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Fabrication and Mach inability Analysis of Silicon Carbide and Nickel Particles reinforced Aluminium Matrix Composites

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ABSTRACT

This study presents the investigation on machinability of stir cast silicon carbide (10% fixed) and nickel (0%, 5% and 10% by weight) reinforced aluminium matrix composites using coated carbide tool. The turning tests of novel composites are performed on conventional lathe at various cutting parameters (viz. cutting speeds, feed rates and depths of cut), the responses selected for the study are surface roughness and material removal rate with an objective to minimize the surface roughness and maximize material removal rate. Analysis of variance is used to analyze the effects of Ni particles inclusion and cutting parameters in cutting of novel composites. It is apparent from results that surface roughness of the base composite (Al-10SiC) is affected significantly with the inclusions of nickel particles and cutting speed, which is contributed 23.46% and 23.21% respectively. However, the material removal rate is considerably affected with the cutting parameters, while the weight percentage of Ni inclusion has a minor effect on it. The results are validated using Analysis of variance and the significant level of each input parameter, which affects the responses, is identified. Also, the surface roughness is unavoidable to achieve maximum material rate.

KEYWORDS: Aluminum matrix composite, nickel, silicon carbide, surface roughness

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INTRODUCTION

Composites comprise two or more distinguished materials, whose properties are tailored. The metal matrix composite (MMC) exhibits the most significant properties as compared to the pure metals/alloys. The future interest in aluminium matrix composites (AMCs) is because of the low cost and low-density reinforcements present in it.[1,2] Nowadays, extensive research work has been extended to fabricate Al/SiC composites. These composites materials exhibit many applications in automobile and aerospace industries due to higher strength/weight ratio, lower composite density, higher wear resistance etc.[3,4]

The quality of the machined surface depends on the cutting tool geometry, workpiece-tool interface, process parameters (viz. speed, feed, depth of cut), environmental conditions utilized during machining. These parameters have a significant effect on the surface roughness, material removal rate, cutting forces and internal stresses induced during machining.[5,6] Among these, surface roughness could be considered as one of the important parameters of the machined surface as the choice of machining processes and their processing parameters are strongly influenced with it.[7]. Surface roughness and material removal rate are significant output parameters to assess the machinability aspect of a composite material. Different methods used for machining of composite materials include turning, milling, grinding, electric discharge machining etc.[8] Of these, turning is used effectively in removing the material of many composite materials.[9]

Over 2-3 decades, a number of researchers have worked to assess the machining behaviour of Al-SiC composites. According to Dabade[6], the minimum surface roughness during the turning of Al/SiC composite can be obtained, when turned with the help of wiper shaped insert (0.8mm nose radius) at a speed of 40m/min, feed of 0.05 mm/rev and cutting depth of 0.2mm. Palanikumar et al.[10] reported that while the turning A356-20SiC composite, the surface roughness is decreased with increasing cutting speed and increased with increasing the feed rate. However, superior surface finishing is achieved at a medium depth of cut. Manna and Bhattacharyya[11] compared the tooling systems and reported that minimum tool wear is achieved in the rotary circular tooling system along with better tool life. Many authors have reported the BUE formation at low cutting speed conditions, which causes smaller cutting forces and poor surface finishing.[12,13] Muthukrishnan et al.[14] noticed that superior surface quality can be obtained at high cutting speed conditions, but with the rapid wearing of the tool surface. Kumaran et al.[15] observed higher surface roughness at a low cutting speed. They have observed that surface roughness is reduced with the increase of feed and cutting depth. Authors have also observed increased material removal rate with the increase of cutting parameters (viz. speed. feed. depth of cut).

In the current study, aluminium matrix composites were developed through stir casting method as this route is simple and comparatively cheaper. The main factors affecting this process include melting temperature of matrix, stirring speed/time, rate of reinforcements addition molten metal/alloy, mould temperature etc.[16,17] The limitations of this method are irregular dispersion of reinforcements, lack of wettability among constituents resulting higher porosity level, internal reactions etc.[18,19] which can be minimized with efficient stirrer design, using wetting agents (like Mg, CNT, Si), using copper metal coatings on the reinforced particles, choosing optimum stirring speed and time etc.[16,20]

In this experimental study, the turning tests are conducted as per L_{27} orthogonal array on the HMT LB-17 lathe centre (7.5kW) using multi-layer coated (TiN+TiCN+Al_2O_3+TiN) carbide tool. The purpose of this investigation is to optimize the Ni contents and cutting parameters to obtain minimum surface roughness and maximum material removal rate. To determine the significance level of each input parameter, the results are validated using ANOVA. The obtained best settings for the cutting parameters and Ni contents enhance the machinability aspects of the novel composites.

MATERIALS AND METHODS

Materials Selection

For this investigation, the aluminium-silicon alloy was chosen as the base matrix with 10% SiC and (0, 5 and 10%) nickel particles. before fabrication, the composition of the matrix is analyzed using spark electromagnetic analysis and it contains 85.10Al, 10.30Si, 0.26Mg, 1.87Cu, 0.98Fe, 0.95Zn, 0.13Mn, Ti0.04, 0.025Cr, 0.096Ni. The micro-particles of commercially available silicon carbide and Ni were selected as reinforcements for the composites. SiC belongs to the light ceramic group of materials and Ni belongs to the metallic group of materials. Both are hard materials and can improve the properties, when introduced in the grain structure of the matrix and can withstand high temperatures.[21]

Composites preparation

Stir casting route was used for the preparation of composites because it is simple, inexpensive and due to stirring action, it can develop composites with regular dispersion of reinforcements.[16] Figure 1 illustrates the schematic diagram of the stir casting setup. The required amount of aluminium alloy was placed in the ceramic crucible and charged in the electric furnace. The melting temperature of $730^oC \pm 20^oC$ was maintained to melt the alloy completely. The required amount of reinforcements was preheated at about 800^oC for half an hour to eliminate the moisture contents. The atmospheric contamination was prevented by supplying inert gas in the vicinity of molten metal.

The small amount of Mg (1wt.%) was also introduced to strengthen the interface bonding between the constituent particles and to enhance the wettability between them. The graphite stirrer was heated before introduction in liquid metal and placed at a depth of 2/3 height of the molten metal from the bottom. Thereafter, the mixture of reinforcements was poured in the molten metal in three stages and stirred at an average speed of 400 rpm for 8-10 minutes. Finally, the semi-solid mixture was transferred in a preheated steel mould and allowed to solidify at room temperature.

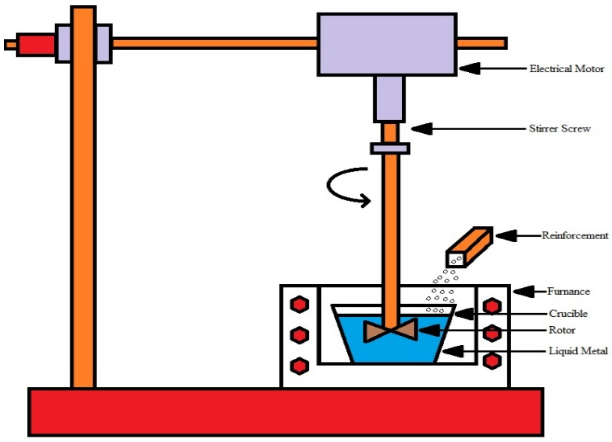
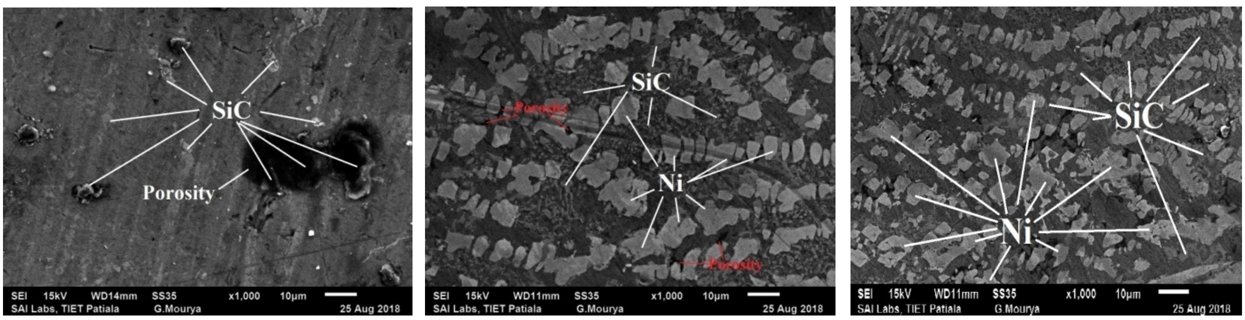


Figure 1. Illustration of the Conventional Stir Casting Setup

Testing of composites

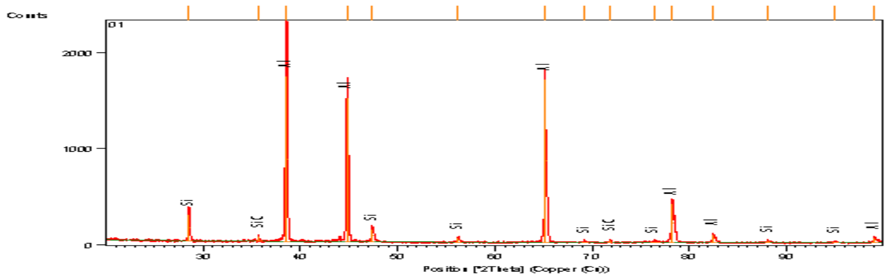
The properties of the Al-SiC-Ni composites were evaluated as per ASTM standards and listed in Table 1. For SEM analysis, samples were prepared according to ASTM E3 standard and etched with Keller's reagent (Hydrofluoric Acid-2ml, Hydrochloric Acid-3ml, Nitric Acid-5ml and Distilled water-190ml). The SEM images (Figure 2) are indicating that SiC and Ni particles are distributed uniformly throughout the matrix grain structure without agglomeration or clusters formation.



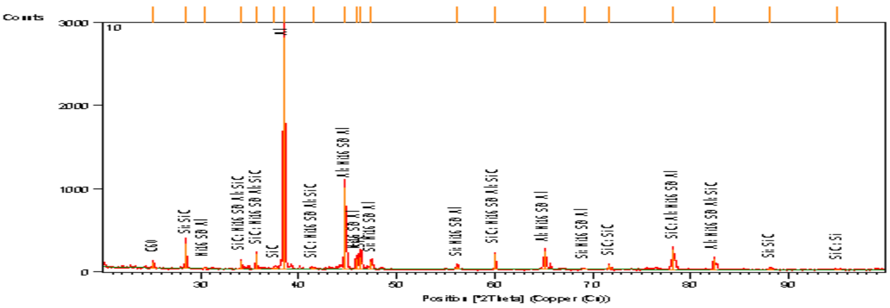
(a) (b) (c)

Figure 2. SEM Images of (a) Al-10%SiC; (b) Al-10SiC-5%Ni; (c) Al-10SiC-10%Ni

The X-Ray Diffraction (XRD) analysis was carried out with the help of XPERT-PRO diffractometer system using Cu Kα radiations at 45kV volt and 40mA current. During scanning, the specimen is kept fix and the arms of X-Ray tube are revolving against each other from 20^o to 100^o of angle-2θ. XRD patterns of hybrid composites (Figure 3b and Figure 3c) are indicating that the mesoporous NiSiAl mixed oxide compound are formed, when Ni particles introduced in the base matrix with SiC.



(a)



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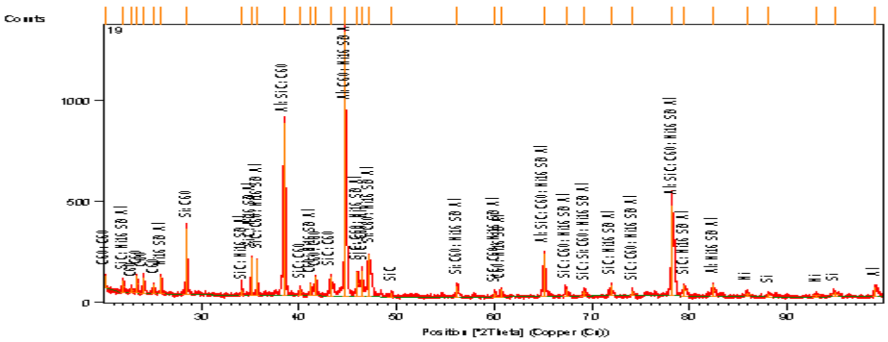


(c)

Figure 3. X-Ray Diffraction Patterns of (a) Al-10%SiC; (b) Al-10%SiC-5%Ni; (c) Al-10%SiC-10%Ni

The microhardness of novel composites was determined according to ASTM E384 standard (normal load of 300g applied for 15s) using Vicker hardness tester and results are enlisted in Table 1. To evaluate strength of the composites, the tensile test is conducted on the standard specimen as per ASTM-E8-M09. Results reveal that tensile strength significantly increased with the addition of SiC contents in the base aluminium alloy. This improvement is attributed to the transferring of applied loads by the matrix to the hard SiC particles and the loads are carried by these particles. Furthermore, the addition of 5% Ni particles with 10%SiC indicates marginal improvement in the strength and elongation resulting from better bonding among the constituents with minor porosity. But, further increasing of Ni particles (up to 10%) with SiC (10%) reduces the strength and elongation of the base matrix (see Fig. 3c) due to mesoporous NiSiAl compound formation, which caused a deleterious effect on the strength.[22,23] The intensity of this compound is increased with increasing the Ni contents, which in turn increased porosity level.

Table No. 1: Properties of the Composites evaluated as per ASTM Standards

Composite	Microhardness (Hv)	σ_{UTS} (MPa)	ρ_{th} (g/cm^3)	ρ_{act} (g/cm^3)	Porosity Level
Al-10%SiC	112.8	189	2.727	2.687	1.45%
Al-10%SiC-5%Ni	136.2	190	2.802	2.755	1.67%
Al-10%SiC-10%Ni	159.4	163	2.951	2.860	3.07%

The density analysis is employed to calculate the porosity levels in each casted composite. The actual density is calculated according to Archimedes's principle as per equation 1, where m_a represents mass of sample in air, m_w represents mass of sample in water ρ_w represents distilled water density (0.998 g/cm^3 at 20^{o}C). The theoretical density is calculated with the rule of mixtures as per Equation 2, where W is the weight-fraction and ρ is the density (g/cm^3) of constituent particles. The porosity level of each composite is obtained by using equation 3. The porosity analysis indicates that the composites are free from casting defects as the maximum porosity level is less than 5%.[15]

$$\rho_A = m_a/[m_a - m_w] \times \rho_w \tag{1}$$

$$\rho_T = \rho_{Matrix} \times W_{Matrix} + \rho_{SiC} \times W_{SiC} + \rho_{Ni} \times W_{Ni} \tag{2}$$

$$\%Porosity = 1 - [\rho_A / \rho_T] \times 100 \tag{3}$$

Turning of composites

The tool materials mostly used for the machining of MMCs are PCD, CBN, WC, Si_4N_3, Al_2O_3 etc. Of these, PCD tools are best suitable for the machining of metal matrix composites in terms of tool life.[24,25] However, the high cost of the PCD material limited their use in the cutting of MMCs. To overcome this limitation, carbide tools are considered as the alternative of PCD tool materials. The use of multi-layer coatings of TiN, TiCN, Al_2O_3 etc. on the carbide substrates reduces the tool wear rate during composite machining.[26] Also, these tools are exhibited better tool life at low cutting speed and high feed-rate. The turning performed using coolant/ lubricants (wet turning), is produced airborne particulates resulting from the vaporization, condensation and atomization of these liquids.[27] These unwanted particulates may cause harmful effect on the operator's health. Also sudden quenching of workpiece during turning may influence the material properties. So, all the turning tests were performed under dry environment with the help of HMT LB-17 lathe centre (7.5kW). Multi-layer coated (TiN+TiCN+Al_2O_3+TiN) carbide tool (Grade-AC630M, designation CNMG120408-SU, rake angle-13^o, relief angle- 0^o, nose radius-0.08mm, supplied by Sumitomo, Japan) is used during turning tests. Initially a rough cut is made to remove the oxide layer from circular rod surface. Surface roughness (Ra) and material removal rate (MRR) are selected as outcome parameters with an objective to minimize the R_a and maximize MRR.

Surface roughness determines the quality of a machined surface. For each sample, surface roughness tester (Mitutoyo, Japan made SJ:400 Model) with 0.25 mm/s measuring speed and 5mm sampling length is used to measure surface roughness. In cutting of AMCs, the presence of reinforcements caused a big problem, due to this reason, the surface roughness is measured at five different locations and average value is used for analysis. Prior and after turning operation, the diameter of each sample is measured. On each 30 mm of cutting length, turning operation is performed and cutting time is recorded. The MRR is obtained by dividing the total volume of the composite sample removed in one cut with the actual cutting time. The cutting speed, feed, depth of cut and wt.% of Ni are considered as turning parameters for all samples and turning operation is performed as per run order generated by Taguchi technique (L_{27} OA). Based upon literature and pilot study, four factors and each having three levels are chosen for this study (see Table 2).

Table No. 2: Input Factors and their Levels

Factors	Notations	Level-I	Level-II	Level-III
Cutting speed (m/min)	*V*	50	75	100
Feed rate (mm/rev)	*F*	0.08	0.14	0.20
Depth of cut (mm)	*A*	0.50	0.75	1.00
Weight percentage of Ni	*Ni%*	0	5	10

RESULTS AND DISCUSSIONS

The turning of novel composites is carried out using Taguchi based L_{27} (3^4) OA and the results for the different combination of input parameters are evaluated and listed in Table 3. The experimental response values are converted into S/N ratios using MINITAB 18. The results are validated using analysis of variance (ANOVA).

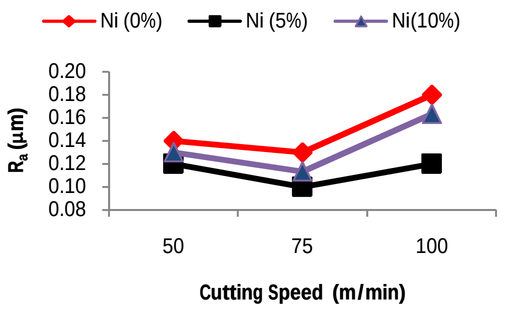
Table No. 3: Experimental Layout and Results

Run No.	*Cutting speed (m/min)*	*Feed rate (mm/rev)*	*Depth of cut (mm)*	*Contents of Ni (wt.%)*	Surface roughness (µm)	Material Removal Rate (mm^3/min)
1	50	0.08	0.50	0	0.10	1917.64
2	50	0.08	0.75	5	0.09	2869.08
3	50	0.08	1.00	10	0.10	3695.54
4	50	0.14	0.50	5	0.10	3440.35
5	50	0.14	0.75	10	0.13	4813.03
6	50	0.14	1.00	0	0.17	6005.25
7	50	0.20	0.50	10	0.16	4239.00
8	50	0.20	0.75	0	0.15	6417.38
9	50	0.20	1.00	5	0.17	9184.50

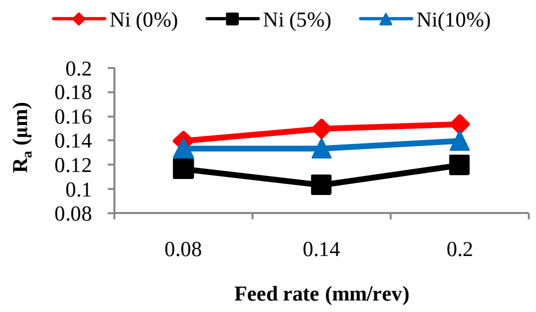
10	75	0.08	0.50	0	0.13	2777.28
11	75	0.08	0.75	5	0.11	4356.75
12	75	0.08	1.00	10	0.10	5543.31
13	75	0.14	0.50	5	0.11	4945.50
14	75	0.14	0.75	10	0.11	6794.87
15	75	0.14	1.00	0	0.12	9608.40
16	75	0.20	0.50	10	0.13	6195.46
17	75	0.20	0.75	0	0.14	8885.60
18	75	0.20	1.00	5	0.08	13359.27
19	100	0.08	0.50	0	0.19	3501.78
20	100	0.08	0.75	5	0.15	5601.54
21	100	0.08	1.00	10	0.20	7206.30
22	100	0.14	0.50	5	0.10	6594.00
23	100	0.14	0.75	10	0.16	8885.60
24	100	0.14	1.00	0	0.18	12010.50
25	100	0.20	0.50	10	0.13	7321.91
26	100	0.20	0.75	0	0.17	12834.75
27	100	0.20	1.00	5	0.11	18369.00

Effect of input parameters on surface roughness

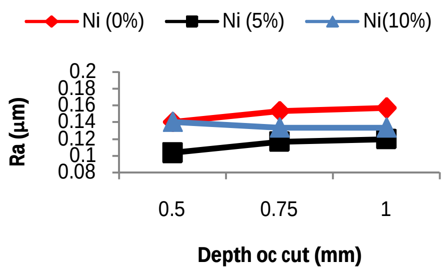
The surface roughness is an essential parameter as it reflects the quality of machined surface. The better surface finishing can be achieved with the proper selection of machining parameters, size and percentage of reinforcement particles and their dispersion in the matrix. From the results, it is observed that R_a is small at medium cutting speed and is increased at low and high speeds, irrespective of the type of composite (see Figure 4a). This reduction in R_a at low cutting speed is due to built up edge (BUE) formation, which have negative effect on the surface finishing.[28,29] With increasing the cutting speed, no BUE is observed and the discontinuous chips are formed resulting better surface finishing. But at high speed, discontinuous chips are transferred in to snarled continuous ones and acts as third body at tool-workpiece interface resulting increase the surface roughness. Also with increasing Ni contents with SiC in base matrix, the tool wear rate increases drastically, causing more surface in contact at the interface and reducing the surface finishing. Figure 4b and Figure 4c reveals that R_a is increased marginally with the increase of feed-rate and cutting depth. This increment in R_a is attributed to temperature rise at a high feed-rate and depth of cut, which exhibited a harmful effect on the surface finishing due to high temperature zone of the workpiece in the vicinity of cutting tool tip[15] and significant control on this rise in temperature is required to achieve products with better dimensional accuracy. [30]



(a) Influence of Cutting Speed



(b) Influence of Feed Rate



(c) Influence of Depth of Cut

Figure 4(a-c). Influence of Machining Parameters on the Surface Roughness at different wt.% of Ni

The main effects plot (see Figure 5) indicates that maximum surface finishing is achieved for the AMC comprising 5%Ni and 10%SiC, when turned at 75m/min cutting speed, 0.08mm/rev feed rate and 0.5mm depth of cut.

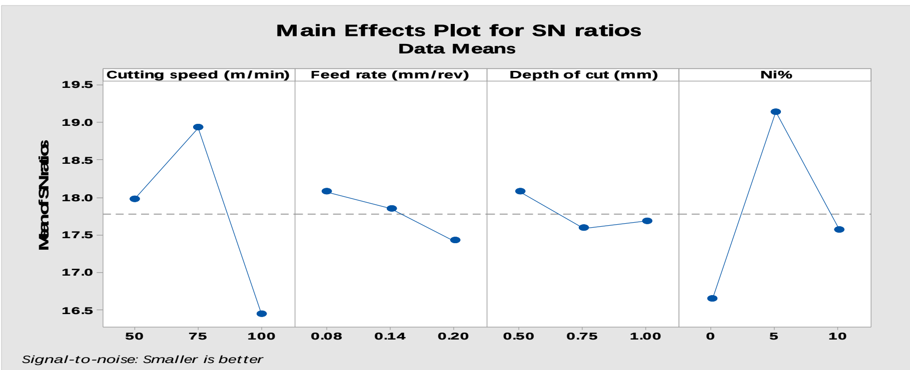


Figure 5. Main Effects plot for Surface Roughness

The ANOVA result shows that R_a is affected significantly with the Ni particles, cutting speed and the interactions between cutting speed and feed rate, which are contributed 23.46%, 23.31% and 30.61% respectively to obtain minimum surface roughness (see Table 4).

Table No. 4: Analysis of Variance for SN Ratios for R_a

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
v (m/min)	2	28.417	28.417	14.2085	15.21	0.004*	23.31
f (mm/rev)	2	2.988	1.988	0.9938	1.06	0.402	2.45
a (mm)	2	1.182	1.182	0.5912	0.63	0.563	0.97
Ni%	2	28.595	28.595	14.2974	15.3	0.004*	23.46
v (m/min)**f* (mm/rev)	4	37.319	37.319	9.3297	9.99	0.008*	30.61
v (m/min)**a* (mm)	4	14.329	14.329	3.5823	3.83	0.07	11.75
v (m/min)**Ni%*	4	4.466	4.466	1.1166	1.2	0.402	3.66
Residual Error	6	4.605	5.605	0.9342			3.78
Total	26	121.901					100.00

*Significant influence (α=0.05)

Influence of input parameters on Material Removal Rate

The material removal rate is a significant response parameter, which reduces the production cost and is considered to evaluate in a particular machining process. The considerable reduction in machining time is achieved at higher MRR. But higher MRR exhibits a negative effect on surface finishing and increases tool wear. Also, higher MRR increases the load on the work-tool interface and increases the power consumption. The MRR can improve with increasing depth of cut and feed. But with increasing these input parameters, the interface temperature and friction is also increased, which formed built up edge on the tool rake surface.[24] This built up edge produced scratches on the workpiece surface and destroyed the surface finishing. So it is required to choose adequate input parameters to achieve higher MRR and desirable surface finishing.

The main effects plot shows that MRR influenced significantly with the machining parameters viz. speed, feed and depth of cut (see Figure 6).

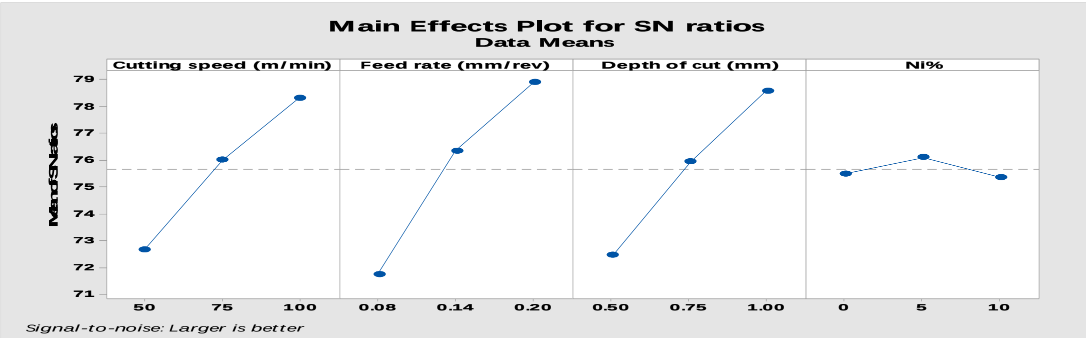


Figure 6. Main Effects Plot for Material Removal Rate

The outcome of ANOVA (Table 5) indicates that the feed rate is the most significant parameter, which contributed 42.55% to achieve the maximum MRR, followed by depth of cut (30.65%) and cutting speed (25.95%). Also, the inclusion of Ni particles shows considerable effect on the MRR. However, the interactions between processing parameters are insignificant to maximize the MRR.

Table No. 5: Analysis of Variance for SN ratios for MRR

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
v (m/min)	2	144.007	144.007	72.004	453	0.000*	25.95
f (mm/rev)	2	236.167	236.167	118.083	742.9	0.000*	42.55
a (mm)	2	170.124	170.124	85.062	535.15	0.000*	30.65
Ni% (wt.%)	2	2.78	2.78	1.39	8.75	0.017*	0.5
*v*f*	4	0.117	0.117	0.029	0.18	0.938	0.02
*v*a*	4	0.584	0.584	0.146	0.92	0.51	0.11
*v*Ni%*	4	0.294	0.294	0.074	0.46	0.762	0.05
Residual Error	6	0.954	0.954	0.159			0.17
Total	26	555.027					100

*Significant influence (α=0.05)

Prediction of optimum conditions

The optimum levels of input parameters are chosen for minimizing R_a value and maximizing the MRR. To minimize the surface roughness and to maximize material removal rate, results of main effects plots of these responses are analyzed and the best input parameters level settings are chosen and listed in Table 6.

Table No. 6: Prediction of Input Parameter's Level for Optimum Responses

Aim of study	Significant Parameters	Best level of input parameters
Minimum Surface Roughness	*Ni% & v*	Cutting velocity = 75 m/min; feed rate = 0.08mm/rev; depth of cut = 0.50mm; weight percentage of Ni = 5
Maximum Material Removal Rate	*f, a and v*	Cutting velocity = 100 m/min; feed rate = 0.20mm/rev; depth of cut = 1.0mm; weight percentage of Ni = 5

CONCLUSION

In this study, Ni with SiC reinforced AlSi alloy matrix composites were fabricated through conventional stir casting process. The turning is carried out to evaluate the effect of Ni inclusion on the machinability (in term of surface roughness and material removal rate) of the cast composites. Based on the results, the following conclusions are obtained:

- The inclusion of Ni with SiC in the aluminium alloy shows most significant effect on surface roughness and contributes 23.46%, followed by cutting speed (23.21%) and interaction between cutting speed and feed rate. However, poor surface finishing is obtained with increasing the Ni contents in aluminium alloy, as well as at the lower and higher cutting speed conditions. Feed-rate and depth of cut are insignificant to achieve the better finishing.
- The best settings to achieve better surface finishing are: cutting speed 75m/min; feed-rate 0.08mm/rev; depth of cut 0.5mm and the composite comprised of 5 wt.% of Ni.
- Highest material removal rate is obtained at high level of the machining parameters (viz. cutting speed, feed-rate and depth of cut). However, at higher MRR, the surface roughness cannot be avoided. Also the addition of Ni shows significant effect to obtain better MRR.

- The confirmatory tests are performed and improved results are reported.

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Nomenclature

σ_{UTS}	Ultimate tensile strength
ρ_{th}	Theoretical density
ρ_{act}	Actual density
R_a	Surface roughness
v	Cutting speed
f	Feed rate
a	Depth of cut
wt.%	Weight percentage

Conflict of interest

The authors declare no conflict of interest.

REFERENCES

1. Alaneme KK, Aluko AO. Fracture toughness (K1C) and tensile properties of as-cast and age-hardened aluminium (6063)–silicon carbide particulate composites. Scientia Iranica. 2012; 19(4): 992-96.
2. Sharma A, Sharma VM, Mewar S, Pal SK, Paul J. Friction stir processing of Al6061-SiC-graphite hybrid surface composites. Materials and Manufacturing Processes. 2018; 33(7): 795-804.
3. Macke A, Schultz BF, Rohatgi P. Metal matrix composites. Adv. Mater. Processes. 2012;170(3): 19-23.
4. Alaneme KK, Ademilua BO, Bodunrin MO. Mechanical properties and corrosion behaviour of aluminium hybrid composites reinforced with silicon carbide and bamboo leaf ash. Tribology in Industry. 2013; 35(1): 25-35..

5. Dabade UA, Joshi SS. Some aspects of improving integrity of machined surfaces on Al/SiCp metal matrix composites. InKey Engineering Materials 2010; 443: 596-601.
6. Dabade UA. Multi-objective process optimization to improve surface integrity on turned surface of Al/SiCp metal matrix composites using grey relational analysis. Procedia CIRP. 2013; 7: 299-304.
7. Wang X, Feng CX. Development of empirical models for surface roughness prediction in finish turning. The International Journal of Advanced Manufacturing Technology. 2002; 20(5): 348-56.
8. Bains PS, Sidhu SS, Payal HS. Fabrication and machining of metal matrix composites: a review. Materials and Manufacturing Processes. 2016; 31(5): 553-73.
9. Uthayakumar M, Prabhakaran G, Aravindan S, Sivaprasad JV. Influence of cutting force on bimetallic piston machining by a cubic boron nitride (CBN) tool. Materials and Manufacturing Processes. 2012; 27(10): 1078-83.
10. Palanikumar K, Muthukrishnan N, Hariprasad KS. Surface roughness parameters optimization in machining A356/SiC/20p metal matrix composites by PCD tool using response surface methodology and desirability function. Machining Science and Technology. 2008; 12(4): 529-45.
11. Manna A, Bhattacharyya B. A study on different tooling systems during machining of Al/SiC-MMC. Journal of Materials Processing Technology. 2002; 123(3): 476-82.
12. Chen P, Hoshi T. High-performance machining of SiC whisker-reinforced aluminium composite by self-propelled rotary tools. CIRP Annals. 1992; 41(1): 59-62.
13. Lin JT, Bhattacharyya D, Lane C. Machinability of a silicon carbide reinforced aluminium metal matrix composite. Wear. 1995; 181: 883-8.
14. Muthukrishnan N, Babu TM, Ramanujam R. Fabrication and turning of Al/SiC/B4C hybrid metal matrix composites optimization using desirability analysis. Journal of the Chinese Institute of Industrial Engineers. 2012; 29(8): 515-25.
15. Kumaran ST, Uthayakumar M, Slota A, Aravindan S, Zajac J. Machining behavior of AA6351–SiC–B4C hybrid composites fabricated by stir casting method. Particulate Science and Technology. 2016; 34(5): 586-92.
16. Aramesh M, Shi B, Nassef AO, Attia H, Balazinski M, Kishawy HA. Meta-modeling optimization of the cutting process during turning titanium metal matrix composites (Ti-MMCs). Procedia CIRP. 2013; 8: 576-81.

17. Purushotham G, Hemanth J. Action of chills on microstructure, mechanical properties of chilled ASTM A 494 M grade Nickel alloy reinforced with fused SiO2 metal matrix composite. Procedia Materials Science. 2014; 5: 426-33.
18. Barman N, Kumar P, Dutta P. Studies on transport phenomena during solidification of an aluminum alloy in the presence of linear electromagnetic stirring. Journal of Materials Processing Technology. 2009; 209(18-19): 5912-23.
19. Saha P, Tarafdar D, Pal SK, Saha P, Srivastava AK, Das K. Multi-objective optimization in wire-electro-discharge machining of TiC reinforced composite through Neuro-Genetic technique. Applied Soft Computing. 2013; 13(4): 2065-74.
20. Elango G, Raghunath BK, Palanikumar K, Thamizhmaran K. Sliding wear of LM25 aluminium alloy with 7.5% SiC+ 2.5% TiO2 and 2.5% SiC+ 7.5% TiO2 hybrid composites. Journal of Composite Materials. 2014; 48(18): 2227-36.
21. Shabani MO, Mazahery A. Suppression of segregation, settling and agglomeration in mechanically processed composites fabricated by a semisolid agitation processes. Transactions of the Indian Institute of Metals. 2013; 66(1): 65-70.
22. Rouquerol J, Avnir D, Fairbridge CW, Everett DH, Haynes JM, Pernicone N, Ramsay JD, Sing KS, Unger KK. Recommendations for the characterization of porous solids (Technical Report). Pure and Applied Chemistry. 1994; 66(8): 1739-58.
23. Xiang X, Zhao H, Yang J, Zhao J, Yan L, Song H, Chou L. One-Pot Synthesis of Ordered Mesoporous NiSiAl Oxides for Catalyzing CO2 Reforming of CH4. European Journal of Inorganic Chemistry. 2016; 2016(21): 3396-404.
24. El-Gallab M, Sklad M. Machining of Al/SiC particulate metal matrix composites: Part II: Workpiece surface integrity. Journal of Materials Processing Technology. 1998; 83(1-3): 277-85.
25. El-Gallab M, Sklad M. Machining of Al/SiC particulate metal matrix composites part III: comprehensive tool wear models. Journal of materials processing technology. 2000; 101(1-3): 10-20.
26. Kannan S, Kishawy HA. Surface characteristics of machined aluminium metal matrix composites. International Journal of Machine Tools and Manufacture. 2006; 46(15): 2017-25.
27. Sutherland JW, Kulur VN, King NC, Von Turkovich BF. An experimental investigation of air quality in wet and dry turning. CIRP Annals. 2000; 49(1): 61-4.
28. Sahin Y, Kok M, Celik H. Tool wear and surface roughness of Al2O3 particle-reinforced aluminium alloy composites. Journal of Materials Processing Technology. 2002; 128(1-3): 280-91.

29. Manna A, Bhattacharayya B. A study on machinability of Al/SiC-MMC. Journal of Materials Processing Technology. 2003; 140(1-3): 711-6.
30. Kannan S, Kishawy HA. Tribological aspects of machining aluminium metal matrix composites. Journal of Materials Processing Technology. 2008; 198(1-3): 399-406.