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APPLICATIONS OF ANOVA IN VALIDATING HYBRID MMC MACHINABILITY DATA

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ABSTRACT

This paper presents the analysis of variance (ANOVA) carried out on the experimental data collected during machining of hybrid metal matrix composite (MMC) workpiece using polycrystalline diamond (PCD) tool tip in a lathe at various machining conditions. The influence of finishing parameter like V_b and R_a for various speeds, feeds, depth of cuts have been presented using ANOVA. The ANOVA has ensured the significancy of the data collected.

Keywords: ANOVA, hybrid MMC, aluminium, machinability, turning data.

INTRODUCTION

Aluminium matrix composites (AMCs), (Paulo Davim J., Muthukrishnan, 2008; Muthukrishnan *et al.*, 2007; Palanikumar and Karthikeyan, 2006; Ibrahim *et al.*, 1991) refers to the class of light weight high performance Aluminium centric material systems. The reinforcement in AMCs could be in the form of continuous / discontinuous fibres, whisker or particulates, in volume fractions ranging from a few percent to 70%. Properties of AMCs can be tailored to the demands of different industrial applications by suitable combinations of matrix, reinforcement and processing methods. Several grades of AMCs are manufactured by different methods. Three decades of intensive research have provided a wealth of new scientific knowledge on the intrinsic and extrinsic effects of ceramic reinforcement like physical, mechanical, thermo-mechanical and tribological properties of AMCs, (Dolauy, 1986; Tmoac and Tonnessen, 1992; Weinert, 1993; Chadwick,1990; Brun and Lee, 1985; Cronjage and Merister, 1992). Aluminium matrix composites have been utilized in high-tech structural and functional applications including aerospace, defense, automotive, and thermal management areas, sports and recreation.

MATERIALS AND METHODS

Fabrication of hybrid Al-Sic MMC

Hybrid Aluminium metal matrix composites are fabricated in house. The set up consists of a graphite crucible, motor with stirrer setup, furnace control unit, argon gas tank, and the desired mould to make the casting of the hybrid MMC. The Aluminium a 6061 is placed in

A6061-----90% SiC ----------5% Graphite--- 5%	A6061---- 85% SiC ------ 7.5% Graphite - 7.5%	Al 80% SiC 10% Graphite 10%

Figure-1. Cast Aluminium workpiece with different volume percentage.

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the graphite crucible and is heated to a temperature higher than the melting temperature 660°C of Aluminium. The reinforcements like Silicon Carbide and Graphite are preheated for 3 hours in a separate furnace and after preheating, it is poured into the graphite crucible. The motor with stirrer set up is made on and the stirrer is made to rotate with high speed in order to mix the reinforcements uniformly with Aluminium A 6061. After thorough mixing is done, the liquid MMC is poured into the mould kept at the bottom of the furnace, through the Argon gas chamber with a pressure of 2 bars. It is done to cool the hybrid MMC. The solid hybrid Al-SiC MMC rod is obtained after the liquid MMC in the mould is made to settle for several hours. Thus the solid hybrid Al-SiC MMC rod with diameter 50 mm and length 250 mm is fabricated. Figure-1 shows three work pieces manufactured using metal matrix Aluminium composites with different volume fractions. Figure-2 presents the microstructure of MMC with 15% volume fraction. The presence of SIC and graphite are seen.

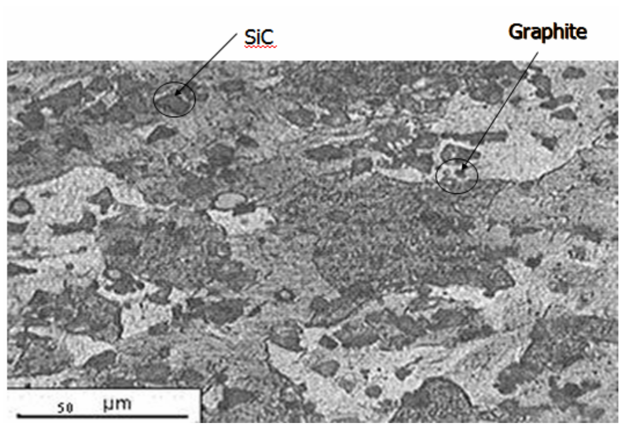

Figure-2. Al/SIC/C Composite SEM Microstructure 15 % Vol. fraction.

Experimental setup

The schematic diagram of the experimental setup is given in Figure-3. The three components of forces, namely, axial force (F_x), radial force (F_y) and tangential force (F_z). To measure the cutting forces, a three-component piezoelectric crystal type of dynamometer (KISTLER type 9441) was used. The value of V_b was measured by a toolmaker's microscope. The R_a was measured using profilometer.

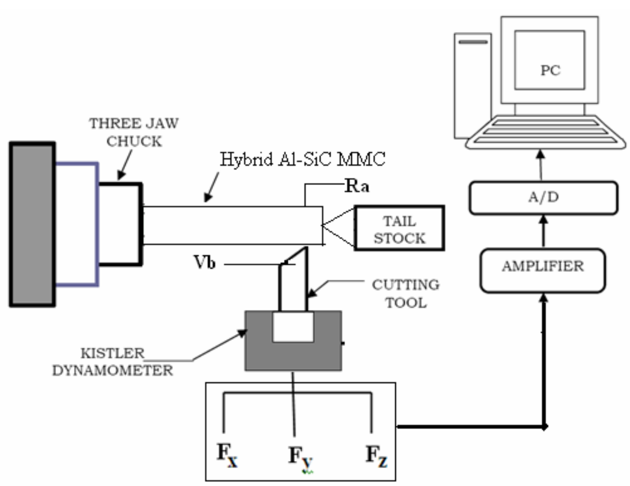

Figure-3. Experimental setup.

1. Volume percentage versus V_b
2. Volume percentage versus R_a
3. Speed versus V_b
4. Speed versus R_a
5. Feed versus V_b
6. Feed versus R_a
7. Depth of cut versus V_b
8. Depth of cut versus R_a
9. F_x versus V_b
10. F_x versus R_a
11. F_y versus V_b
12. F_y versus R_a
13. F_z versus V_b
14. F_z versus R_a

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The tool used is a single point PCD indexable tip. PCD contains a small amount of cobalt as a result of the manufacturing process. If a PCD tool is subjected continuous and significant heating during cutting, the diamond is likely to transform back to graphite. In order to avoid this effect, the use of coolant is recommended. Due to the polycrystalline nature of PCD, it is not possible to create cutting edges as perfect as those of single crystal diamond. Even with the finest grade PCD, which has a particle size of 2 microns, it is not possible to machine plastics and produce optically flat surfaces.

PCD tools are relatively expensive, compared with conventional cutting tools. Poor quality materials, which have inclusions that break conventional cutting tools, or work holding systems that do not locate and hold the part securely, are likely to have the same effect on PCD tools but at a greater cost.

Metal matrix composite (MMC) materials, Aluminium reinforced with Silicon carbide particles or filaments can be machined with PCD, but as the SiC content increases the tool life reduces and materials with more than 30% SiC are practically impossible to machine other than by grinding. The size of the workpiece is 55 x 250 mm length. The turning experiments were conducted and the readings are given in Table-1.

Table-1. Experimental data.

S. No.	**Volume fraction** (%)	**Speed** (m/min)	**Feed** (mm/rev)	**Depth of cut,** (mm)	**F_x N**	**F_y,N**	**F_z, N**	**Machining time** (min)	**Flank wear V_b,** (mm)	**Surface roughness, R_a** (µm)
1	10	50	0.2	0.5	35	65	70	2	0.03	1.71
2	10	50	0.4	1.5	40	65	75	5	0.14	3.83
3	10	50	0.6	2.5	40	75	80	8	0.31	5.48
4	10	100	0.2	1.5	50	75	90	5	0.15	1.85
5	10	100	0.4	2.5	45	85	105	8	0.35	3.12
6	10	100	0.6	0.5	60	90	110	2	0.04	2.65
7	10	150	0.2	2.5	40	80	65	8	0.36	1.74
8	10	150	0.4	0.5	45	80	70	2	0.04	1.73
9	10	150	0.6	1.5	45	90	85	5	0.18	2.81
10	15	50	0.2	1.5	50	90	85	8	0.39	2.11
11	15	50	0.4	2.5	40	105	105	2	0.07	2.75
12	15	50	0.6	0.5	45	110	105	5	0.19	3.17
13	15	100	0.2	2.5	50	125	190	2	0.08	1.34
14	15	100	0.4	0.5	40	75	95	5	0.21	1.81
15	15	100	0.6	1.5	60	80	125	8	0.49	2.78
16	15	150	0.2	0.5	55	85	130	5	0.21	1.01
17	15	150	0.4	1.5	60	150	210	8	0.52	1.82
18	15	150	0.6	2.5	60	100	115	2	0.09	2.02
19	25	50	0.2	2.5	60	90	125	5	0.35	1.48
20	25	50	0.4	0.5	55	85	140	8	0.56	1.91
21	25	50	0.6	1.5	60	100	120	2	0.11	2.27
22	25	100	0.2	0.5	25	70	85	8	0.62	0.93
23	25	100	0.4	1.5	60	100	125	2	0.12	1.30
24	25	100	0.6	2.5	70	100	115	5	0.43	1.95
25	25	150	0.2	1.5	50	80	105	2	0.12	0.72
26	25	150	0.4	2.5	50	85	100	5	0.45	1.28
27	25	150	0.6	0.5	25	70	90	8	0.72	1.40

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ANALYSIS OF VARIANCE (ANOVA) ON FACTOR EFFECTS

Analysis of variance is an important statistical analysis method that describes about the nature of data. Analysis of variance meets the need by how much an estimate must differ from zero in order to judge "statistically significant". Analysis of variance is a method of portioning variability into identifiable sources of variations and the associated degrees of freedom in an experiment. In statistics, for analyzing the significant effects of the parameters on the quality characteristic, F test is used. When F value is high then p value is low. If p value is low, then the data is significant. In the following figures, one way ANOVA has been used using Matlab software to understand the significance of each variable on the outputs of V_b and R_a.

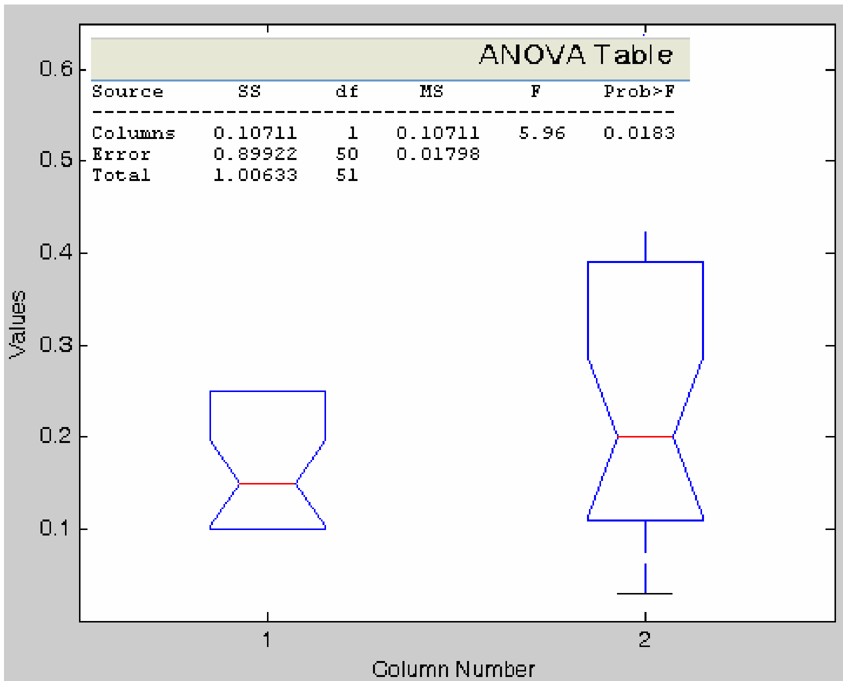

Figure-4. Volume percentage versus V_b.

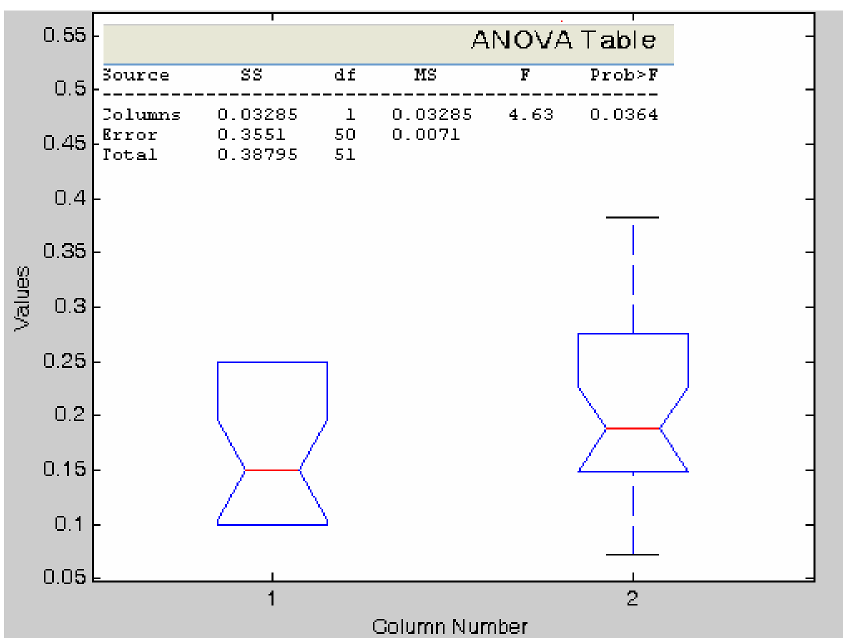

Figure-5. Volume percentages versus R_a.

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ANOVA is performed for volume % of composite and V_b and presented in Figure-4. The p value is 0.0183. Hence the data is significant. ANOVA is performed for volume % of composite and Ra and presented in Figure-5. The p value is 0.0364. Hence, the data is significant. ANOVA is performed for rotation speed of the workpiece and V_b and presented in Figure-6. The p value is 2.362 e-006. Hence, the data is significant. ANOVA is performed for rotation speed of the workpiece and Ra and presented in Figure-7. The p value is 1.00947e-009. Hence, the data is significant.

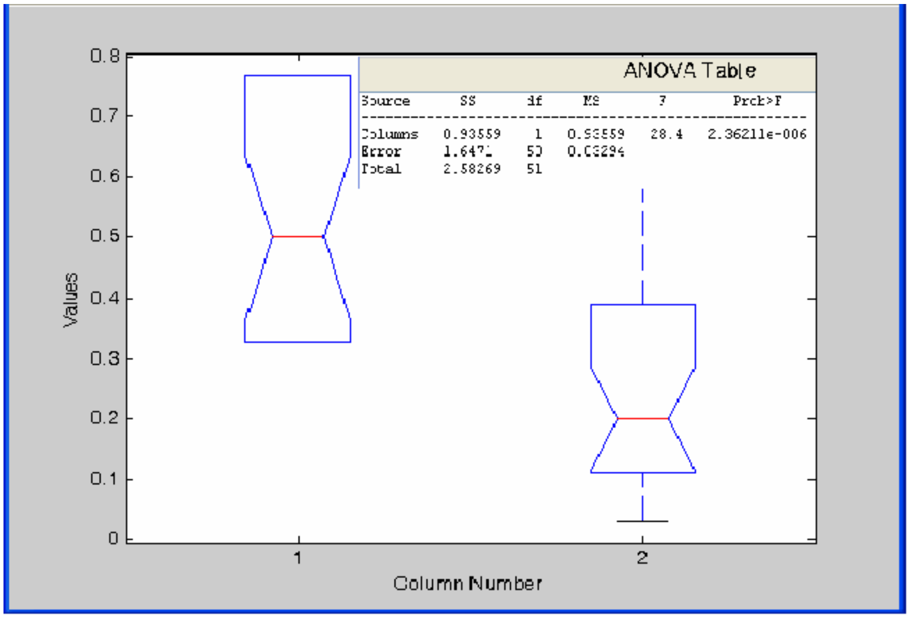

Figure-6. Speed versus $V_{b.}$

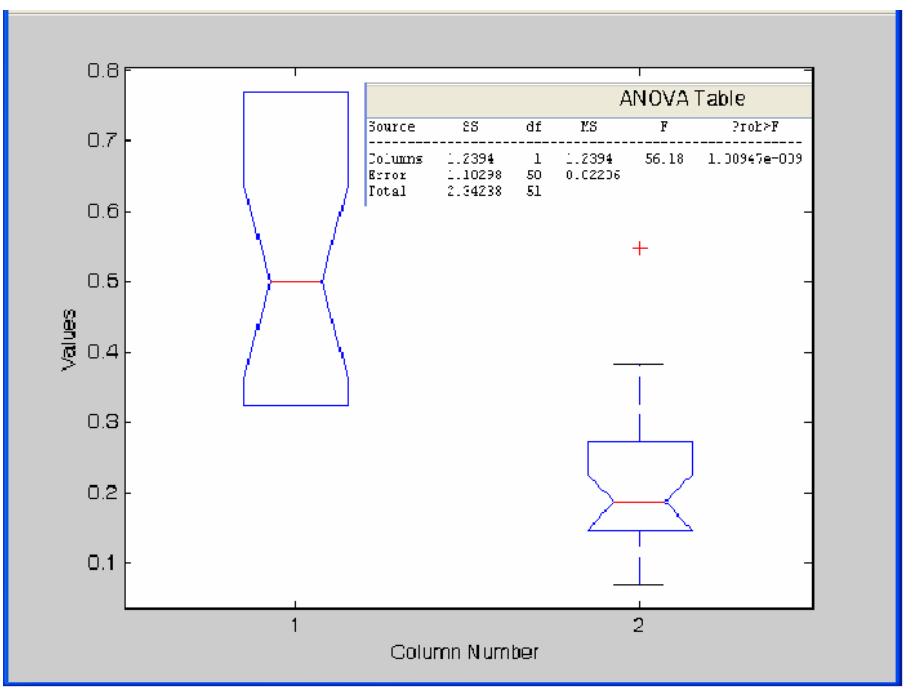

Figure-7. Speed versus $R_{a.}$

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ANOVA is performed for axial feed of the tool and V_b and presented in Figure-8. The p value is 0.1224. Hence, the data is insignificant. ANOVA is performed for axial feed of the tool and Ra and presented in Figure-9. The p value is 0.4377. Hence, the data is insignificant.

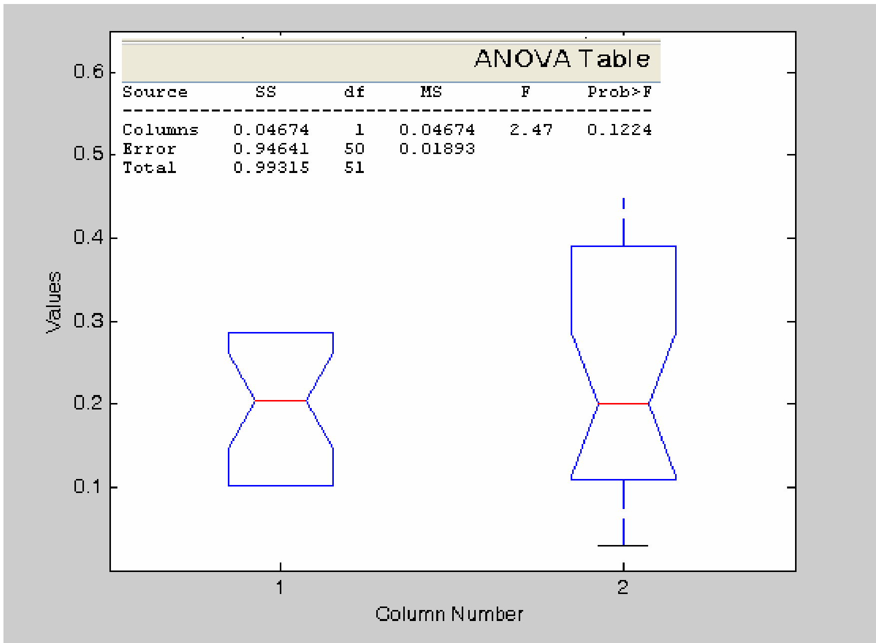

Figure-8. Feed versus V_b

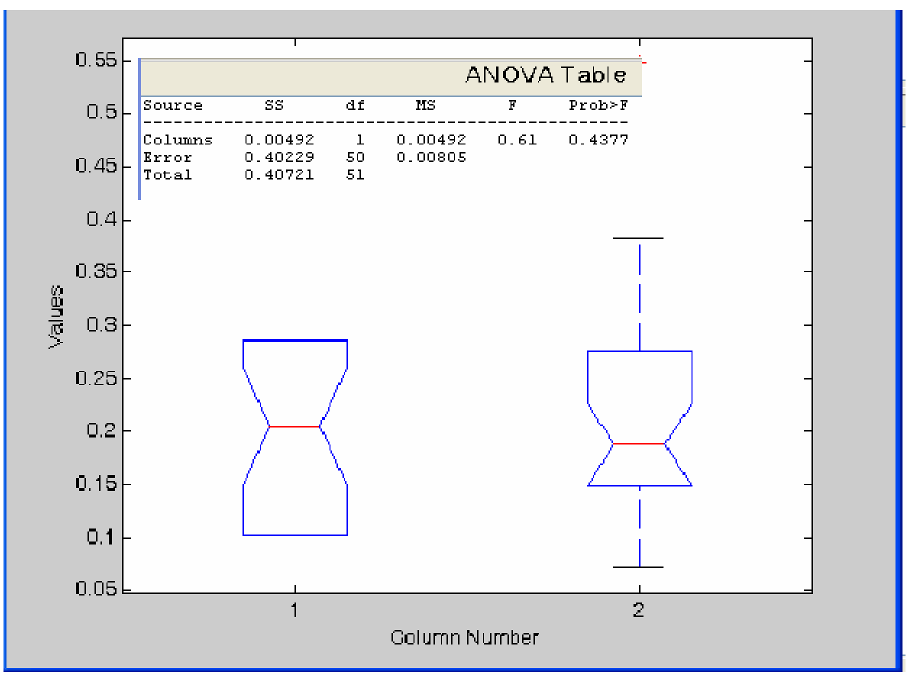

Figure-9. Feed versus R_a.

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ANOVA is performed for depth of cut by the tool and V_b and presented in Figure-10. The p value is 7.06e-005. Hence, the data is significant. ANOVA is performed for depth of cut by the tool and R_a and presented in Figure-11. The p value is 1.93e-006. Hence, the data is significant.

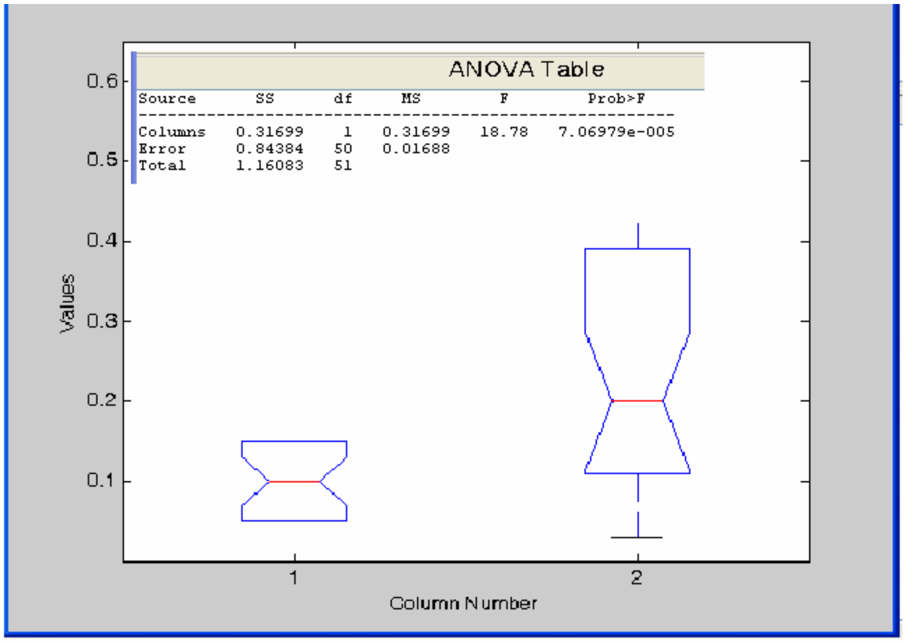

Figure-10. Depth of cut versus V_b.

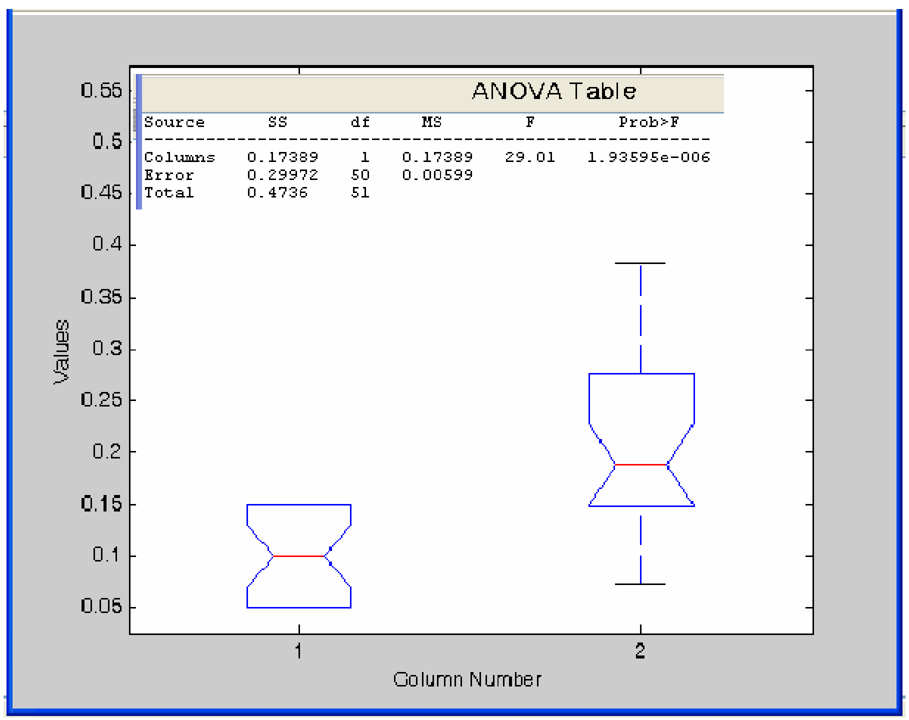

Figure-11. Depth of cut versus R_a.

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ANOVA is performed for axial force by the tool and V_b and presented in Figure-12. The p value is 0.0002. Hence, the data is significant. ANOVA is performed for axial force by the tool and R_a and presented in Figure-13. The p value is 2.9383e-005. Hence, the data is significant.

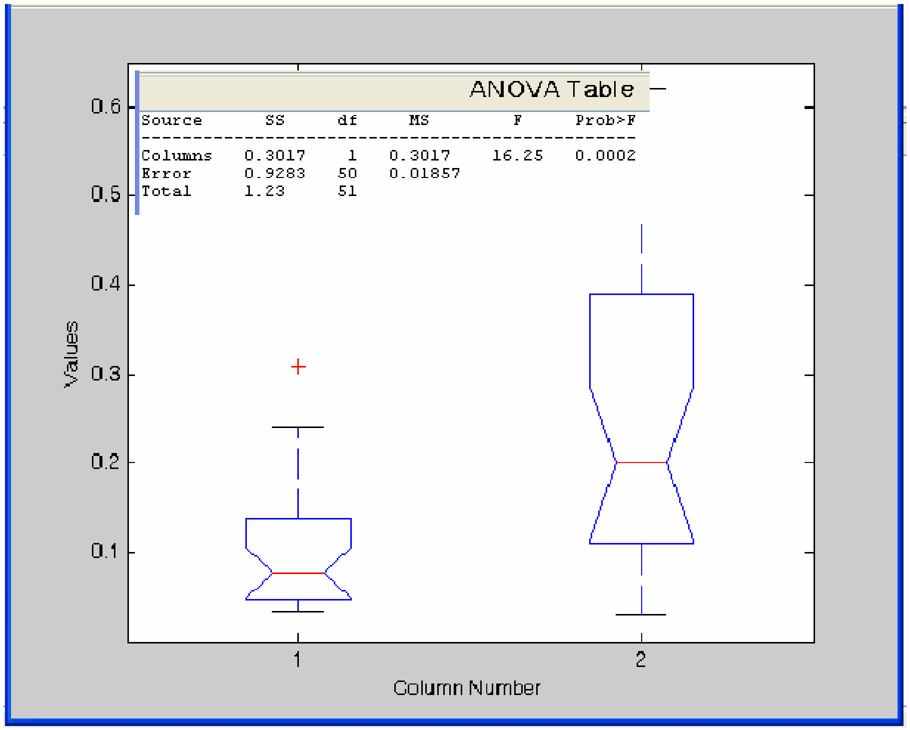

Figure-12. F_x versus V_b.

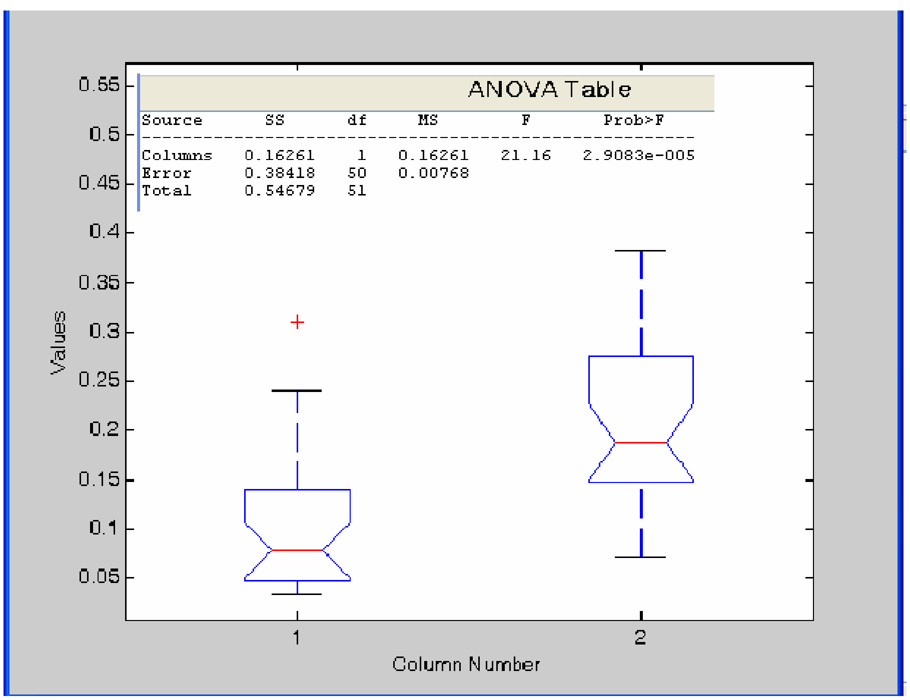

Figure-13. F_x versus R_a.

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ANOVA is performed for Radial cutting force by the tool and V_b and presented in Figure-14. The p value is 1.48e-005. Hence, the data is significant.

ANOVA is performed for depth of cut by the tool and V_b and presented in Figure-15. The p value is 4.548e-007. Hence, the data is significant.

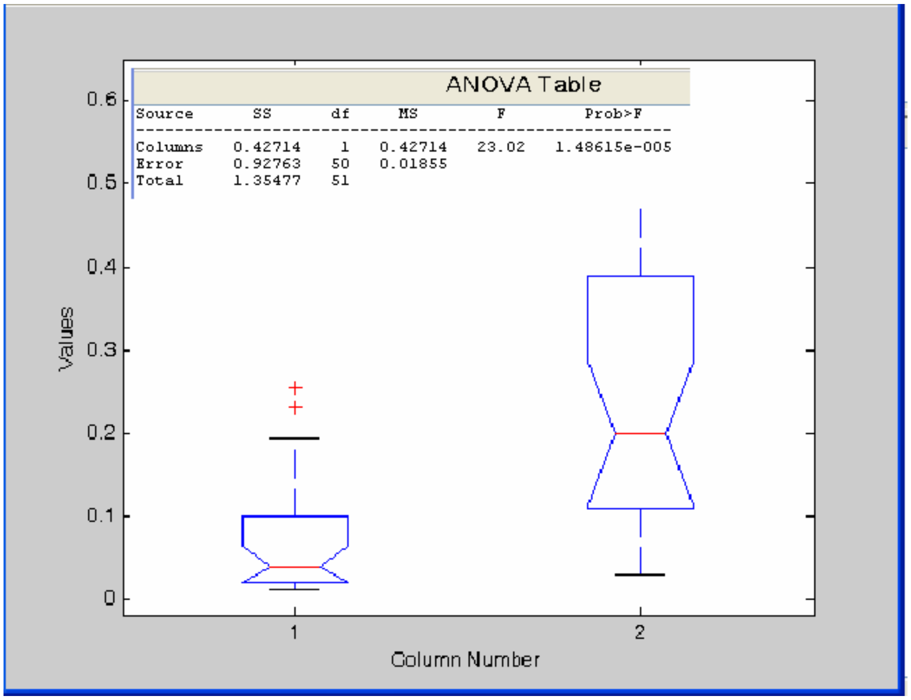

Figure-14. F_y versus V_b.

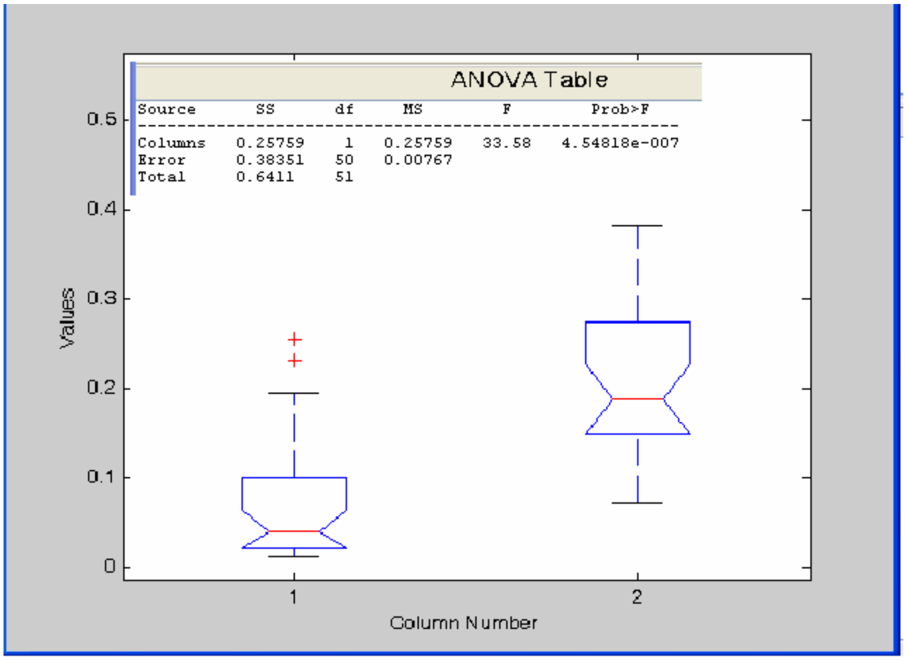

Figure-15. F_y versus R_a.

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ANOVA is performed for tangential force by the tool and V_b and presented in Figure-16. The p value is 0.1489. Hence, the data is insignificant. ANOVA is performed for tangential force by the tool and R_a and presented in Figure-17. The p value is 0.4824. Hence, the data is insignificant.

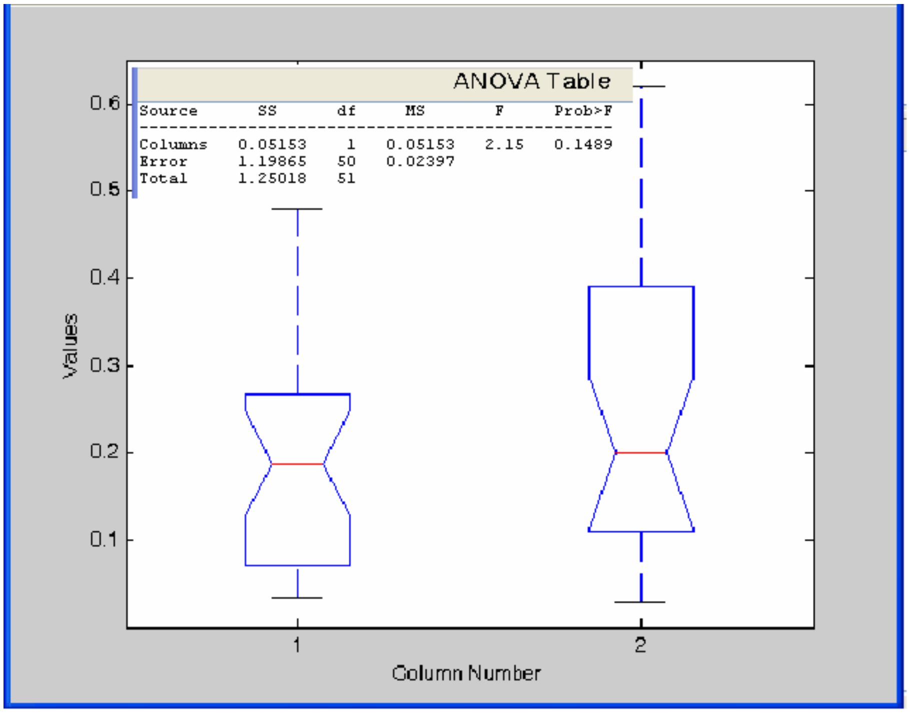

Figure-16. F_z versus V_b.

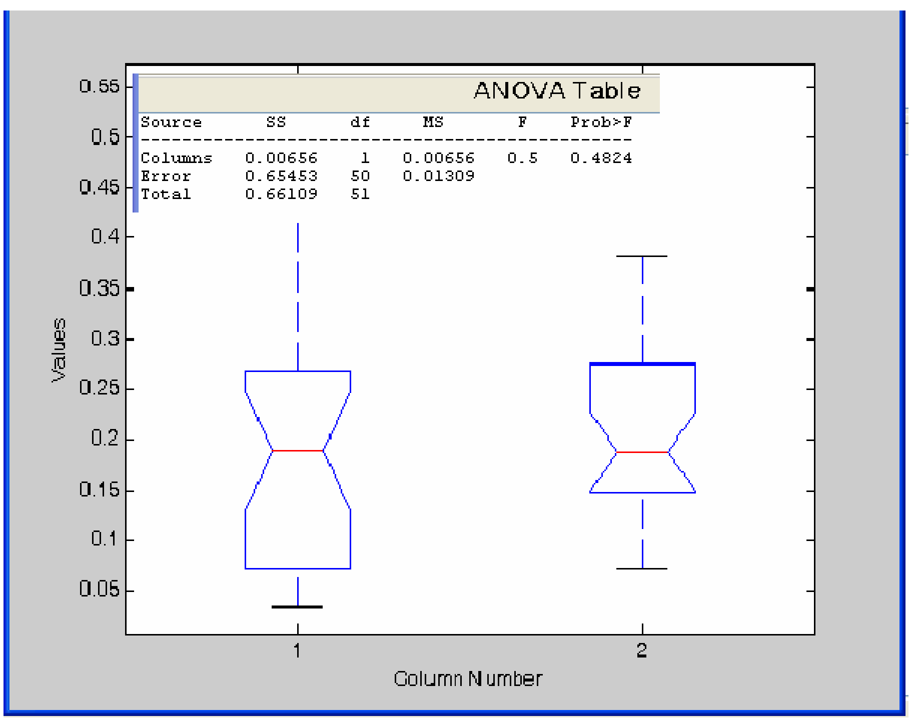

Figure-17. F_z versus R_a.

From the analysis of results using one way ANOVA, the data are statically significant (Figure-18). X-axis represents feature names (1-Volume, 2-Speed, 3-Feed, 4-Depth of cut, 5-F_x, 6-F_y, 7-F_z). In the y-axis, p-values obtained using one way ANOVA is presented. The blue color line is plotted for R_a. In this, feed and F_z are not significant. The red color line is plotted for V_b. In this, all the variables are significant.

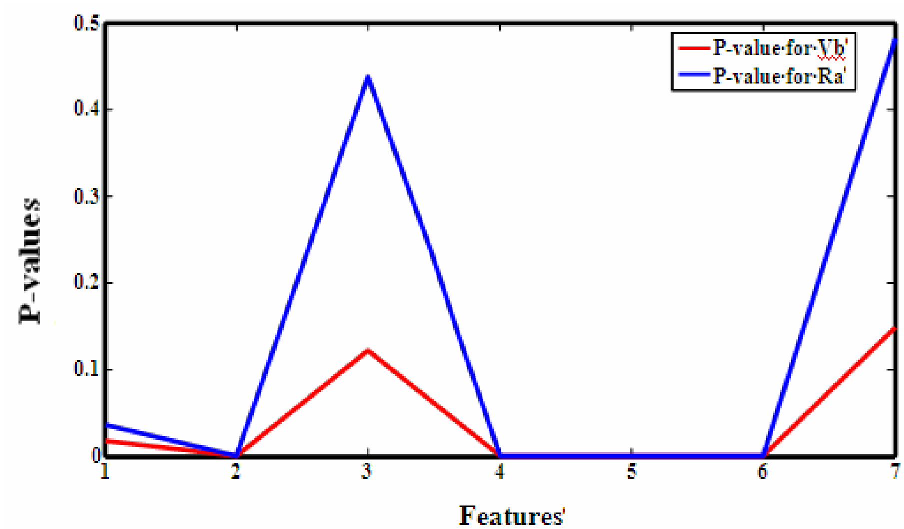

Figure-18. P-values from ANOVA.

CONCLUSIONS

This paper presents graphical plots using ANOVA for the different variables such as volume fraction, speed, feed, depth of cut, axial force, radial force, tangential force, flank wear and surface roughness of the experimental data collected. The various effects are analyzed by using analysis of variance (ANOVA) for Ra, V_b, F_x, F_y, F_z with given speed, feed and depth of cut. The results indicated that % volume fraction of SiC shows more effect on forces, whereas spindle speed and feed are highly influential parameters for flank wear and surface roughness in machining of hybrid Al-SiC metal matrix composites.

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