Al7129 Metal matrix enhanced with Titanium carbide (TiC) and Boron carbide(B₄C) optimized machining parameters utilizing Taguchi method for Surface roughness

Madri. Rajesh [1], Dr. G Naga Malleswara Rao [2], Dr.B. Chandra Mohana Reddy [3]

[1]*Research Scholar, Department of Mechanical Engineering,JNTUA, Anantapur, Andhra Pradesh, India.*

[2]*Principal and Professor, Department of Mechanical Engineering, Eswar College of Engineering, Narasaraopet, Andhra Pradesh, India*

[3]*Associate Professor and HOD, Department of Mechanical Engineering, JNTUA, Anantapur, Andhra Pradesh, India*

madrirajesh@gmail.com[1]

Abstract

The influence of spindle speed, feed rate, and depth of cut of alumina particle on lowering surface roughness during turning of Al7129/TiC/B₄C hybrid composite is investigated in this study. The composite is turned using a TiN coated solid carbide tool. Taguchi's experimental design concept is utilized to optimize three tiers of design parameters for improved for better surface finish. The results of the experiments and the microstructure of the machined surface demonstrate that the samples with the lowest feed rate perform better in terms of surface roughness. Surface roughness is also influenced by the wt% of alumina, which is followed by spindle speed when spinning the produced samples.

Keywords: Machining parameters, Turning, Surface roughness, Taguchi method, Al7129/TiC/B₄C hybrid composite

1. Introduction

Aluminum matrix composite (AMC) is a relatively new material that has a wide range of uses due to its quantifiable benefits. In many engineering domains, they are employed in a variety of structural, non-structural, and functional applications. In recent years, the particulate reinforced AMCs are replacing the conventional materials that are used in aircraft and automotive components. The most common applications are aircraft's engine cowlings, landing gear doors, automotive pistons, bearings, etc. In those major applications, the manufactured components are expected to be with good surface finish and accuracy. Particulate reinforced Aluminium (Al) based composite are found very difficult in machining due to the presence of hard ceramic oxide reinforcement. Turning is one of the most prevalent machining operations related with the manufacturing process. In practise, producing machined with a decent surface quality has proven to be extremely challenging. As a result, minimising surface roughness in turning parts is difficult and must be managed.The hard ceramic particles in the matrix, such as Al2O3/SiC, make it difficult to machine, which affects the surface finish by increasing the composite's surface roughness. In such circumstances, adding graphite to the matrices minimises tool wear during milling and improves the composite's surface polish. [1]. Most of the studies on Metal matrix composite (MMC) are focused on the study of tool wear characteristics during machining of aluminium alloy composite. The surface finish of the component can be varied along the process parameters such as spindle speed, feed etc.The present work is focused on minimizing surface roughness in turning of Al7129/TiC/B4C hybrid composite. From the various literatures available,

it has been observed that feed rate, cutting speed and wt % of the reinforcements are key factors influencing surface roughness. Palanikumar and Karthikeyan [2] made an attempt on assessing the factors influencing surface roughness on machining of Al/SiC particulate composite. They have used K 10 tungsten carbide tool inserts for machining. The machining parameters considered were % vol fraction of SiC, cutting speed, depth of cut and feed rate. They employed ANOVA technique to optimize the machining parameters. Saravanakumar and Sasikumar [3] made a study on prediction of surface roughness in turning using design of experiments. They concluded that selection of reinforcements plays an important role in improving the material properties and machinability of the composite. Considering two levels of factors, they had developed a mathematical model for the proposed cutting parametersIt contributes to the product's durability. The Taguchi method is used in a very short period of time and with minimal effort. As a result, Taguchi's method is being used in a variety of industries to improve process quality in the manufacturing sector.Surface roughness and cutting force are both critical parameters in the machining process.[4-8]. Cutting force is required for power machining calculations. Cutting forces have an impact on dimensional accuracy, work-piece deformation, and chip formation.In industries, components with a specific surface roughness are always required based on the needs of the customer. This can be accomplished through the optimization process.d that the quality of the drilled holes can be improved by proper selection of cutting parameters.In the present study, an attempt has been made to optimize the machining parameters for better surface roughness in turning of Al7129/TiC/B4C hybrid composite.[9-14].

2. Experimental methods

2.1.Materials and methods

For the present work, Turning of Aluminium 7129 (Al7129) has been used as matrix phase and Titanium carbide (TiC) and Boran carbide (B4C) powder as reinforcement phase. Al 7129 has been chosen as the matrix material due to its lower strength and better machinability performance. In order to increase the strength of the matrix Al2O3 particles are added as the reinforcements where as particlesTiC& B4C addition improves the

machiniablity. The chemical composition of the base metal and its physical properties are shown in Tables 1 & 2 respectively While the chemical compositions and physical properties reinforcement are shown in Tables 3 & 4 respectively.

Tables 1: Aluminium 7129 (Al7129) chemical composition.

Element	Content (%)
Aluminum, Al	90.9 – 94
Zinc, Zn	4.2 - 5.2
Magnesium, Mg	1.3 – 2

Tables 2: Aluminium 7129 (Al7129) Physical composition

Element	Weight Percentage (%)
Aluminum	90.9 – 94
Zinc	4.2 - 5.2
Magnesium	1.3 – 2
Copper	0.50 - 0.90

Tables 3: Titanium carbide properties

Element	Identification
Chemical formula	TiC
Molar mass	59.89 g/mol
Appearance	black powder
Density	4.93 g/cm3
Melting point	3,160 °C (5,720 °F; 3,430 K)
Boiling point	4,820 °C (8,710 °F; 5,090 K)
Solubility in water	insoluble in water
Magnetic susceptibility (χ)	+8.0·10−6 cm3/mol

Tables 4: Boron carbide properties

Property	Value
Density (g.cm-3)	2.52
Melting Point (°C)	2445
Hardness (Knoop 100 g) (kg.mm-2)	2900 - 3580
Fracture Toughness (MPa.m-½)	2.9 - 3.7

Young's Modulus (GPa)	450 - 470
Electrical Conductivity (at 25 °C) (S)	140

Al2O3 provides good wettability between the matrix and reinforcements particles acts as a solid lubricator which helps in easy machining of the composite.The composite have been fabricated using stir casting technique at an optimal speed to ensure even distribution of the reinforcements along the matrix. The composite is fabricated at three different compositions taking as 3-9 wt% in steps of 3 wt% to the matrix material. The machined composite are tested for surface roughness using Handy Surf surface roughness measuring device of E-DT5706 which consists of a probe connected to it. Figure 1 shows used and the surface roughness measuring device.

Fig.1. (a) Surface roughness measuring device

Fig.1. (b) Experimental set up for machining

Table 5: Process parameters and its levels.

Exp. No	Speed (rpm)	Feed (mm/min)	DOC (mm)	Ra (µm)
1	150	25	0.2	2.34
2	150	80	0.6	4.2
3	150	125	1	10.2
4	200	25	0.6	2.24
5	200	80	1	3.31
6	200	125	0.2	5.42
7	250	25	1	2.13
8	250	80	0.2	2.68
9	250	125	0.6	4.85

To eliminate the effects of noise, the studies were performed three times. Spindle speed, feed rate, and wt% alumina are the machining parameters chosen. The studies were carried out under L9 orthogonal array trial circumstances in order to optimize the machining parameters listed in table 4.

3. Results and discussion

3.1. Taguchi method

Taguchi's experimental design is used to reduce quality loss by using the three possibilities provided in Taguchi's design analysis, according to a lot of research. The terms "the-nominal-the-best," "the-larger-the-better," and "the-smaller-the-better" are used to describe them. The concept of taguchi method is to find out the best combination of design parameters by conducting minimum number of experiments. As a result, it provides main effects and interaction effects which uses S/N ratio to quantify the data variation. For the present analysis, the machining parameters have to be optimized for minimum surface roughness. Therefore, "the-smaller-the-better" concept is chosen using the equation,

$$\eta = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}Y_i^2\right)$$

Where, "n" is the number of replications of experiment and "y" is the quality score with smaller-the-bettervalueofexperimentaldata"i".
Statistical software Minitab18 is used for the analysis and the results arrived are "main effects" and responsetable for the variables. The impacts of the design parameters and levels on the response

variables are depicted in the main graphs for S/N ratio. The optimal factor levels are those that optimise the proper S/N ratio. At the greatest spindle speed (250 rpm), lowest feed rate (25 mm/min), and wt of alumina, a superior surface finish. The surface roughness of the composite increases with increasing feed rate and decreases with spindle speed, according to the findings. When the feed rate is increased, the tool's load is increased, which increases cutting force, resulting in a poor surface finish. At all situations, a similar effect was observed in reduced spindle speed.

Table 6: Experimental values of surface roughness

Speed	feed	doc	Ra	SNRA1	MEAN1
150	25	0.2	2.80	-8.9432	2.80
150	80	0.6	4.00	-12.0412	4.00
150	125	1.0	9.20	-19.2758	9.20
200	25	0.6	2.30	-7.2346	2.30
200	80	1.0	3.30	-10.3703	3.30
200	125	0.2	5.10	-14.1514	5.10
250	25	1.0	1.13	-1.0616	1.13
250	80	0.2	2.50	-7.9588	2.50
250	125	0.6	4.80	-13.6248	4.80

3.1.1 Response Table for Signal to Noise ratios
Smaller is better
LevelSpeedfeeddoc
1   -13.420-5.746-10.351
2   -10.585-10.123   -10.967
3   -7.548-15.684-10.236

3.1.2 Response Table for Means
LevelSpeedfeeddoc
1   5.3332.0773.467
2   3.5673.2673.700
3   2.8106.3674.543
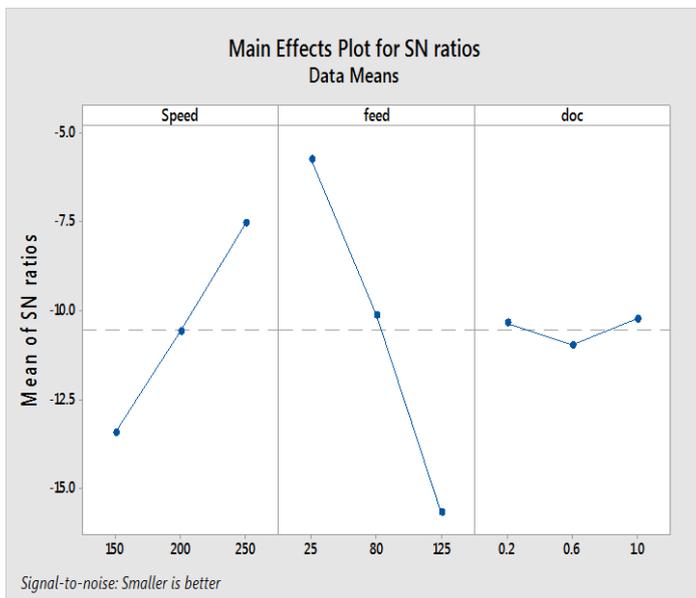
Fig 2: mean of s/n ratio values
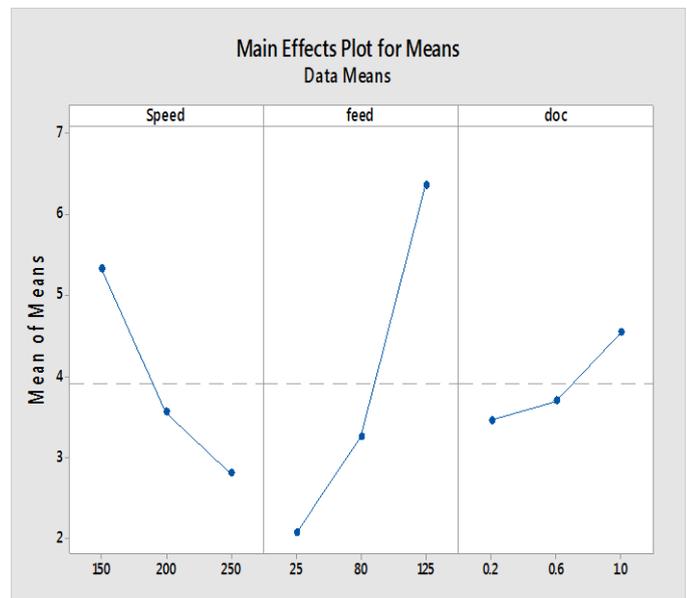
Fig:3 mean of means vs parameter

3.2 Responsetablefor S/N ratio

A response table can be used to determine the impact of machining parameters on surface roughness. The average response characteristics for each level of each factor in the design are shown in the response table. According to the features of the answer, the rank orders the components from the largest effect to the least influence based on the delta values in the response table. It shows for S/N ratio in which it is clearly visible that feed is the most influencing factor since it is ranked first followed by alumina and spindle speed in minimizing the surface roughness.

3.4. Analysis of Variance

Source DF Adj SS Adj MSF-Value P-Value

Speed 210.065.0300.890.460

Error 634.055.675

Total 844.11

DF: degrees of freedom; Adj.SS: adjusted sums of squares; Pc- percentage of contribution.

3.3 Analysis of variance (ANOVA)

Analysis of variance can be used to investigate and model the relationship between a response variable and independent variables. The link between a response variable and independent factors can be investigated and modelled using analysis of variance. With the help of the P-value, it was also possible to check the elements that are statistically significant at a 95% confidence level. The higher level of significance is indicated by a P-value of less than or equal to 0.05.
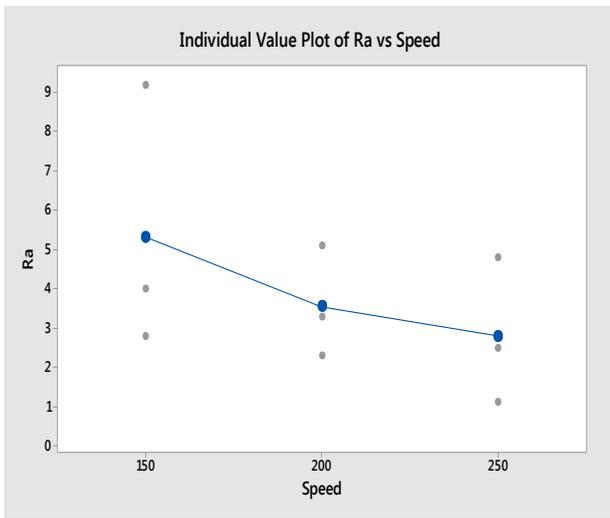
Fig:4 Speed Vs Ra
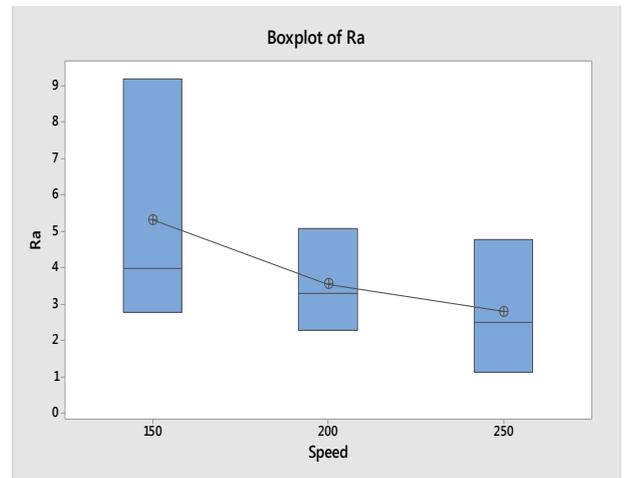
Fig:5 Speed Vs Ra
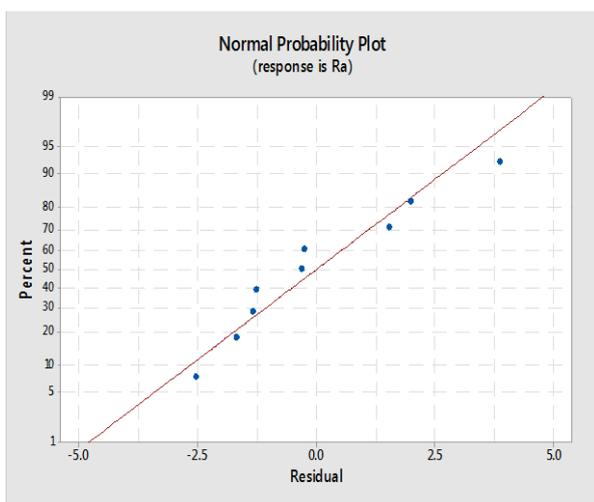
Fig:6 Speed Vs Ra
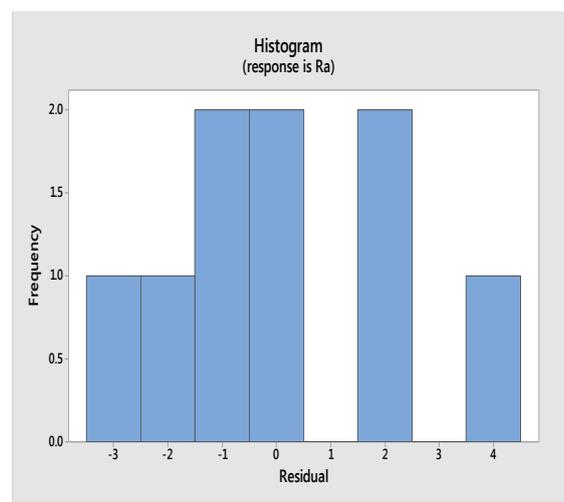
Fig:7 histogram residual Vs frequence
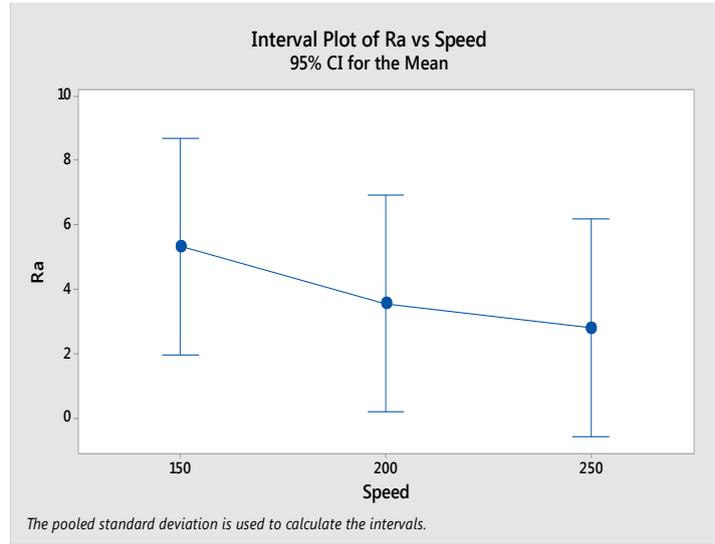
Fig:8 Speed Vs Ra

3.4. Microstructural examination

Figure 9 depicts the microstructure of Al 7129-composite, which reveals the fractures and voids generated during the composite's machining. The presence of hard ceramic particles in the samples with 9 wt% Al2O3 composition causes substantial distortions during machining, making it difficult to machine and providing a poor surface finish to the material.
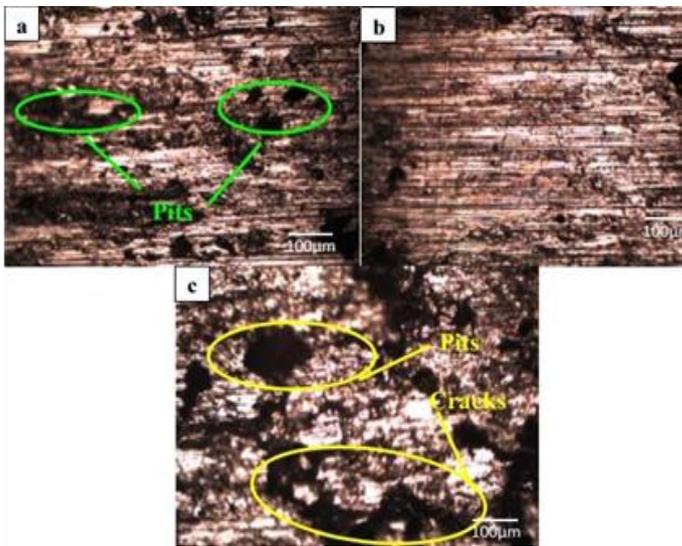
Figure 9: Microstructure of (a) 3 wt% , (b) 6 wt % , (c) 9 wt % of alumina.

3.5. Confirmation tests

A confirmation tests has to be carried out at the optimal level of parameters. The parametric combinations obtained for minimum surface roughness was obtained as 250 rpm (spindle speed), 25 mm/min (feed rate), 6% (wt of alumina).

Table 7: Confirmation tests.

Surface roughness(µm)			
Initial level	Optimal level	Experimental	Predicted
A1B1C1	A3B1C2	1.13	1.19
Improvement in Surface finish from initial level			0.06µm

Conclusions

Using Taguchi's experimental design, the process parameter that has an impact on surface roughness during machining Al7129/TiC/B4C hybrid composite is optimized in this study. The experimental out comes drawn are:

i. As the speed and feed rate are raised, the surface roughness of the rotating work piece reduces.

ii. ii. It is visible from the major impacts plot for S/N ratio that 6 wt% alumina has a superior surface finish than other alumina compositions.

iii. According to the S/N ratio response table, feed rate is the most important element in lowering surface roughness during machining of Al7129/TiC/B4C hybrid composite, followed by wt% alumina and spindle speed.

iv. The optimal parametric conditions obtained for minimizing surface roughness are at highest spindle speed of 250 rpm, lowest feed rate 25 mm/min, 6wt % of Al2O3.

v. The microstructure of the machined samples clearly reveals that the 6% Al2O3 composition shows less deformation during machining when compared to other samples.

References

Journals

[1].Seeman M., Ganesan G., Karthikeyan R., Velayudham A. Int. J. Adv. Technol. 48 (2010) 613.

[2].Palanikumar K., Karthikeyan R. Mater. Design. 28 (2007) 1584.

[3].Saravanakumar A., Sasikumar P. IJMEMS. 5(1) (2012) 19.

[4].PavloDavim J., Conceicao Antonio C.A. J. Mat. Pro. Tech. 112 (2001) 78.

[5].K. Suryanarayanan, R. Praveen, S. Raghuraman, Silicon carbide reinforced with aluminium metal matrix composites for aerospace application: A literaturereview, Int. J. Innov. Sci. Eng. Technol. 2 (11) (2013)

[6].Ibrahim, M. F., H. R. Ammar, A. M. Samuel, M. S. Soliman, A. Almajid, and F. H. Samuel. "Mechanical properties and fracture of Al–15 vol.-% B4C based metal matrix composites." International Journal of Cast Metals Research 27, no. 1 (2014): 7-14.

[7].R. S. Vajjha and D. K. Das, "Experimental determination of thermal conductivity of three nanofluids and development of new correlations," International Journal of Heat and Mass Transfer, vol. 52(21–22), pp. 4675– 4682, 2009.

[8]. C. Mao, Y.Huang, X.Zhou, H.Gan, J.Zhang, and Z. Zhou. "The tribological properties of nanofluid used in minimum quantity lubrication grinding", The International Journal of Advanced Manufacturing Technology, vol.71, pp. 1221– 1228, 2014.

[9].Basavarajappa S., Chandramohan G., Paula davim J., Prabhu M., Mukund K., Ashwin M., Prasannakumar

[10].Suresh P. V. S., Rao P. V. and Deshmukh S. G., (2002), "A genetic algorithmic approach for optimization of surface roughness prediction model", International Journal of Machine Tools and Manufacture, Volume 42, pp. 675–680.

[11].Lee S. S. and Chen J. C., (2003), "Online surface roughness recognition system using artificial neural networks system in turning operations" International Journal of Advanced Manufacturing Technology, Volume 22, pp. 498–509.

[12].Kirby E. D., Zhang Z. and Chen J. C., (2004), "Development of An Accelerometer based surface roughness Prediction System in Turning Operation Using Multiple Regression Techniques", Journal of Industrial Technology, Volume 20, Number 4, pp. 1-8.

[13].Pal S. K. and Chakraborty D., (2005), "Surface roughness prediction in turning using artificial neural network", Neural Computing and Application, Volume14, pp. 319–324.

[14].Singh H. and Kumar P., (2006), "Optimizing Feed Force for Turned Parts through the Taguchi Technique", Sadhana, Volume 31, Number 6, pp. 671–681