

The relation among process parameters and response variables was developed by linear model using Minitab-16 software.

The regressing equation for the Surface Roughness is

Surface Roughness (µRa) = 4.57 - 0.0112 Cutting Speed (m/min) + 4.0 Feed (mm/rev)
+ 1.39 Depth of Cut (mm)

The regressing equation for the flank wear is

Flank Wear (mm) = - 0.220 + 0.00357 Cutting Speed (m/min) - 4.67 Feed (mm/rev)
+ 0.461 Depth of Cut (mm)

From above equations predicted values were calculated and compared with the actual measured values and it shows good agreement between them.

5. Conclusion

This experimental work shows the analysis of tool wear and surface finish which helps to know the machinability of Al/SiC/20p composites. Techniques like ANOVA and AOM plots are used for significance parameters on surface finish and tool wear. Optimization is carried out using taguchi methodology. From above work conclusion as follows.

1. Cutting speed is the most significant parameter contributing to a better surface finish and flank wear followed by the depth of cut, and feed rate respectively.
2. Optimized cutting parameters for turning Al/SiCp/20p for surface roughness are speed of 200 m/min, feed rate 0.07 mm/rev, and depth of cut of 0.5 mm.
3. Optimized cutting parameters for turning Al/SiCp/20p for flank wear are speed of 150 m/min, feed rate 0.07 mm/rev, and depth of cut of 0.75mm.
4. A developed mathematical model for surface roughness and flank wear shows good agreement between the actual value and predicted value.

References

1. Rathod, B. S., & Pandey, B. (2017). Effect of Turning Parameters on Aluminium Metal Matrix Composites -A Review. *IOP Conference Series: Materials Science and Engineering*.
2. Dabade, U. A., & Jadhav, M. R. (2016). Experimental study of surface integrity of Al/SiC particulate metal–matrix composites in hot machining 48th CIRP Conference on MANUFACTURING SYSTEMS - CIRP CMS 2015. *Procedia CIRP,* 41, 914-919.
3. Jadhav, M. R., & Dabade, U. A. (2016). Multi-Objective Optimization in Hot Machining of Al/SiCp Metal MAtrix Composites. *IOP Conf. Series: Materials Science and Engineering*. 114, 1-10
4. Jadhav, M. R., & Dabade, U. A. (2016). Modelling and Simulation of Al/SiC$_p$ MMCs During Hot Machining *ASME International Mechanical Engineering Congress and Exposition*. 50527, V002T02A023.
5. Dabade, U., Joshi, S., Balasubramaniam, R., & Bhanuprasad, V. V. (2007). Surface finish and integrity of machined surfaces on Al/SiCp composites. *Journal of Materials Processing Technology.* 192–193, 166–174.
6. Dabade, U. A. (2013). Multi-objective process optimization to improve surface integrity on turned surface of Al/SiCp metal matrix composites using grey relational analysis. *Procedia CIRP, 7,* 299-304.
7. Senthilkumar. D. (2015). Experimental Investigation on Al-Cu-Sic MMC in Turning Operation. *International Journal of Engineering Research & Technology.* 4(12), 268-271.
8. Niknam, S. A. (2018). Dry and semi-Dry Turning of Titanium Metal Matrix Composites (Ti-MMCs). *8th CIRP Conference on High*

Performance Cutting (HPC 2018). 62-65.

9. Gururaja, S., Ramulu, M., & Pedersen, W. (2013). Machining of MMCs:A Review. *Machining science and technology: An International Journal*. 17(1), 41-73.
10. Tomadia, S. H. (2017). Effect of Cutting Parameters on Surface Roughness - End Milling of AlSi/AlN Metal Matrix Composite. *Procedia Engineering, 184 ,* 58 – 69.
11. Senthilkumar, N & Tamizharasan, T. (2014). Experimental investigation of cutting zone temperature and flank wear correlation in turning AISI 1045 steel with different tool geometries. *Indian Journal of Engineering & Materials Sciences*. 21, 139-148.
12. Asad, M., Girardin, F., Mabrouki, T., & Rigal, J. F. (2008). Dry cutting study of an aluminium alloy (A2024-T351): a numerical and experimental approach. *International Journal of Material Forming,* 1, 499-502.

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