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Preparation, Characterization and Machinability of Al7075-Al_2O_3 Matrix Composite Using Multi Layer Coated Carbide Insert

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Abstract

This experimental study is done to investigate distribution of Al_2O_3 (15% wt) having particle size of 20µm in Al-7075 (T6) matrix composite, fabricated by stir casting method and study influence of cutting parameters on surface finish using multi coated carbide inserts. Uniform distribution of Al_2O_3 particles was observed using microstructure study. The characterization of the prepared samples was carried out using X-ray diffraction and scanning electron microscopy. Machinability study was done on medium duty lathe using multi coated carbide insert. Taguchi L9 orthogonal array method is applied for designing an experiments with the selection of cutting parameter, cutting speed of 80,100,120m/min, feed rate of 0.103, 0.206, 0.296mm/rev, and cutting depth of 0.3, 0.6, 0.9mm. The optimal cutting conditions was found using the signal-to-noise (S/N) ratio for surface roughness parameters (Ra, Rt), cutting force, tool wear according to the ‘‘the-smaller-the-better’’ approach. Taguchi response analysis and ANOVA is used to optimize the parameters influencing the objectives. The optimum cutting levels for surface roughness at cutting speed of 80m/min, feed rate of 0.103mm/rev and depth of cut at 0.3mm, for tool flank wear cutting speed of 120m/min, feed rate of 0.296mm/rev and depth of cut at 0.9mm and for cutting force cutting speed of 120m/min, feed rate of 0.103mm/rev and depth of cut at 0.3mm.In order to achieve good surface finish and reduced tool wear, higher cutting speed and lower feed rate combination is suggested for machining Al-7075(T6) - Al_2O_3 matrix composite.

Keywords: Al-7075; Microstructure; cutting parameters; surface roughness; tool wear; Cutting force.

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1. Introduction and literature review

Composites refer to a system which is composed of a matrix and reinforcement. Aluminium Metal Matrix Composites (AMMC's) refers to a system that has aluminium or aluminium alloy as base matrix and ceramic particles as reinforcements. M.K.Surappa et. al author observed that when compared to unreinforced materials (i.e. pure alloys or metals) aluminium MMC's show many advantages like increase in strength, temperature resistance, hardness, abrasion and wear resistance, damping capabilities and decrease in thermal coefficient of expansion. None of the existing monolithic materials offer superior properties when compared to AMMC's. In recent years AMMC's are widely used in aerospace, automobile and mineral processing industries for producing high performance components. The author also noted that ceramic reinforcement is prepared mainly in form of whisker, continuous fibers or particulates. Reinforcement that is commonly used in AMMCs is Al_2O_3, SiC, B_4C. G. B. Veeresh Kumar et. al and Ali Kalkanlı et.al authors observed stronger matrix produces stronger composite and also observed 7075 aluminium alloy has high strength to weight ratio, higher toughness and it finds application in field of aerospace and for structural purpose. Ali Kalkanlı et.al and Muhammad Hayat Jokio et. al noted that Al 7075 compared to other commercially available aluminium alloys is strongest and literature reveals very few experimental study has been conducted using Al 7075 with Al_2O_3 as reinforcement, therefore we have preferred Al 7075 with Al_2O_3 as reinforcement in our experimental study. During fabrication of AMMC's many challenges are faced like improper distribution of reinforcement material in matrix, porosity formation and decrease in wettability. Hence, to overcome these difficulties there is a need to choose an efficient fabricating technique. There are various techniques involved for manufacturing of AMMC's such as stir casting, powder metallurgy, squeeze casting, spray casting etc. Among the available manufacturing techniques for AMMC's stir casting technique is preferred because of its simplicity, can be used for large production, economical etc by J. Hashim et.al. In study done by M.K.Surappa et. al author concluded that microstructure in a composite is influenced by the factors such as alloy composition, pouring temperature, viscosity of the melt, cooling rate etc. Therefore in order to obtain uniform distribution of reinforcement particles in matrix, stir casting method is preferred in our experimental study.

In the present world, the main component that will give customer satisfaction is quality of the product. In each and every industry surface roughness of the component is the main thing that defines the surface finish. Hence it is important to achieve high surface finish which helps to increase productivity observed by D.I. Lalwani et. al. Surface texture of machined surface is controlled by a lot of parameters. Among them surface roughness is the important parameter. Surface integrity controls various surface functions such as stress, friction, corrosion, temperature conducted by Abeesh et. al. Therefore there is a need to conduct detail study on any machined surface. From study done by M.Kok et. al author concluded that MMC's reinforced with ceramic fibers has always resulted in machining problems and in the work done by E.O. Ezugwuet et. al author said that surface finish improves corrosion resistance, creep life, and fatigue strength which are the preliminary requirements in the case of aerospace components. In the study conducted by Basheeret et. al, the author concluded that the size of reinforcements in the composite material influences roughness of the machined surfaces significantly. Therefore much focus is done on production technique. From work done by Dr. C. J. Rao et. al. author concluded that in order to achieve minimum power consumption for best surface finish, it is necessary to determine surface parameters such as cutting speed, feed and DOC. Feed Force and thrust force also influence power consumption. Cutting force is defined as product of specific energy co-efficient, feed and cutting depth. Cutting force can be resolved in three components Feed force (F_x), cutting force (F_y) and thrust force (F_z). In our experimental study we have focused on influence of cutting parameters such as cutting speed, feed and cutting depth on cutting force and surface finish. In the papers presented by Muthukrishnan et. al and Ramanujam et. al ANOVA analysis for optimization of cutting parameters was clearly explained. In Turning, authors concluded that this statistical technique is effective and provides a systematic method of optimization.

While machining it is necessary to prevent catastrophic failure of tool so that damage to component can be avoided. From study done by H.Shao et. al. author concluded that while machining coated carbide tools have resulted in higher tool life when compared to uncoated carbide tools. Using uncoated carbide tools for machining also result in flank wear which results in excessive tool breakage at the cutting edge. Therefore we have preferred to use coated carbide inserts while machining of Al-7075 with 15% wt Al_2O_3 .

It is clear from the literature survey that no experimental work has been reportedly carried out to study Micro-structure, XRD, SEM and EDAX analysis of Al-7075 alloy with 15% wt Al_2O_3 reinforcement. In addition no experimental work has been reported to investigate the parameters affecting surface quality of Al-7075 alloy with 15% wt Al_2O_3 reinforcement using multi coated carbide inserts.

2. Problem definition

The main objective of present study is to investigate distribution of reinforcements in matrix of Al-7075 alloy reinforcement and to investigate the effect of cutting conditions feed rate, cutting speed, cutting depth on surface finish.

Al-7075 with 15% wt was characterized by using metallographic techniques (XRD, SEM).Microstructure of the cast specimen was studied using optical microscope connected to computer imaging system. Taguchi L9 orthogonal array is utilized for turning AMMC's. The results that are obtained from the study are analyzed to achieve optimal cutting conditions. For this Taguchi Signal to Noise (S/N) ratio analysis was performed. Finally ANOVA is conducted to know the most influencing parameters on surface finish. The experimental details are listed as follows:

- Matrix – Al7075
- Reinforcement – Al_2O_3 (20 µm - 15% wt)
- Cutting force measurement: 9121 type Kistler dynamometer.
- Tool insert – Multi Coated insert (CNMG 120408 – FR – TN8135).
- Fabricating technique – Stir Casting.
- X-ray Diffractometer- D8 Advanced, Bruker
- Scanning Electron Microscope-SUPRA 55
- Lathe – Self-Centered Three Jaw Chuck, Medium duty lathe of spindle power 7.5KW
- Surface Quality testing machine – Mahr Surface Roughness Tester
- Coolant – Dry machining
- Chemical Composition of Base material and reinforcement used in study is shown in Table 1 and Table 2.

Table 1 Chemical composition of Al 7075 alloy

Chemical Composition	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Al 7075	0.4	0.5	1.2-2.0	0.3	2.1-2.9	0.18-0.28	5.1-6.1	0.2	rem

Table 2 Chemical composition of Aluminium oxide powder

Chemical Composition	SiO_2	Fe_2O_3	TiO_2	Na_2O	Al_2O_3
Wt %	0.15	0.05	0.15	0.45	rem

3. Experimental work and procedure:

Fabrication of Metal Matrix Composite requires very good interfacial bond condition between matrix and reinforcement. In study done by J.Hashim et.al. author says that particle surface affect wettability which can be improved by reducing contaminants on absorbed substrate. In order to obtain good interfacial bonding, reinforcement particles need to be preheated to remove contaminants and improve wettability. Therefore ceramic particles are preheated to 800^0 C using Preheater Furnace. Fig1 shows stir casting setup used in the experiment. In this machine a two bladed stirrer is driven by a DC motor. Electric Furnace was used to melt Al-7075. In the present study, Al-7075 and Al_2O_3 are taken in the proportions of 85% and 15% respectively.Al7075 was heated up to 850^0C. Once metal melts flux is added to remove impurities and magnesium is added to increase wettability. Later inert atmosphere was maintained using Argon gas and Al_2O_3 was added to molten metal. Stirring was carried out for 10 min at 650 rpm. Once the matrix and reinforcement were thoroughly stirred, melt was poured into a die of diameter 30mm and length 200mm. Fabricated Composite was skin turned on a medium duty lathe from 30mm diameter to 28.8mm diameter.

Fig 1 Stir casting setup used in experiment

4. Metallographic study

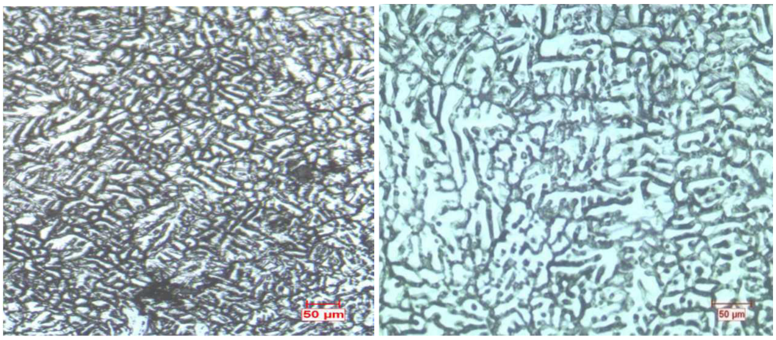


Fig 2 Microstructure of Al-7075 with 15% wt Al_2O_3 at (a) 100X (b) 200X

After fabrication of discontinuous reinforced matrix, it is necessary to investigate distribution of reinforcement in matrix. Quality of specimen prepared can be checked by studying the microstructure of the specimen. Metallographic study was done by using optical microscope connected to computer imaging system and scanning electron microscope. XRD analysis was also carried out for metallographic study. Skin turned work piece was used to investigate microstructure. A specimen of 28.8 diameter and 5mm length was initially polished using emery paper of grit size 200, 400, 600, 800, 1000 .Later the specimen was polished using disc polishing machine. Kellar reagent was applied to specimen and microstructure study was carried out. Microstructure of cast composite was observed at 100X and 200X. From Fig 2 it is revealed that reinforcement is uniformly distributed on dendrites. Black spots in Fig 2 are porosity; it is formed due to entrapment of gas during stirring.

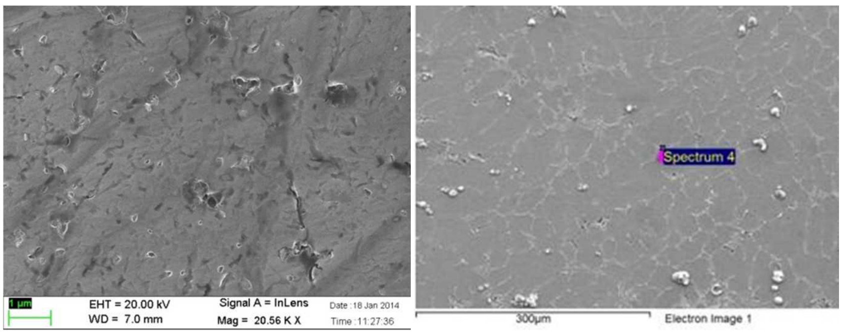


Fig 3 SEM image of Al-7075 with 15% wt Al_2O_3

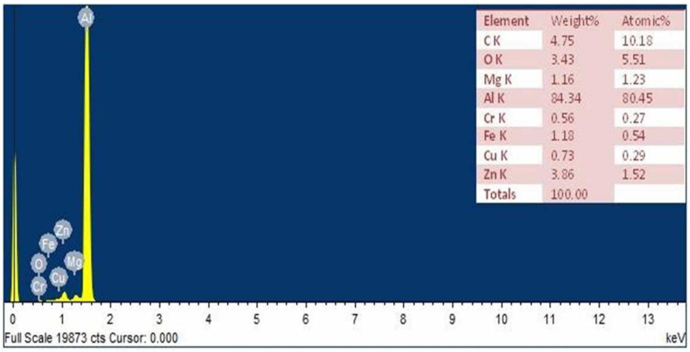


Fig 4 Elemental analysis of Al-7075 with 15% wt Al_2O_3

Polished sample was analyzed in scanning electron microscope. From Fig 3it is observed that reinforcement distribution is uniform but at some places in particles was agglomerated in small quantity. From Fig 3 we can observe that cracks formed may be due brittle nature of the reaction product formed. From elemental analysis as shown in Fig 4, it was traced Al, Mg, O, Fe, C in composition. Presence of oxygen may be due to addition of Al_2O_3 and due to oxide layer formation on prepared cast composite. From elemental analysis it was observed that chemical composition of Aluminium in prepared cast composite was reduced to 84.34% due to addition of Al_2O_3 reinforcement. From study done by K.M. Shorowordi et.al., presence of voids at reinforcement/matrix interface may be due to weak bonding between aluminium and alumina.

XRD result of Al-7075 alloy reinforced with Al_2O_3 is shown in fig 5. From fig 5 it is confirmed that presence of Al matrix and Al_2O_3 reinforcement in prepared specimen. Interfacial reaction between Al matrix and Al_2O_3 reinforcement is needed because this interfacial reaction permits efficient transfer of load from aluminium matrix to Al_2O_3 reinforcement. Presences of voids reveal that it may due to formation of strong inter-metallic brittle phases such as $CuAl_2$ between matrix and reinforcement. From study done by Belete Sirahbizu Yigezu et. al., author reported that formation of these brittle inter-metallic phases reduce bonding strength between aluminium and alumina which results in lower strength consequently reducing load transfer. Presence of brittle inter-metallic phases will also raise local stress in microstructure and form particle cracking which results in lower mechanical properties. It was observed from Fig 5, main peaks are of Al matrix and Al_2O_3 reinforcement which indicates uniform distribution of reinforcement in matrix.

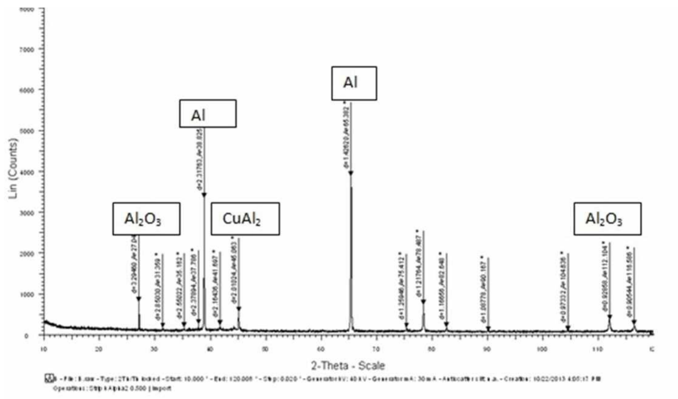
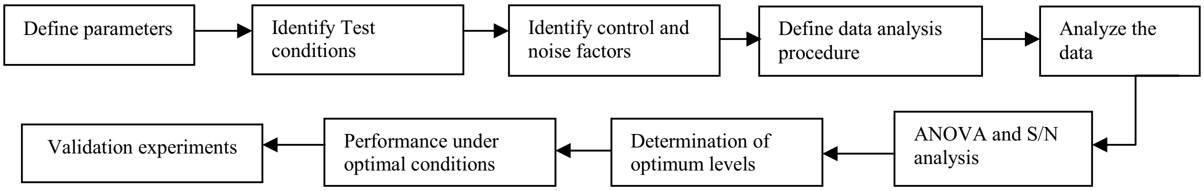


Fig 5 XRD image of Al-7075 with 15% wt Al_2O_3

5. Machinability study

5.1. Taguchi method-Design of experiments

Designs of experiments (DOE) are considered as a useful method for determining optimal cutting parameters from the experimental observations. In this experimental study, orthogonal array (OA) has been used to find the effect of three process parameters (cutting speed, feed and cutting depth) on surface roughness parameters and tool wear of machining of 7075 Al alloy Al_2O_3 composites.



5.2. Process parameters based on L9 orthogonal array

Table 3 Process parameters used at various levels

Process parameter	Unit	Level 1	Level 2	Level 3
Cutting Speed (A)	m/min	80	100	120
Feed rate (B)	mm/rev	0.103	0.206	0.296
Depth of cut (C)	Mm	0.3	0.6	0.9

The cutting parameters selected for turning operations are cutting speed, feed rate and cutting depth. From the literature, it is observed that the influence of cutting speed and feed rate are more significant when compared to cutting depth. The experiments are planned using the Taguchi's orthogonal array. The machining tests were conducted according to a 3-level and 3-factor L9 orthogonal array. The experiments were conducted at three different cutting speeds (80, 100 and 120 m/min) with three different feed rates (0.103, 0.206and 0.296 mm/rev) and varying cutting depth (0.3, 0.6 and 0.9 mm). The cutting parameters and their levels are indicated in Table 3. The experimental layout for the L9 orthogonal array is shown in Table 4. To obtain optimal cutting performance, the-lower-the-better quality characteristic for surface roughness, cutting force and tool wear must be taken.

5.3. Results and discussion

5.3.1 *S/N ratio analysis*

Table 4 shows the experimental results and signal to noise ratio values of surface roughness parameters, flank wear, and Cutting force. Taguchi Signal to Noise (S/N) ratio is used as a performance index for evaluating various responses. Smaller-the-better quality characteristics are used for the responses of surface roughness, tool wear and cutting force. As the Taguchi experimental design is orthogonal, we can separate out the effect of each and every cutting parameter at different levels. The mean S/N ratio for the feed rate at different levels 1, 2 and 3 can be calculated by finding the average of S/N ratios for the trials. For e.g. in table 4, mean S/N ratio is calculated by finding average of level 1–3, 4–6, and 7–9, respectively and this process is repeated to calculate for depth of cut and cutting speed at different factors according to Taguchi L9 orthogonal array. Similarly this process is carried out for other parameters. The mean S/N ratio for each level of the cutting parameters is summarized and called the S/N response table for surface roughness, flank wear and cutting force (Table 5, 6, 7 and 8).In addition the total mean S/N ratio for the nine experiments is also calculated and listed in Table 5, 6, 7 and 8. The greater is the S/N ratio, the smaller is the variance of surface roughness, flank wear and cutting force parameters around the desired (the-lower-the-better) value.

Table 4 Experimental and Signal to noise ratio results

Trial No.	Cutting Parameters			Experimental results				Single to noise ratio			
	Cutting Speed	Feed rate	Depth of cut	Ra µm	Rt µm	Flank Wear µm	Fz (kN)	Ra dB	Rt dB	Flank Wear dB	Fz dB
1	80	0.103	0.3	0.5976	4.5498	76.41	42.72	4.47179	-13.159	-37.663	-32.6126
2	80	0.206	0.6	1.2632	8.3809	76.94	198	-2.0294	-18.465	-37.723	-45.9333
3	80	0.296	0.9	1.3197	10.849	55.77	182.4	-2.4095	-20.707	-34.928	-45.2205
4	100	0.103	0.6	0.7327	6.4784	74.57	58.01	2.70148	-16.229	-37.4513	-35.2701
5	100	0.206	0.9	1.2461	9.4927	69.96	130.9	-1.9110	-19.547	-36.897	-42.3388
6	100	0.296	0.3	1.5539	11.4377	70.44	235.6	-3.8284	-21.166	-36.9564	-47.4435
7	120	0.103	0.9	0.9576	8.6756	72.9	92.29	0.37632	-18.766	-37.2546	-39.3031
8	120	0.206	0.3	1.1887	7.7761	65.36	60.55	-1.5014	-17.815	-36.3062	-35.6423
9	120	0.296	0.6	1.4758	10.2888	61.51	233.5	-3.3805	-20.247	-35.7789	-47.3657

Table 5 Response table for the mean S/N ratio for surface roughness (Ra)

Parameters	Level 1	Level 2	Level 3	Max-Min	Rank
V	0.0109	-1.012	-1.501	1.5127	3
F	2.4985	-1.813	-3.206	5.7046	1
D	-0.286	-0.902	-1.314	1.0286	2

Total Mean S/N ration:-0.8365

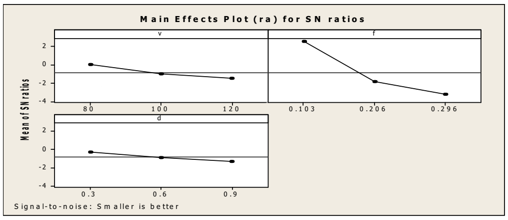


Fig 6. The main effect of plot for S/N ratio for Ra

Table 6 Response table for the mean S/N ratio for surface roughness (Rt)

Parameters	Level 1	Level 2	Level 3	Max-Min	Rank
V	-17.444	-18.981	-18.942	1.4984	3
F	-16.051	-18.609	-20.707	4.6556	1
D	-17.380	-18.314	-19.673	2.2932	2

Total Mean S/N ration:-18.456

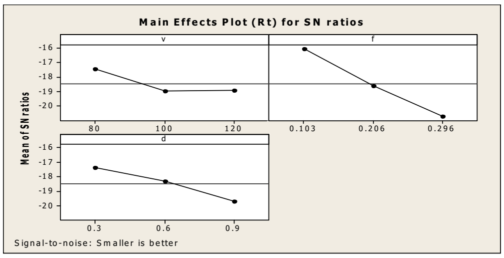


Fig 7. The main effect of plot for S/N ratio for Rt

Therefore, based on the S/N ratio response analysis, the optimal cutting parameters influencing R_a, R_t are the cutting speed, feed rate and cutting depth at level 1 i.e. cutting speed at 80m/min, feed rate at 0.106mm/rev, depth of cut at 0.3mm, optimal cutting parameters influencing F_z are the cutting speed, feed rate and cutting depth at level 3,level1 and level1 i.e. cutting speed at 120 m/min, feed rate at 0.106mm/rev, cutting depth at 0.3mm.Similarly cutting parameters that are influencing flank wear are cutting speed, feed rate and cutting depth at level 3 i.e cutting speed at 120m/min, feed rate at 0.296mm/rev, cutting depth at 0.9mm. By observing table 5,6, 7 and 8 feed has strongest influence on surface roughness parameters, cutting force and flank wear followed by cutting depth and cutting speed. S/N response graph for surface roughness parameters, flank wear and cutting force is shown in Fig 6,7,8 and 9 respectively.

Table 7 Response table for the mean S/N ratio for flank wear

Parameters	Level 1	Level 2	Level 3	Max-Min	Rank
V	-36.771	-37.101	-36.446	0.3302	3
F	-37.456	-36.975	-35.887	1.5686	1
D	-36.975	-36.984	-36.359	0.6246	2

Total Mean S/N ration:-36.773

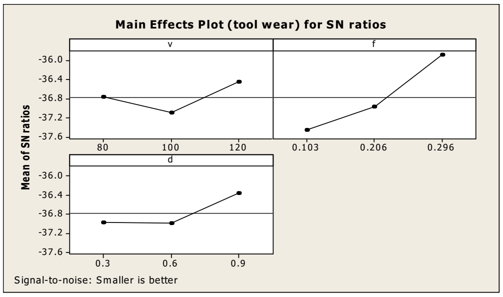


Fig 8. The main effect of plot for S/N ratio for flank wear

Table 8 Response table for the mean S/N ratio for cutting force

Parameters	Level 1	Level 2	Level 3	Max-Min	Rank
V	-41.255	-41.683	-40.770	0.9135	3
F	-35.728	-41.304	-46.676	10.9434	1
D	-38.566	-42.856	-42.287	4.2902	2

Total Mean S/N ration:-41.3476

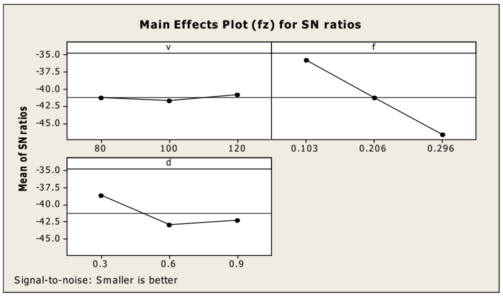


Fig 9. The main effect of plot for S/N ratio for cutting force

5.3.1. ANOVA analysis

The recorded experimental results are investigated using analysis of variance (ANOVA) for determining the parameters affecting the performance measures on the total variance of the results. The table 9 ANOVA has the following components: Source of variation, degrees of freedom (DOF), sum of square (SS), mean square (MS), F-values (F), % contribution. Table 9 shows the results of ANOVA of Ra, Rt, tool wear and Fz respectively. Results of the analysis of variance (Table 9) indicate that speeds, feed and cutting depth are the significant cutting parameters for affecting response characteristics, where feed rate is the most significant factor.From the table 9, it is clearly evident that, feed is most affecting parameters on surface roughness, tool wear and cutting force (84.71%), followed by cutting depth (15.85%) and cutting speed (9.156%).

6. Tool wear analysis

In order to achieve good surface finish and higher life of tool study of flank wear during machining is studied. Tool wear of multi coated carbide insert was observed under optical microscope for all the 9 trials. From table 4, lowest tool wear was observed at trial 3 i.e 55.77 µm, but at same trial coating loss of insert was more i.e 358.5µm (fig 3). For trial 7, edge chipping was observed at the flank face therefore coating loss was found to be maximum i.e. 604.7µm (Fig 12). For trial 2, tool wear is found to be maximum i.e 76.94µm (Fig 10). For trial 8 and 9 the observed tool wear is 65.39µm and 61.51µm. For trial 8 and 9 (Fig 12) it was observed that tool wear as well as coating loss is found to be less at higher feed and speed. Though surface roughness was less at lower feed, tool flank wear was found to be more. In order to achieve lower surface roughness as well as lower tool flank wear it necessary to use optimum combination of cutting parameters. Therefore using higher feed and cutting speed is best possible combination in order to achieve lower tool wear, coating loss and to achieve good surface finish. The tool wear measured at optimal cutting levels is nearly negligible, and therefore CNMG 120408 – FR – TN8135 multi coated carbide insert can be successfully used for machining of Aluminium matrix composites.

Table 9 Results of ANOVA

Source	DF	SS	MS	F	P	P%	SS	MS	F	P	P%
Surface roughness (Ra)							Surface roughness (Rt)				
v	2	4.609	2.304	0.90	0.527	9.156	3.576	1.788	0.8	0.555	5.66
f	2	32.617	16.309	6.36	0.136	64.80	53.441	26.720	11.98	0.077	84.71
DOC	2	7.979	3.990	1.56	0.391	15.85	1.608	0.804	0.36	0.735	2.54
Error	2	5.129	2.564			10.18	4.459	2.230			7.06
Total	8	50.334				100	63.084				100
S = 1.60138 R-Sq = 89.81% R-Sq(adj) = 59.24%							S = 1.49322 R-Sq = 92.93% R-Sq(adj) = 71.72%				
Tool Wear							Cutting Force				
v	2	1.25	0.63	0.03	0.974	0.48	0.6436	0.3218	0.37	0.732	9.13
f	2	179.81	89.90	3.86	0.206	69.09	3.8745	1.9373	2.20	0.312	54.99
DOC	2	32.58	16.29	0.70	0.589	12.51	0.7688	0.3844	0.44	0.696	10.91
Error	2	46.60	23.20			17.90	1.7590	0.8795			24.96
Total	8	260.24				100	7.0458				100
S = 4.82721 R-Sq = 82.09% R-Sq(adj) = 28.37%							S = 0.937812 R-Sq = 75.04% R-Sq(adj) = 0.14%				

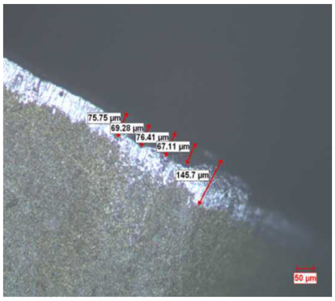
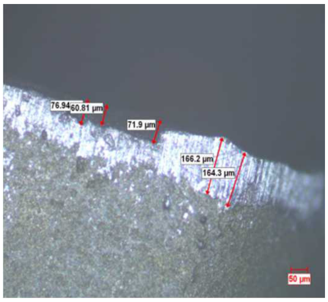
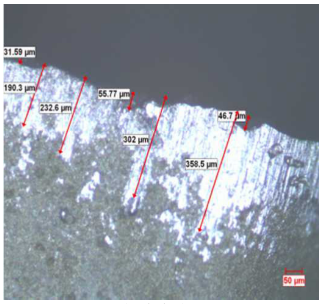


Fig 10 (Trial1)



(Trial 2)



(Trial 3)

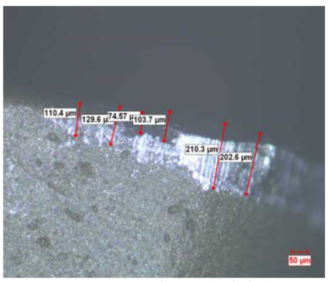
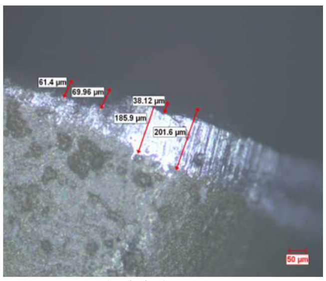


Fig 11 (Trial 4)



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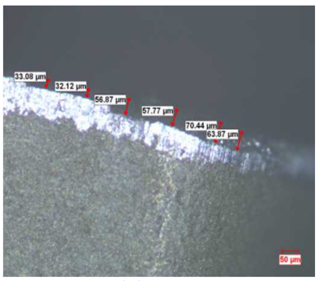

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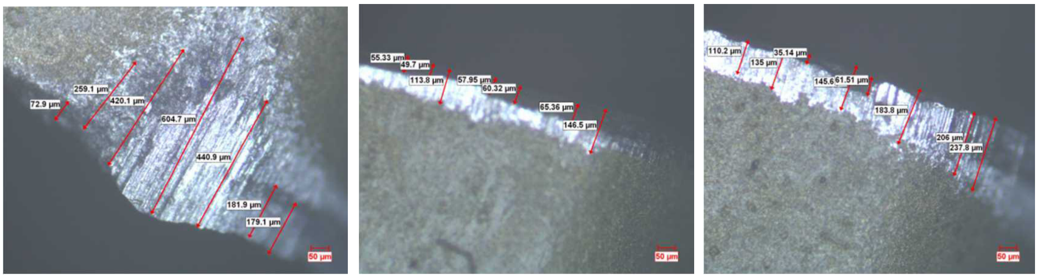

Fig 12 (Trial 7) (Trial 8) (Trial 9)

7. Conclusion

Taguchi L9 orthogonal array with ANOVA analysis was used to optimize machining parameters of Al7075-Al_2O_3 (15%) MMC and performance characteristics are reported in this paper.

- From Anova analysis, to obtain good surface finish optimal combination of cutting parameters is v1f1d1 i.e v1=60m/min, f1=0.103mm/rev, d1=0.3mm, to reduce tool flank wear optimal combination of cutting parameters is v3f3d3 i.e. v3=120m/min, f3=0.296mm/rev, d3=0.9mm and optimal combination of cutting parameters for cutting force is v3f1d1 i.e. v3=120m/min, f1=0.103mm/rev, d1=0.3mm
- Feed rate shows more influence on surface roughness parameters R_a and R_t, tool flank wear and cutting force. Next to feed rate is cutting depth and cutting speed.
- Maximum flank wear observed during experimental study is 76.94µm which is very less. Better performance of the tool may be due to coated carbide insert.
- In order to achieve good surface finish and reduce tool flank wear, using higher cutting speed and feed is best possible combination i.e. v=120m/min and f=0.296mm/rev.

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