International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-7, Issue-6S, March 2019

Surface Roughness Study on Forged Al-TiB2 Composite by Regression Analysis

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ABSTRACT--- Aluminum composites are very rapidly replacing engineering metals and alloys because of its light weight and high strength in aerospace and biomedical applications etc. In the present work Al-TiB2 (Aluminum alloy A2024) composite is fabricated by In-Situ technique. The serious examination on impact of surface roughness of Aluminum TiB2 composite is done. The material is subjected for turning operation to contemplate the surface roughness. This investigation centers around building up an exact model for expectation of surface unpleasantness on manufactured composite. The working parameters are speed, feed, depth of cut and tool nose radius. One of the data mining techniques non-linear regression analysis is applied in developing the empirical model, this model is transferred to software by visual basic programming language.

The test results show that the value of surface roughness is low at high cutting speed and comparatively high at low cutting speed. Surface roughness increases with increase in feed and depth of cut. However it decreases with increasing tool nose radius and surface roughness increases as what% of TiB2 increases in aluminum. The values of surface roughness of models compared with experimental results. This models developed in this study have a satisfactory compatibility in both model construction and verification and there is a scope for future work.

Keywords: Al 2024 alloy, In-situ technique, surface roughness, regression analysis, tool nose radius.

INTRODUCTION

Many of the applications in the world today require material with unusual combinations of properties that cannot be the conventional monolithic materials. This is especially true for materials that are needed for high technology areas such as jet engines, airframes, space shuttles, deep-sea submersibles, hypersonic spacecrafts etc. There is a need of materials having lightweight and high strength, offering a unique combination of properties and to find an extensive application in structural, aerospace and automotive industries. It consists of a homogeneous matrix, particulate reinforced Al-metal matrix composite. In earlier turning tests, it found that tool wear is excessive and surface finish is very poor when carbide tip tools used for machining. For example in grinding wheel on the tool edge is worn out by abrasion leads to poor surface finish. While using MMC specimen it involves consequently friction, high temperature and pressure, particles adhere to cutting tool edge and so called Build-up edge (BUE). When machining also need to consider wear resistance and fatigue strength. The various roughness parameters are average roughness (R_a), smoothing depth (R_p), root mean square (R_q), maximum peak-to-valley height (R_t). The aim of the present study is to develop the surface roughness prediction model for Al-TiB$_2$ composite with the aid of a statistical method, using silicon carbide coated tool tip under various cutting conditions (without coolant). Al-TiB$_2$ is a new material, which belongs to MMC family, which is prepared by in- situ casting. This MMC is likely to have applications in aerospace, marine, and defense, because of its higher specific strength.

Al-TiB2 composite being another material very little information is accessible on machining the equivalent and it require to streamline the cutting parameters so as to have a good surface finish, which is one of the imperative criteria in aerospace application. Consequently practicality consider on this material has been carried out. Finally building up a scientific model utilizing data mining method, this is usually commonly as nonlinear-regression investigation. The scientific model is exchanged to programming, which can anticipate ideal cutting parameter for surface roughness and the other way around. Further real work machining has been completed to find out the possibility of predator, additionally a similar strategy of building up a surface roughness demonstrate for Al-TiB2 composite is done after the materials exposed to forging process and the outcomes are analyzed with forged process. It is possible to fabricate Al-TiB$_2$ composite by in-situ technique and enrichment of TiB$_2$ particles in Al matrix (2024 alloy).It is observed that surface roughness is low at high speed and comparatively high at low cutting speed; Roughness is low at wt% of TiB$_2$ and high at higher % of TiB$_2$ in aluminum.

MATERIALS AND METHODS:

1. Material compositions: The material used for present work is Al 2024 and TiB2 are shown in table. Table 1 shows composition of aluminum 2024 alloy according to ASM standards and Table 2 shows properties of TiB$_2$.

Table 1: Chemical composition of aluminum alloy 2024

	Si	**Fe**	**Cu**	**Mn**	**Mg**	**Cr**	**Zn**	**Ti**	**Others -Each**	**Others Total**	**Al**
2024	0.50	0.50	3.8-4.9	0.30-0.9	1.2-1.8	0.10	0.25	0.15	0.05	0.15	Remainder

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Revised Manuscript Received on March 10, 2019.

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Table 2: Properties of TiB_2

Theoretical density, gm/cm3	4.52
Melting point ºC	2980
Thermal conductivity, W/m-k	25
Hardness, Kg/mm2	1800-2700
Crystallography	Hexagonal
Color	Gray to dark gray

2. Selection parameters: In the present work experiments are conducted by in-situ technique adapted to regression analysis. The experiments were conducted considering 4 parameters, cutting speed, feed, depth of cut and tool nose radius.

Table 3: Parameters

Sl no	Parameters	Levels	
		1	2
01	Cutting speed	420	1200
02	Feed	0.05	0.11
03	Depth of cut	0.1	0.3
04	Tool nose radius	0.4	0.8

3. Aluminum and its alloys: The important factors in selecting in aluminum and its alloys is their lightweight to high strength, resistance to corrosion by many chemicals, high thermal and electrical conductivity, non-toxicity, reflectivity, appearance, and ease of formality machinability and to be non-magnetic.

Table 4: Properties of various Al alloys at room temperature.

Alloy-Temper	Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (%)
2024-O	17	11	18
$2024\text{-}T_3$	70	50	16
$2024\text{-}T_4$	68	47	20

METHODOLOGY:

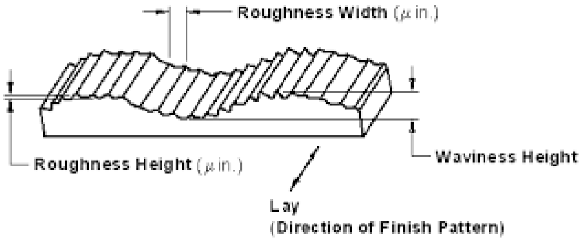
1. In-situ technique: In-situ composites are multiphase materials where the strengthening stage is combined inside the grid amid composite manufacture. In-situ procedure can make an assortment of support morphologies, going from spasmodic to constant, and the fortification might be either flexible or fired stages. For the most part, the fortifications in spasmodically strengthened metallic grid in-situ composites are on the request of 0.5-5 µm, and volume portions go from 0-50 vol. %.

2. Machinability: Machinability alludes to the simplicity with which a metal can be cut allowing the expulsion of the material with an agreeable completion easily. Materials with great machinability require little capacity to cut, can be cut rapidly, effectively get a decent completion, and don't wear the tooling much, such materials are said to be free machining.

Table 5: Materials and their specific machinability ratings

Material	Hardness	Machinability Ratings (%)
6061-T Aluminum 7075-T Aluminum	-	190
Aluminum	-	120
B1112 Steel	160BHN	100
416 Stainless Steel	200BHN	90
1120 Steel	160BHN	80
1020 Steel	148BHN	65

3. Surface Roughness: The quality of machined surface is characterized by the accuracy of its manufacture with respect to the dimensions specified by the designer. Every machining operation leaves characteristic evidence on the machined surface. This evidence in the form of finely spaced micro irregularities left by the cutting tool. Each type of cutting tool leaves its own individual pattern which therefore can be identified. This pattern is known as surface finish or roughness.



4. Regression Analysis: In statistics, relapse investigation looks at the connection of a reliant variable (reaction variable) to indicated free factors (indicators). The scientific model of their relationship is the regression condition. A regression condition contains appraisals of at least one obscure regression parameters (constants), which are connected to the two factors. Utilization of regression incorporate expectation (counting estimating of time-arrangement information), displaying of causal connections, and testing logical speculations about connections between factors. Relapse examination Software bundles are SAS System, SPSS, Minitab, or stata, perform different kinds of relapse investigation accurately and in an easy to understanding way. In this project work Minitab is used to carry out regression analysis to get the regression equation, which relates cutting parameters (speed, feed, depth of cut, tool radius and %of TiB_2 in Aluminum) to predict surface roughness.

5. Regression modeling : A function relationship between surface roughness (Ra) and the independent variables under investigation is postulated by equation

$Ra= Ct^{a1} s^{a2} f^{a3} d^{a4} r^{a5}$

Where Ra=surface roughness in micrometer, t=Wt% of TiB_2 in Al composite, s=Cutting speed in rpm, f=Feed in mm/rev,

r=tool nose radius in mm,

d=depth of cut in mm, C, a_1, a_2, a_3, a_4 and a_5 are constants.

A logarithmic transformation converts the nonlinear form of equation into the following: $\ln Ra=\ln C+a_1\ln t+a_2\ln s+a_3\ln f+a_4\ln d+a_5\ln r$

For simplicity, above equation is rewritten as: $Y=b_0+b_1X_1+b_2X_2+b_3X_3+b_4X_4+b_5X_5$

Where Y is the estimated surface roughness value after logarithmic transformation, b_0, b_1, b_2, b_3, b_4 and b5 are estimates of the parameters respectively. In addition, X_1, X_2, X_3, X_4 and X_5 are the logarithmic transformation of wt% of TiB_2 in Al composite. In the present work constants of above equation is obtained by software called Minitab the levels of each factor are presented in the table 6. As a result, a full factorial design 2^5(i.e. 2 stands for two levels, and 5 for five factors) shown in Table 7 is used to facilitate model construction by regression analysis.

Table 6: Factors and levels of experiment for model construction

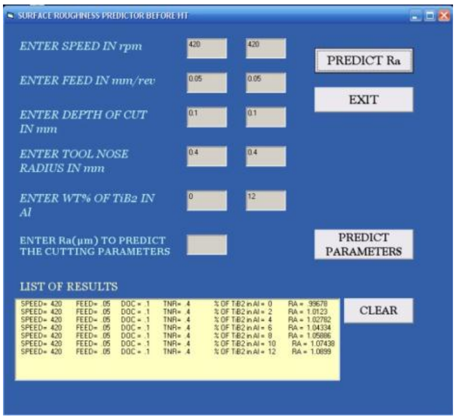
Level			Factors		
	% of TiB_2 in Al composite	Cutting speed in rpm	Feed in mm/rev	Depth of cut in mm	Tool nose radius in mm
	T	S	F	D	R
Low	00.00	420	0.05	0.1	0.4
High	12.00	1200	0.11	0.3	0.8

Table 7: Design of experiments and data for model construction

Sample no	% of TiB_2 in Al	Speed	Feed	Depth of cut	Tool nose radius
1	0	420	0.05	0.1	0.8
2	0	420	0.11	0.3	0.8
3	0	1200	0.05	0.1	0.4
4	0	1200	0.11	0.3	0.4
5	12	420	0.05	0.1	0.4
6	12	420	0.11	0.3	0.4
7	12	1200	0.05	0.1	0.8
8	12	1200	0.11	0.3	0.8

6. Development of software for surface roughness prediction: This software is developed by using visual basic programming language for predicting surface roughness for given cutting parameters and vice versa. In the shown fig the window of software, to predict surface roughness of cutting parameters.

Supporting document:



ENTER SPEED IN rpm: 420 420

ENTER FEED IN mm/rev: 0.05 0.05

ENTER DEPTH OF CUT IN mm: 0.1 0.1

ENTER TOOL NOSE RADIUS IN mm: 0.4 0.4

ENTER WT% OF TiB2 IN Al: 0 12

ENTER Ra(µm) TO PREDICT THE CUTTING PARAMETERS:

LIST OF RESULTS

```
SPEED= 420   FEED= .05   DOC = .1   TNR= .4   % OF TiB2 in Al = 0    RA = .99678
SPEED= 420   FEED= .05   DOC = .1   TNR= .4   % OF TiB2 in Al = 2    RA = 1.0123
SPEED= 420   FEED= .05   DOC = .1   TNR= .4   % OF TiB2 in Al = 4    RA = 1.02782
SPEED= 420   FEED= .05   DOC = .1   TNR= .4   % OF TiB2 in Al = 6    RA = 1.04334
SPEED= 420   FEED= .05   DOC = .1   TNR= .4   % OF TiB2 in Al = 8    RA = 1.05886
SPEED= 420   FEED= .05   DOC = .1   TNR= .4   % OF TiB2 in Al = 10    RA = 1.07438
SPEED= 420   FEED= .05   DOC = .1   TNR= .4   % OF TiB2 in Al = 12    RA = 1.0899
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Material preparation:

Aluminium-TiB_2 composite preparation:-

The in-situ composite was made by stir casting technique using the following procedure.

1} Development of software roughness prediction model from regression analysis.

2} Development of software to predict optimum cutting parameter for given surface roughness and surface roughness for the given cutting parameter.

3} Synthesis of TiB_2 by initiating an exothermic reaction in aluminum melt between “Ti” And “B” bearing compounds. Forged Al-TiB_2 enriched composite.

4} Machinability study on Al-TiB_2 composite by varying cutting parameters like speed, feed, Depth of cut, and tool nose radius.

5} Known quantity of Aluminum alloy (Al-2024) was taken in the crucible and kept in the electric furnace for melting.

6} Temperature of the furnace was set at 810°C.

7} The chemical reactants TiO_2, Na_3-AlF_6 and KBF_4 were in the weight ratio of 4:4:1.

8} The quantity of the mixture taken was 2 to 12% by weight of aluminum.

9} The mixture was preheated to 300ºC for four hours.

10} The mixture was then slowly added to the liquid aluminum when the temperature of the melt was 810ºC.

11} After the addition, the slurry was stirrerd for a period of about 30min in order that the reaction will occurs.

12} The speed of the stirrer was maintained at 700rpm.

13} After the reaction, the byproducts were skimmed off before pouring.

14} The finger mould and cylindrical mould were coated with chalk powder and preheated for one hour at 300ºC.

15} After stirring, melt was kept in furnace for 5 min for reaction to complete.

16} The slurry was poured into the mould at a uniform rate, at room temperature.

17} The castings were removed from the dies after the complete solidification.

- **Chemical Reactants**: The reactants used were:

1} Titanium di oxide(TiO_2) particles

2} Cryolite (Na_3 AlF_6, i.e. Sodium hexafluro aluminum) particles

3} Potassium tetra fluoro borate(KBF_4)

Typical applications: ceramic sintered parts, structural applications including cutting tool composites, ceramic armor nozzles, wear parts, seals and molten metal crucibles.

- **Reactions:**

$4Al+3TiO_2 \rightarrow 3Ti+2Al_2O_3$ $Ti+3A \rightarrow TiAl_3$
$2TiO_2+2Na_3AlF_6 \rightarrow 2Na_2TiF_6+Na_2O+Al_2O_3$
$2Na_2TiF_6+6Al \rightarrow 4NaF+4F_2+2TiAl_3$
$Al_2O_3+2Na_3AlF_6 \rightarrow 3NaO+4Al+6F_2$
$2Na_2TiF_6+4Al+KBF_4 \rightarrow TiAl_3+TiB+4NaF+AlF_3+KF+4F_2$
$2Na_2TiF_6+3Al+2KBF_4 \rightarrow TiAl_3+TiB_2+4Naf+2KF+7F_2$
$Na_2TiF_6+KBF_4 \rightarrow TiB+2NaF+KF+4F_2$

RESULTS AND DISCUSSIONS:

Influence of cutting parameters on surface roughness predicted by surface roughness model equations:

1. $Ra=0.432+0.00432T+0.000456S-5.14F+0.029D+0.341R$
2. $Ra=0.950+0.023T+0.000031S-3.43F+0.415D-0.129R$

Table 8: Observed and predicted Ra values after forging

Sample no	% of TiB_2 in Al	Speed	Feed	Depth of cut	Tool nose radius	Experimental Ra	Predicted Ra	Error	Relative error
1	0	420	0.05	0.1	0.8	0.24	0.39	0.15	38.48
2	0	420	0.11	0.3	0.8	0.46	0.74	0.28	37.83
3	0	1200	0.05	0.1	0.4	0.13	0.73	0.6	82.19
4	0	1200	0.11	0.3	0.4	0.22	0.44	0.22	50
5	12	420	0.05	0.1	0.4	0.23	0.43	0.2	46.51
6	12	420	0.11	0.3	0.4	0.26	0.43	0.17	39.53
7	12	1200	0.05	0.1	0.8	0.20	0.79	0.59	74.68
8	12	1200	0.11	0.3	0.8	0.30	0.50	0.2	40

Table 9: Effect of wt%TiB_2 on surface roughness

Sample no	% of TiB_2 in Al	Speed	Feed	Depth of cut	Tool nose radius	Ra
1	0	420	0.05	0.1	0.4	0.21
2	2	420	0.05	0.1	0.4	0.98
3	4	420	0.05	0.1	0.4	0.4
4	6	420	0.05	0.1	0.4	0.78
5	8	420	0.05	0.1	0.4	0.69
6	10	420	0.05	0.1	0.4	0.23
7	12	420	0.05	0.1	0.4	0.23

Fig 1: Effect of wt%TiB_2 on surface roughness

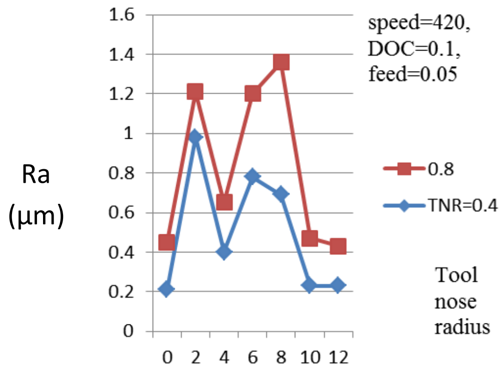

Fig 2: Effect of speed on surface roughness

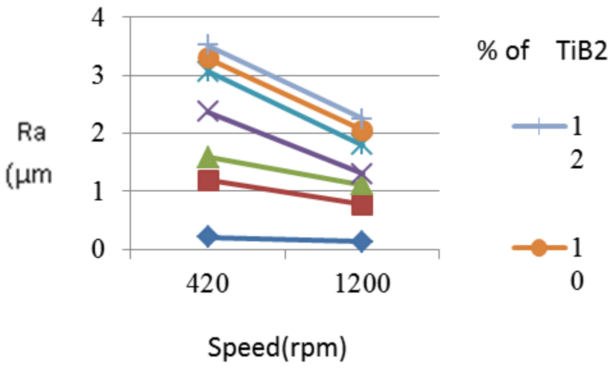

Table 10: Effect of speed on surface roughness

Sample no	% of TiB_2 in Al	Speed	Feed	Depth of cut	Tool nose radius	Ra
1	0	420	0.05	0.1	0.4	0.21
2	0	1200	0.05	0.1	0.4	0.13
3	2	420	0.05	0.1	0.4	0.98
4	2	1200	0.05	0.1	0.4	0.64
5	4	420	0.05	0.1	0.4	0.40
6	4	1200	0.05	0.1	0.4	0.34
7	6	420	0.05	0.1	0.4	0.78
8	6	1200	0.05	0.1	0.4	0.19

Table 11: Effect of feed on surface roughness

Sample no	% of TiB_2 in Al	Speed	Feed	Depth of cut	Tool nose radius	Ra
1	0	420	0.05	0.1	0.4	0.21
2	0	420	0.11	0.1	0.4	0.7
3	2	420	0.05	0.1	0.4	0.98

4	2	420	0.11	0.1	0.4	1.14
5	4	420	0.05	0.1	0.4	0.40
6	4	420	0.11	0.1	0.4	0.26
7	6	420	0.05	0.1	0.4	0.78
8	6	420	0.11	0.1	0.4	0.76

Table 12: Effect of depth of cut on surface roughness

Sample no	% of TiB_2 in Al	Speed	Feed	Depth of cut	Tool nose radius	Ra
1	0	420	0.05	0.1	0.4	0.21
2	0	420	0.05	0.3	0.4	0.55
3	2	420	0.05	0.1	0.4	0.98
4	2	420	0.05	0.3	0.4	0.84
5	4	420	0.05	0.1	0.4	0.40
6	4	420	0.05	0.3	0.4	0.52
7	6	420	0.05	0.1	0.4	0.78
8	6	420	0.05	0.3	0.4	0.81

Fig 3: Effect of feed on surface roughness

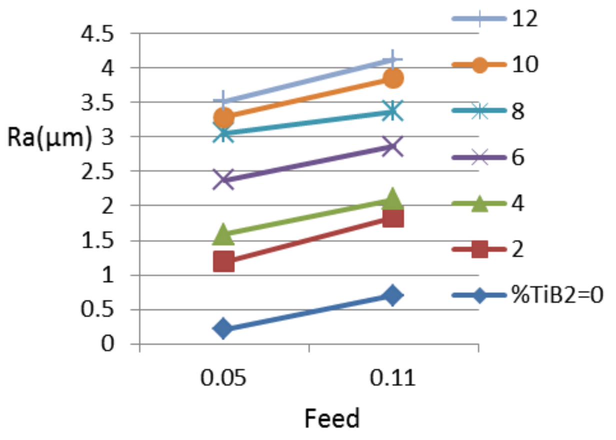

Fig 4: Effect of depth of cut on surface roughness

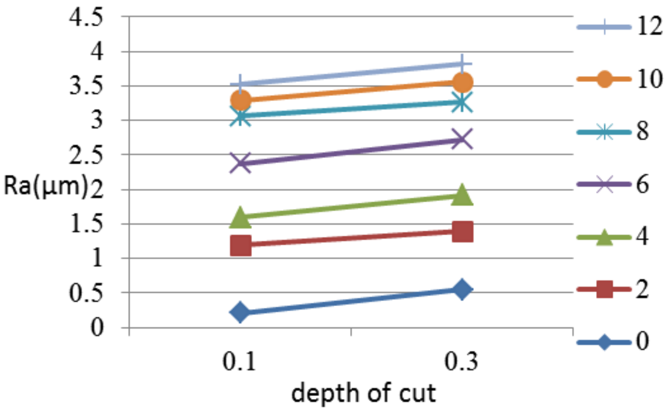

Table 13: Effect of Tool nose radius on surface roughness

Sample no	% of TiB_2 in Al	Speed	Feed	Depth of cut	Tool nose radius	Ra
1	0	420	0.05	0.1	0.4	0.21
2	0	420	0.05	0.1	0.8	0.24
3	2	420	0.05	0.1	0.4	0.98
4	2	420	0.05	0.1	0.8	0.23
5	4	420	0.05	0.1	0.4	0.40
6	4	420	0.05	0.1	0.8	0.25
7	6	420	0.05	0.1	0.4	0.78
8	6	420	0.05	0.1	0.8	0.42

Table 14: Comparison of Experimental and predicted Ra when cutting speed is varied

Sample no	% of TiB_2 in Al	Speed	Feed	Depth of cut	Tool nose radius	Experimental Ra	Predicted Ra	Error	Relative error
1	2	420	0.05	0.1	0.4	0.98	0.983	0.003	0.305
2	2	1200	0.05	0.1	0.4	0.64	0.75	0.11	14.66

Table 15: Comparison of Experimental and predicted Ra when feed is varied

Sample no	% of TiB_2 in Al	Speed	Feed	Depth of cut	Tool nose radius	Experimental Ra	Predicted Ra	Error	Relative error
1	2	420	0.05	0.1	0.4	0.98	1.11	0.13	11.71
2	2	420	0.11	0.1	0.4	1.14	0.99	-0.15	-15.15

Fig 5: Effect of Tool nose radius on surface roughness

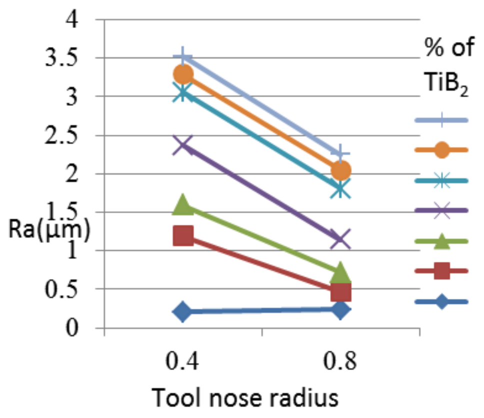

Fig 6: Comparison of Experimental and predicted Ra When Cutting speed is varied

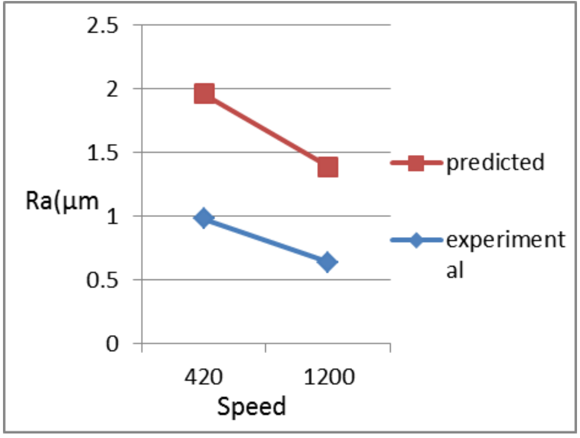

Table 15: Comparison of Experimental and predicted Ra when feed is varied

Sample no	% of TiB$_2$ in Al	Speed	Feed	Depth of cut	Tool nose radius	Experimental Ra	Predicted Ra	Error	Relative error
1	2	420	0.05	0.1	0.4	0.98	1.11	0.13	11.71
2	2	420	0.11	0.1	0.4	1.14	0.99	-0.15	-15.15

Table 16: Comparison of Experimental and predicted Ra when depth of cut is varied

Sample no	% of TiB$_2$ in Al	Speed	Feed	Depth of cut	Tool nose radius	Experimental Ra	Predicted Ra	Error	Relative error
1	2	420	0.05	0.1	0.4	0.98	0.983	0.003	0.305
2	2	420	0.05	0.3	0.4	0.84	0.4	-0.44	11.04

Fig 7: Comparison of Experimental and Predicted Ra when feed is varied

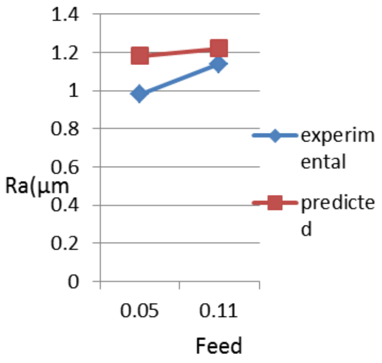

Fig 8: Comparison of Experimental and predicted Ra when depth of cut is varied

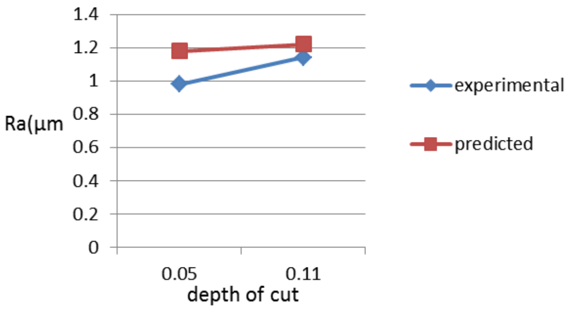

Fig 9: Comparison of Experimental and predicted Ra when Tool nose radius is varied

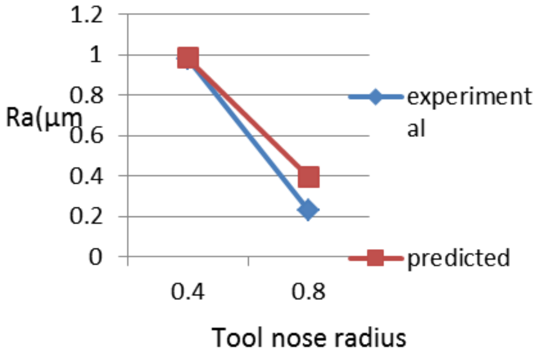

Fig 10: Comparison of Experimental and predicted Ra when %TiB$_2$ is varied

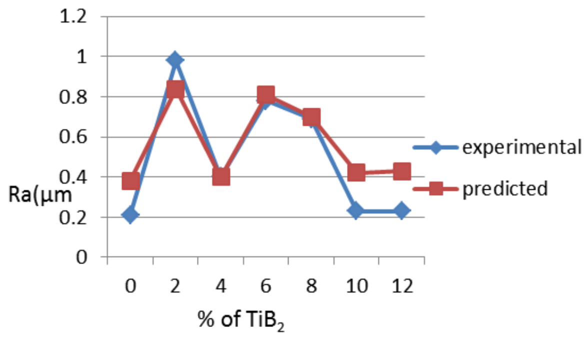

Table 17: Comparison of Experimental and predicted Ra when Tool nose radius is varied

Sample no	% of TiB$_2$ in Al	Speed	Feed	Depth of cut	Tool nose radius	Experimental Ra	Predicted Ra	Error	Relative error
1	2	420	0.05	0.1	0.4	0.98	0.983	0.003	0.305
2	2	420	0.05	0.1	0.8	0.23	0.395	0.165	0.041

Table 18: Comparison of Experimental and predicted Ra when %TiB$_2$ is varied

Sample no	%of TiB$_2$ in Al	Speed	Feed	Depth of cut	Tool nose radius	Experimental Ra	Predicted Ra	Error	Relative error
1	0	420	0.05	0.1	0.4	0.21	0.38	0.17	44.73
2	2	420	0.05	0.1	0.4	0.98	0.84	-0.14	-0.166
3	4	420	0.05	0.1	0.4	0.40	0.40	0.00	0.00
4	6	420	0.05	0.1	0.4	0.78	0.81	0.03	3.7
5	8	420	0.05	0.1	0.4	0.69	0.70	0.01	1.42
6	10	420	0.05	0.1	0.4	0.23	0.42	0.19	45.23
7	12	420	0.05	0.1	0.4	0.23	0.43	0.20	46.51

Conclusion:

1. Surface roughness is low at high speed and comparatively high at low cutting speed.
2. Surface roughness increase by increasing feed and decreases by decreasing feed.
3. Surface roughness increase by increasing depth of cut and decreases by decreasing depth of cut.
4. Surface roughness decreases by increasing tool nose radius.
5. Surface roughness is low at low wt% of TiB$_2$ in aluminum and comparatively high at higher % of TiB$_2$ in aluminum. However maximum value of surface roughness is observed with 2% TiB$_2$ composition.
6. The tread of surface roughness predicted by model is similar to the tread obtained by experimental values. However marginal deviations are observed from prediction which may be due to the model prediction accuracy.
7. Hardness of the forged Al-TiB$_2$ composite increases with wt5% of TiB$_2$.
8. Irrespective of the percentage composition of TiB$_2$ surface roughness increases.
9. In many cases it was observed that forged Al-TiB$_2$ composite had higher surface roughness.

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