Available online at www.sciencedirect.com
ScienceDirect
Procedia Materials Science 10 (2015) 220 – 229
Procedia Materials Science
www.elsevier.com/locate/procedia

2nd International Conference on Nanomaterials and Technologies (CNT 2014)

Optimizing The Machining Parameters For Minimum Surface Roughness In Turning Al/6% SiC/6%RHA Hybrid Composites

Chintada Shoba[a *] Nallu Ramanaiah[b] Damera Nageswara Rao[c]

[a]*Assistant Professor, Department of Industrial Engineering, GITAM University, India, 530045*
[b]*Professor, Department of Mechanical Engineering, Andhra University, India*
[c]*Vice Chancellor, Centurion University, Odisha, India*

Abstract

This paper discusses the use of the Taguchi experimental design technique to find the optimal parameters while machining Al/6% SiC_p/6%RHA_p metal matrix hybrid composites. The hybrid composites were fabricated using the stir casting technique. The objective of this work is to investigate the effect of the controllable variables like spindle speed, feed and depth of cut on surface roughness while turning the hybrid composite. Taguchi's L_9, orthogonal arrays under different combinations are used for experimentation. The influence of the parameters is also evaluated using signal to noise (S/N) ratio analysis. Optimum parameters which give minimum surface roughness are obtained. S/N plot is drawn and the results are validated using analysis of variance (ANOVA) and the percentage of contribution of each parameter is determined. The scanning electron microscope was used to investigate the worn machined surface of the hybrid composites and the related mechanisms are explained and presented. The 3D surface topography parameter (roughness, skewness, Kurtosis) is also analyzed to predict the worn machined surface of hybrid composites using SPIP software.

Peer-review under responsibility of the International Conference on Nanomaterials and Technologies (CNT 2014)
Keywords: Hybrid Composites, Stir Casting, Taguchi technique, Signal to Noise (S/N) ratio, ANOVA;

1. Introduction

The composite material is composed of two or more discrete constituents. Reinforcements added to these materials produce metal matrix composites. When compared to composite's particle reinforced metal matrix composites (MMC) are having more advantages as they have better mechanical properties [Siva Prasad (2012)]. Aluminium metal matrix composites offer an excellent combination of properties such as high strength, high stiffness, and thermal conductivity. They are found in various applications like defense, automotive, aerospace, etc.

* Corresponding author. Tel.: +919985032287;
E-mail address :shobachintada@gmail.com

2211-8128
Peer-review under responsibility of the International Conference on Nanomaterials and Technologies (CNT 2014)
doi:10.1016/j.mspro.2015.06.044

There are various combinations in which matrix and reinforcement are mixed, out of which aluminium reinforced with ceramic particles have distinct advantages.

Ceramics which are relatively harder particles improve the mechanical properties of the composite. As the percentage of reinforcement increases the hardness of the composite increases, which sequentially increases the complexity in turning and makes the surface rough. This encounter difficulty in the use of aluminium reinforced metal matrix composites in many applications. In order to overcome this difficulty reinforcement is balanced in equal proportions with Rice Husk Ash (RHA) and Silicon Carbide (SiC). Rice husk is an agricultural by-product which is found abundantly in rice producing countries like India. Upon controlled burning of rice husk, rice husk ash is produced which is rich in silica content [Siva Prasad (2012)]. The quality of the machined product is based on surface roughness and hence, surface roughness is an important parameter in today's industries. The main objective of any industry is to produce parts with high quality and good surface finish. The efficiency of the machining can be improved if it is done with optimum machining conditions. Taguchi technique is a powerful and simple tool for the design of high quality systems. Kathirvel et.al (2009, 2011) has studied the factors that influence surface finish of hybrid metal matrix composites based on ANOVA on the machinability data. It was observed that the major factors that influence surface finish are volume percentage of SiC, speed, feed and depth of cut. The author emphasized 90.62% predictability in tool wear of CBN/PCD tools during machining of hybrid composites. Jinfeng leng et. al (2008) studied the machinability of Al/SiC/Gr composites. They studied and attributed that the machinability is improved by 7% with the increase in volume fraction of graphite particles. The hardness, wear resistance and tensile strength in stir casting were higher than the powder metallurgy component [Charles (2011)]. Gallab et. al ((1998) studied the effect of speed , feed, depth of cut, rake angle and cutting fluid on the chip formation and the forces generated during aluminium based MMC's. Bruin et.al (1995) performed machining experiments on 40 Vol% SiC reinforced aluminium alloy with various tool materials. They found that the hardness ratio between a tool material and the reinforcement particles is an important parameter for flank wear of the inserts. Taguchi parameter design can optimize the performance characteristics through the setting of design parameters and reduce the sensitivity of the system performance to the source of variation [Ross (1998), Taguchi (1987)].

Aluminum metal matrix composite material systems offer superior combination of properties in such a manner that today, no existing monolithic material can rival. These materials possess good resistance to corrosion and excellent ductility but they are difficult to machine. In the present study, aluminum metal matrix hybrid composites were fabricated and the optimal parameters for minimum surface roughness was investigated.

Nomenclature

RHA	Rice Husk ash
ANOVA	Analysis of Variance
S/N ratio	Signal to Noise ratio
R_{Ku},	Kurtosis
R_{Sk}	Skewness
R_a	Surface roughness

2. Experimental work

2.1Material selection:

In the present study A356 is used as the matrix material. Its chemical composition is given in the Table 1. Rice husk ash (RHA) particulates with an average size of 25µm and silicon carbide (SiC) particulates with an average size of 35µm are used as reinforcement materials. The chemical composition of the Al alloy (A356) used in the investigation is given in the Table 1. SiC is hard ceramic and possess properties such as high oxidation resistance, good thermal shock resistance etc. It has distinct advantages for applications involving car brakes, car clutches, ceramic plates in bullet proof vests, etc. Rice husk ash the agricultural by-product can be added to the aluminium matrix to improve the mechanical properties of the composites. The addition of RHA into aluminium as reinforcement can potentially reduce the density of aluminium [Shoba (2014)]. The chemical composition of RHA is given in the Table 2 with major constituent as silica (90%).

Table 1**:** - Chemical composition of A356 Al alloy matrix (wt. %)

Si	Fe	Cu	Mn	Mg	Zn	Ni	Ti	Al
6.5-7.5	0.15	0.03	0.10	0.4	0.07	0.05	0.1	Bal

Table 2: Chemical composition of RHA

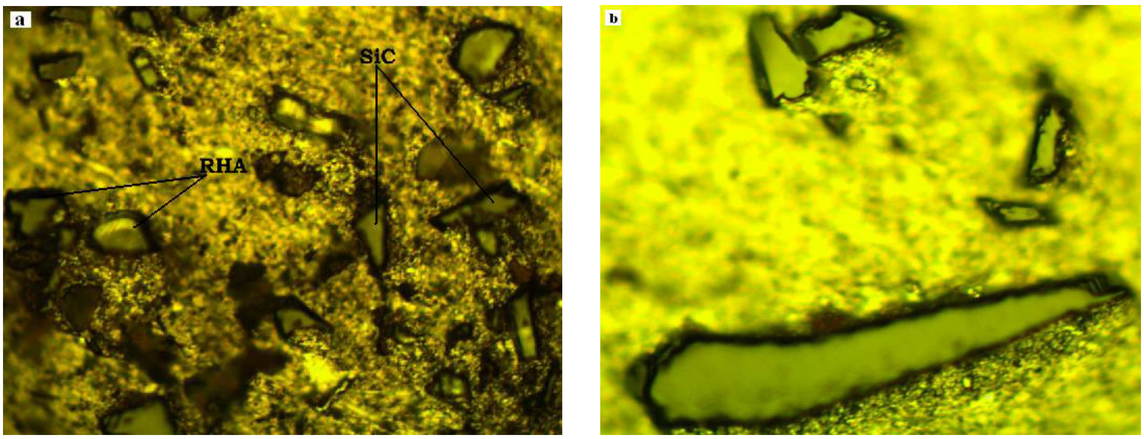
Constituent	Silica	Graphite	Calcium Oxide	Magnesium Oxide	Potassium Oxide	Ferric Oxide
%	90.23	4.77	1.58	0.53	0.39	0.21

2.2 Fabrication of composite:

The composite material is made up of aluminium reinforced with 6% of SiC and 6% of RHA particulates. Test samples are fabricated using stir casting technique in the form of cylindrical rods of dimensions Ø35x350mm.

2.3 Micro-structural characterization:

An OLUMPUS make optical microscope was used to study the Micro-structural characterization of the hybrid composites. JSM-6610LV Scanning electron microscope (SEM) equipped with energy dispersive X- ray analyzer (EDX) is used to study the microstructure of the hybrid composite. Uniform distribution of RHA and SiC reinforcements in the matrix is observed from the optical micrographs as shown in Fig.1. There was a good interfacial bonding between the particles and the matrix material. This feature is shown in Fig 1b. The scanning electron micrograph of Al/6%RHA/6%SiC is shown in Fig 1c.



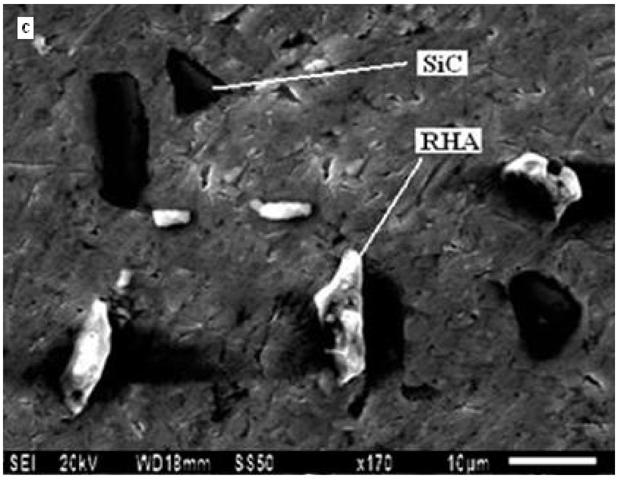


Fig 1: Optical micrograph a) hybrid composite b) at the interface, 100X c) SEM micrograph of the hybrid composite

2.4 Machining of hybrid composites:

The turning operation is carried out on a medium duty lathe having specifications 4.5 feet as the distance between centers and 2KW spindle power. The cutting tool used was cemented carbide insert. All experiments are performed under dry condition. Surface roughness (R_a) were measured using a stylus instrument (Model Surf Test SJ-301) as shown in the Fig 2 for a cut off length of 0.8 mm and the sampling length of 6 mm.

Figure 2: Measurement of surface roughness

2.5 Design of Experiments:

Taguchi proposed an experimental plan in terms of orthogonal array. In the study there are three controllable variables, namely spindle speed, feed, depth of cut and surface roughness as the response variable. Three levels were specified as shown in the Table 3. Orthogonal array chosen was L9, which has 9 rows as shown in the Table 4. The experiment results were illustrated in Table 5. The plan of the experiment is to find the important factors influencing the machining process to achieve low surface roughness.

Table 3: Details of process parameters

Levels	P1	P2	P3
1	560	0.15	0.5
2	900	0.2	0.75
3	1250	0.25	1

Table 4: L 9 orthogonal array

Experiment	P1	P2	P3
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 5: Experimental conditions and machining response

Experiment	Speed	Feed	Depth of cut	Ra (µm)
1	560	0.15	0.5	4.23
2	560	0.2	0.75	4.5
3	560	0.25	1	4.6
4	900	0.15	0.75	3.7
5	900	0.2	1	3.76
6	900	0.25	0.5	4.48
7	1250	0.15	1	2.69
8	1250	0.2	0.5	5.79
9	1250	0.25	0.75	8.48

3. Results and discussion:

Experimental data are analyzed by using Signal to Noise (S/N) ratio. Based on the results optimal parameters for minimum surface roughness are obtained and verified experimentally. In Taguchi S/N ratio is a measure of quality characteristic and deviation from the desired value. The term signal represents desired value and noise represents undesirable value for the output characteristic. S/N ratio is defined as

$$\eta = -10\log(M.S.D) \quad (1)$$

where M.S.D is the mean square deviation for the output characteristic. Smaller the better type of S/N ratio is in the analysis for better accuracy.

S/N ratio for $R_a = -10\log_{10} 1/n\sum(y^2)$ (2)
where n= no. of observations, y= observed data (R_a)

The analysis of the experiment data was carried out using MINITAB 15 software, which is used in the design of experiments (DOE) applications. The response data for signal to noise (S/N) ratio is shown in Table 6. The response data for mean surface roughness shown in Table 7 also arrived, giving the same results as S/N ratio results. The main effects plot for means and S-N is also shown in the Fig 3 and 4. The results of S-N and mean Ra are validated by analysis of variance (ANOVA) which is given in the Table 8 which reveals that the percentage of contribution of all parameters for better machining characteristics. It is observed that the feed rate has 82.6%, depth of cut has 6.8% and spindle speed has 6.43%. The percentage of error is observed to be 4.17%, which is negligible. Hence it may be considered that the design, observations and analysis are going in the right direction.

Hence, from the Tables 6 & 7 and Fig 3 and 4, it is evident that the optimal parameters for turning Al/6% SiC_p/6%RHA_p metal matrix composites are

Spindle speed (N) = 900rpm
Feed (f) =0. 25mm/rev
Depth of cut (d) = 0.5mm

The relationship between the factors and performance measures was modeled by multiple regressions. The regression equation which gives the expected value of surface roughness for any combination of factor level is as below:

$$Surfaceroughness = 2.85 + 0.000315 Speed + 9.8 Feed - 0.969 DepthofCut \quad (3)$$

Table 6: Response table for mean S-N ratio

Levels	Spindle Speed	Feed	Depth of cut
1	-12.95	-13.69	-12.03
2	-11.97	-12.73	-13.07
3	-13.24	-11.75	-13.05
Max-Min	1.28	1.94	1.04
Rank	2	3	1
Optimal Parameters	900 RPM	0.25 mm/rev	0.5 mm

Table 7: Response table for mean Ra

Levels	Spindle Speed	Feed	Depth of cut
1	4.443	4.854	4.017
2	3.981	4.351	4.562
3	4.655	3.874	4.501
Max-Min	0.674	0.98	0.545
Rank	2	3	1
Optimal Parameters	900 RPM	0.25mm/rev	0.5 mm

Table 8: Analysis of variance for Mean Ra

Source	DoF	Seq SS	Mean Square	F	Contribution P (%)
Spindle speed	2	0.596	0.3286	2.141	6.43
Feed	2	9.563	5.683	34.821	82.6
Depth of cut	2	0.512	0.202	1.422	6.8
Error	2	0.9343	0.1869		4.17
Total	8	2.7977			100

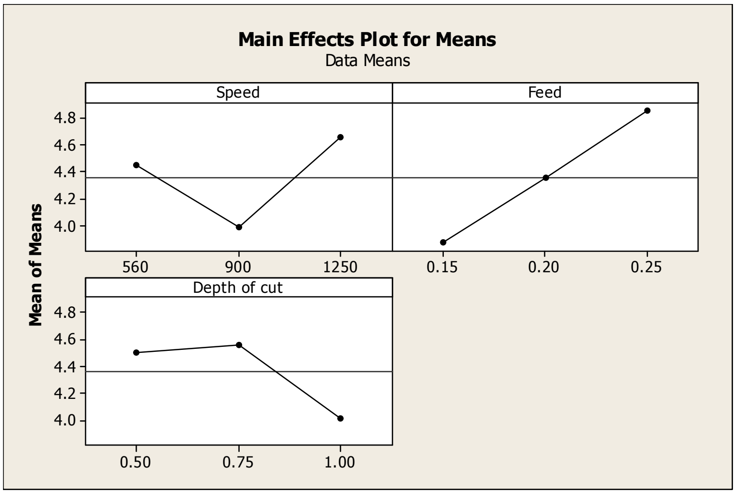


Fig 3: Main effects plot for means

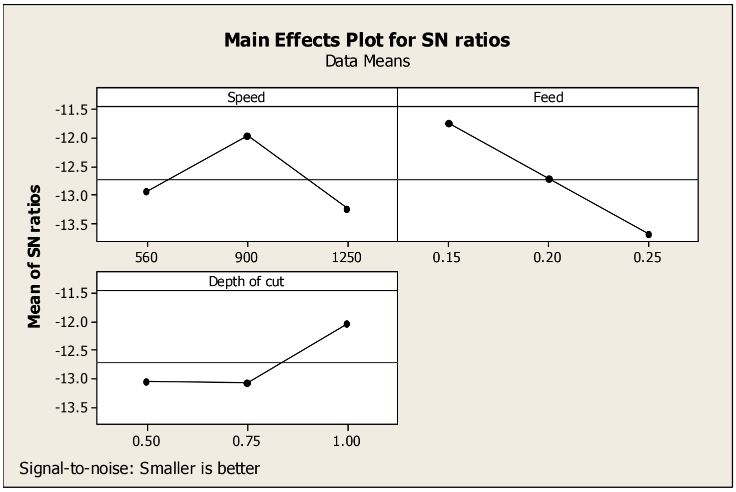


Fig 4: Main effects plot for S- N

Fig 5 shows the SEM micrographs of the worn morphology on the machined surface. Fig 5 a, b shows the worn morphology at 1250 rpm and 900 rpm respectively. The worn surface consists of deep grooves and ridges running parallel to machining direction at 1250 rpm indicating high roughness as shown in Fig 5a. From Fig 5 b, it was observed that the grooves and ridges become shallower indicating less roughness at 900 rpm. Researchers in the past few years have identified that better surface finish is realized only at higher cutting speeds where continuous chips without built-up-edge is formed. In this paper the surface roughness (Ra) observed to be more at speed 1250 rpm when compared to 900 rpm. Hence it may be analyzed that as the speed increases, the temperature increases, which proportionately increase the diffusion rate. When the hardened chip slides over the surface layer of the tool, small particles are removed from the tool which adhere to the machined surface and thus makes it rough. Hence at optimal condition (900 rpm) less roughness values are reported.

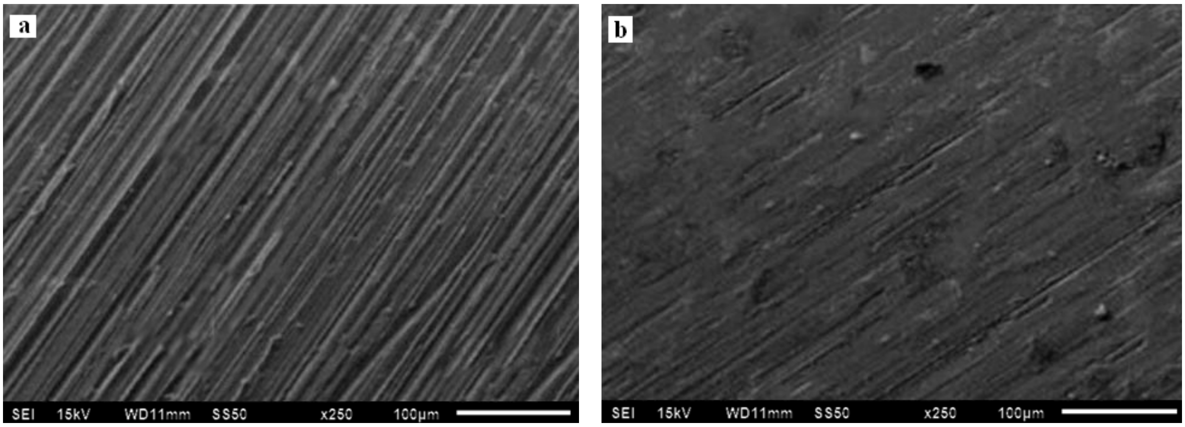
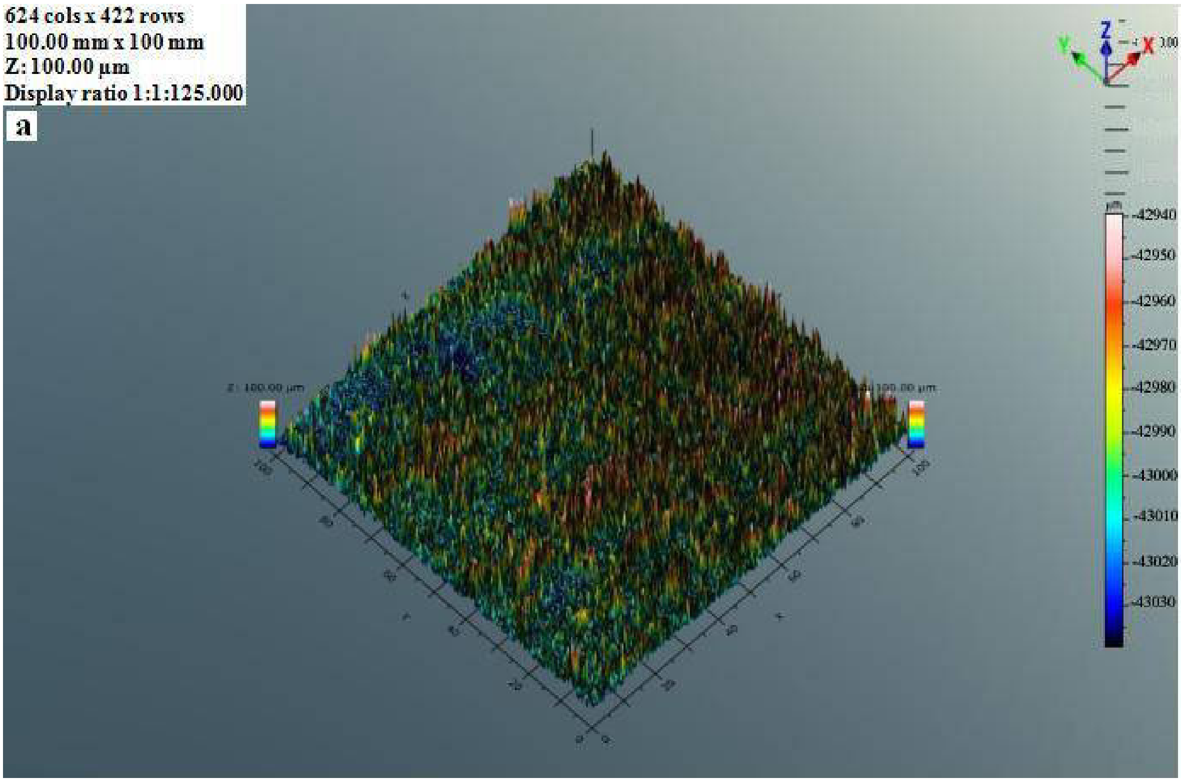


Fig 5: Worn surface of the machined surface at a) 1250 rpm b) 900 rpm

Figure 6 shows the 3D surface topography of the machined surface. It could be observed that a blend of plastic deformation and abrasion was found as the main wear mechanism on the worn surfaces (Fig 5). For those worn surfaces, roughness profiles were examined in terms of skewness (R_{Sk}) and Kurtosis (R_{Ku}) parameters. At a speed of 1250 rpm highest Kurtosis (R_{Ku}) is observed with positive skewness (high peaks, Fig 6a) . At the optimal condition lowest or negligible skewness (R_{Sk}) is observed and Kurtosis (R_{Ku}) the density sharpness of the profile is seen to be moderate (Fig 6b). Hence, for the worn surfaces 3D surface topography gives an appropriate comparison and correlation between surface roughness and machining parameters.



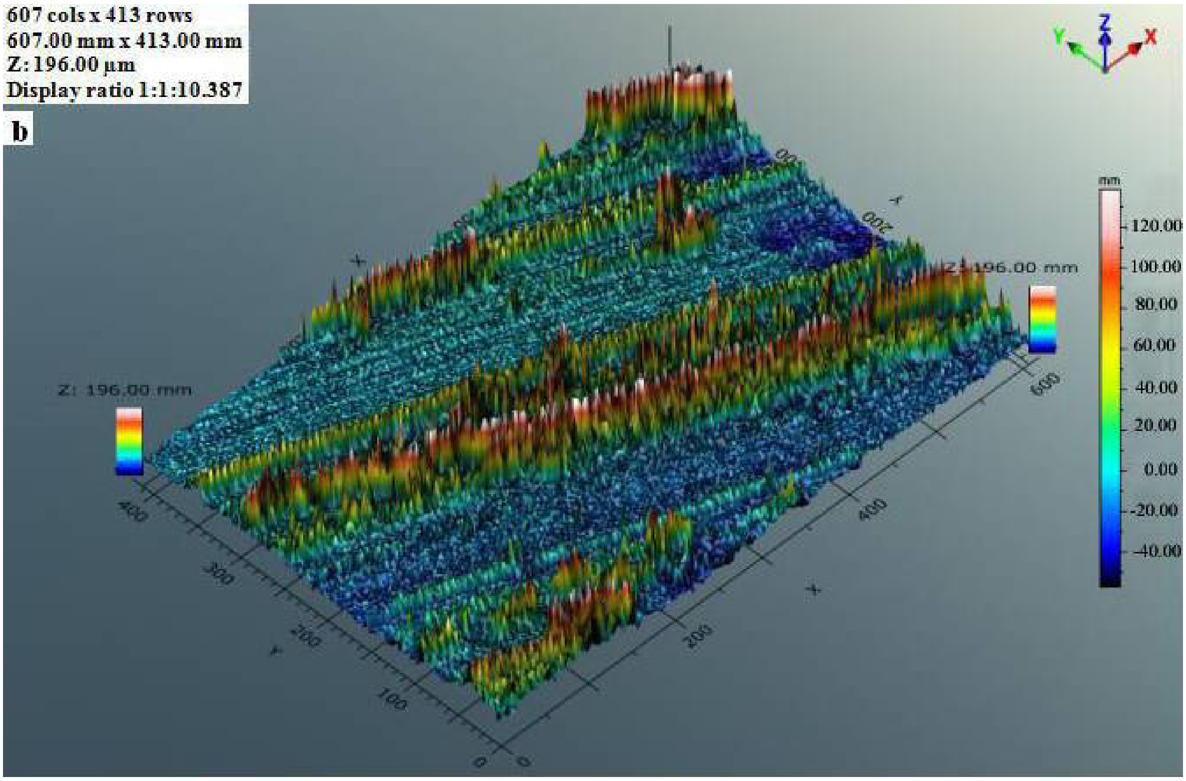


Fig 6: 3D surface topography of the worn surface a) At 1250 rpm b) 900 rpm

4. Conclusions

Based on the experimental and analytical results the following conclusions are drawn. RHA and SiC reinforcements with Vol. fraction of 6% were successfully incorporated into A356. Uniform distribution was observed from the microstructural characterization. By using the Taguchi technique the effect of machining parameters on the surface quality (R_a) has been evaluated and optimal machining conditions are obtained. Optimal parameters for minimal surface roughness obtained for turning the hybrid composite are Spindle speed (N) = 900rpm; Feed (f) =0.25mm/rev; Depth of cut (d) = 0.5mm. The response table and graphs for Means and S-N ratio are also represented.
In ANOVA, it is revealed that feed has a major contribution on the surface roughness (82.6%) followed by depth of cut (6.8%) and the cutting speed (6.43%).

Acknowledgements:

The authors would like to thank Technical Education Quality Improvement Program (TEQIP) for the financial assistance to carry this research work.

References:

Brun, M.K., Lee, M., Gorsler,F., 1995. Wear characteristics of various hard materials for machining SiC reinforced Aluminium alloy. Wear. 104, 21-29.
Charles, Arunachalam, VP., 2011. Property Analysis and Mathematical modeling of machining properties of Aluminium alloy hybrid composites produced by liquid metallurgy techniques. Indian journal of engineering and material science. 11,473-480.

El-Gallab, M., Sklad, M., 1998. Machining of Al/SiC_p metal matrix composites, part 1. Tool performance. J. Mater. Process. Technol. 83, 151-158.
Kathirvel, M., Palani Kumar, K., Muthraman,S., 2009. Implementation of echo state neural network for single point tool wear estimation using hybrid aluminium silicon carbide metal matrix. ARPN journal of engineering and applied science. 4(10), 93-99.
Jinfeng Leng, Lontan Jiang, Qiang Zhang, Gaohui Wu, DonliSun, Qingbo Zhou, 2008. Study of machinable SiS/Gr/Al composites, J.Mater Sci. 43, 6495-6499.
Kathirvel, M., Purushothman, S., Subhash Chandra Bose, R., 2011. Application of ANOVA in validating hybrid MMC machinability data. ARPN journal of engineering and applied science. 6(10), 8-18.
Ross, P.J., 1998. Taguchi technique for quality engineering, Mc graw-Hill, Newyork.
Shoba, CH., Ramanaiah, N., Nageswara Rao, D., 2014. Ageing behavior of aluminum hybrid metal matrix composites. Materials Science- An Indian Journal. 10(11), 484-489.
Siva Prasad, D., Rama Krishna, A., 2012. Tribological Properties of A356.2/RHA Composites. Journal of Materials Science and Technology. 28(4), 367-372.
Siva Prasad, D., Rama Krishna, A., 2012. Effect of heat treatment on the damping behavior of A356.2/RHA composites. Bulletin of Material Science. 35(6), 989–995.
Taguchi,G., Konishi, S., 1987. Taguchi methods: Orthogonal arrays and linear graphs: tools for quality engineering, Dearborn, Mich. : American Supplier Institute. Pp.35-38.