Effect of Machining Factors and Nose Radius on Surface Roughness of Machining Inconel 718 In End Milling

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Abstract:

One of the nickel based super alloyInconel 718 is mostly used in rocket engines, high temperature fasteners, rings and aircraft gas turbine because of their high thermal strength, high oxidation resistance, high temperature fatigue properties and high corrosion resistance. In this study, the experimental specimen models for the parameter of surface roughness has been enhanced in respect offeed rate, depth of cut, corner radius & cutting speed by using L_{27} orthogonal array of Taguchi method. We have used two uncoated solid carbide end mill to performed end milling operation under wet conditions. Two end mill cutters are used with 0.4mm and 0.8mm nose radii and rest all properties of both cutting tool (tool diameter, shank diameter, overall length, no. of flute and tool material) are same. Using the above mentioned technique, that is, L_{27} orthogonal array of Taguchi method , a total of 27 runs have been done by one tool (0.4 mm nose radius) and other 27 by another tool (0.8 mm nose radius). Furthermore, the ANOVA is also used to find the most important significant factor. It is evident from the results that feed rate is most significant factor as compared to other two parameters. Depth of cut has least significant effect on surface roughness. It is also proved that end mill with 0.8 mm nose radius has more roughness as compared to the other end mill cutter used.

Keywords End milling, Inconel 718, nose radius,orthogonal array, surface roughness, Taguchi method

1 Introduction:

Inconel 718 is a hard material (Hardness: 40-47 HRC). Due to hardness, its machining is troublesome. End milling process propelled a fruitful machining procedures for the machining of Inconel 718 components. It contains 5% niobium that allows great quality without sacrifice of malleability. Nickel is the primary component of Inconel 718, which gives higher protection from corrosion and excellent thermal strength due to which it is broadly utilized in reciprocating engine parts, air ships engines, steam power plants, high temperature latches, springs, hot work passes.

The machinability of Inconel 718 is poor because of following reasons:

- Abrasiveness
- Tough, sticky and property to weld and create build-up edge
- High cutting temperature

Number of scientists and researchers had done work in end milling on different material, for example, Al and their composites, hardened steel, fibre reinforced plastic (FRP), mild steel and Ti alloys. In our research, the reason behind choosing Inconel 718 is due to the fact that for this specific material most research is done on wear of tool, mechanism of tool wear and tool life and less research is done on surface roughness. An exceptionally less work is done on Inconel 718 when contrasted with all materials. Nobody has utilized nose radius parameter to study its effect on surface roughness in end milling, especially for Inconel 718. Because of wearing of tools different losses, for example, maximum surface roughness and flawed work-piece incurred. End milling is most generally utilized material removal processes in industry among all machining activities.

2 Literature review

M. S. J. Hashmi*et al.*, [1] contemplated that the surface roughness value is a function of two parameters: Feed rate and cutting speed pace. He used the response surface methodology. He utilized tungsten carbide insert (10mm diameter) under dry condition. He found that feed rate is directly proportional to roughness while cutting speed is inversely proportional to roughness. Dr. R. Ramanujam*et al.*, [2] studied theeffect of feed rate, depth of cut and cutting velocitysurface roughness and material removal rate (MRR). A unique technique, Taguchi based grey relational techniques,was used to enhance and analyse outcomes. He has used uncoated tungsten carbide end mill cutter of 10 mm dia to perform end milling process on Inconel 718. He found that cutting rate has noteworthy impact and it is proportional to the surface roughness. When MRR is increased, the surface roughness is likewise increased. J. B. Jordon *etal*., [3] studied that the fatigue life and the surface roughness of Inconel 718 are considered to be influenced by tool wear. These are controlled by utilizing four machining factors, that is, feed rate, cutting speed, axial depth of cut and radial depth of cut. He has passed on that PVD (pressurized vapour deposition) coated carbide insert to perform end milling operation. He found that less surface roughness is acquired by higher tool wear. Fatigue life of Inconel 718 isn't influenced by tool wear in a particular range (tool wear up to VB 0.2 mm).HasanOktem*et al*., [4] studied that the CBN end milling cutter is utilized to perform end milling process. He has taken three parameters to find the optimum value of the surface roughness which were: depth of cut, cutting velocity & feed rate. Genetic algorithm & coupling neural network is used to analyse the outcome. He found that the residual stresses limits at higher cutting speed. Furthermore, he found that the minimum surface roughness happened at higher cutting speed and a particular range of depth of cut and feed rate.FarshidJafarian*et al*., [5] studied that the surface roughness and residual stress are enhanced by process parameters cutting velocity, depth of cut and feed rate by utilizing a cubic boron nitride tool. He utilized new and standard strategy ANN (artificial neural network) to investigate result. Cutting speed is inversely proportional to both residual stresses and surface roughness. Cutting speed is the fundamental critical factor which has impact on surface roughness.J.A. Ghani*et al*., [6]studied that the impact of machining factors: cutting speed, depth of cut and feed rate during down milling and up milling in end milling for the minimization of wear rate of tool. It was concluded that tool flank wear in the up milling operation was greatest when contrasted with down milling process. Cutting temperature is affected by cutting speed, material volume is impacted by depth of cut and feed rate. Darwish*et al.*, [7] depicted the impact of tool material and machining factors on the response, that is, surface roughness. They revealed that ceramic tool inserts have more effect on surface roughness than cubic boron nitride (CBN) tool inserts. The surface roughness is least at lower feed rate and higher cutting speed.Sadat *et al.,* [8] reported thatthe surface residual stressis directly proportional to cutting speed. At cutting speed of 10, 410, and 810 m/min the surface residual stress was observed. They provided the result that shows the impact of machining factors on residual stresses. Schlauer*et al.,* [9] investigated in his research the optimization of residual stress in end milling action. He observed that at cutting speed of 410 and 810 m/min the residual stress is tensile in nature and at cutting speed of 10 m/min cutting speed the residual stress is compressive.Only three factors (feed, depth of cut & cutting speed) were taken into account. Zhou *et al.,* [10] provided inference from his work that surface roughness is decreased with rise in depth of cut. With increasing depth of cut, there has been increase in residual stresses. Roundinsertwere found to be more better than square insert because they produced a favourite surface roughness and residual stress. Coated insert produces minimum roughness as compared to un-coated insert. Devillez*et al.*, [11]found that the wet machining results in a better surface roughness than dry machining, due to usage of cutting fluid and lubricants, flushing away chips from work-piece. Rishuguptaet *al.*, [12] investigated the effects of different insert nose radius on surface roughness during turning of one of grade of Aluminium, Al 6061. They found that at higher nose radius the surface roughness is maximum and MRR decreases with increase in nose radius. They had taken three tool inserts with nose radius of 0.4 mm, 0.8 mm and 0.12 mm. Maximum surface roughness was found at 0.12 mm nose radius.

3 Experimental Setup

3.1 Vertical Machining Center

In the research we had used the Vertical Milling Center TATA TAL VERTIMACH V-350.Following are the few specifications of VMC:

X axis	45 cm
Y axis	35 cm
Z axis	35 cm
Size of table	60 cm*40 cm

The other specification of TATA TAL VMC machine is as follows:

Distance between spindle face to top of table	200 to 550 mm
T slots	100 mm pitch and 4 slots
Table size	600 mm*400 mm
Max. load on top of table	250 kilograms
Power	3-phase 50 Hz
Supply of compressed air	5 bar
Dimensions of machine	3200D*1850W*2400H

Fig. 1 Tata Tal Vertimach V-350 Vertical Machining Centre

3.2 Work-piece material

In this research, Inconel 718 is used in form of rod. The specimen dimension is 25 mm diameter and 20 mm length. The thermal properties, mechanical properties, chemical composition and specification of material are shown below in tables. Nickel is the main constituent of Inconel 718, which imparts higher resistance to corrosion and better thermal strength. Due to high resistance to corrosion and better thermal strength, it is generally used in reciprocating engine's parts, aircrafts and ship engines, steam power plants, high temperature fasteners, latches, springs, hot work dies,equipmentsand tools.

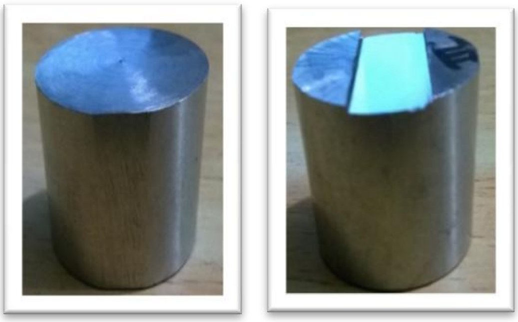

Fig. 2 Work piece before machining and after machining

Table 1. Mechanical properties of Inconel 718

Properties	Hardness (HRC)	Elongation (%)	Melting Temperature (^oC)	Yield strength (MPa)	Tensile strength (MPa)	Density (g/cm^3)
Values	40-47	12-16	1300-1400	1050- 1150	1400	8.19

Table 2.Composition of Inconel 718

Elements	Ni	Cr	Nb	Fe	Al	Ti	Mo
Percentage	68.00	20.99	5.07	2.79	0.59	1.25	3.59

3.3 Cutting tool

In this work, the two uncoated solid carbide tool (Ultra cut P8B8110) with nose radius of 0.4 & 0.8 mm are used. All other properties of both tools, that is, with nose radius of 0.4mm and 0.8 mm are same. The diameter of both tools is 10 mm. Its hardness is 90 HRC higher than the hardness of Inconel 718. The tool has four flute so that there will be reduced chattering. Specification and dimensions of cutting tools used in end milling is shown in table 3.

Table 3. Cutting tool details

Items	Value
No. of tools used	2
Tool diameter	10 mm
Rake angle	9^o

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Helix angle	30^o
No. of flute	4
Density	12.60 g/cm^3

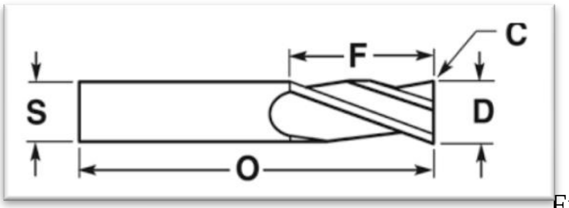

Fig. 3 Schematic sketch of tool

Where-
S- Shank diameter, D- Diameter of cutter, O- Overall length, F- Flute length and C- Corner radius or nose radius.

Tool name	Dimensions	S	D	O	F	C
Tool A	Value (mm)	10	10	100	38	0.4
Tool B	Value (mm)	10	10	100	38	0.8

Table 4. Parameters of the solid carbide end mill cutter.

3.4 Surface roughness measurement

Output response in this paper is surface roughness. For the measurement of it we have usedMitutoyoSurftest SJ-201P which is an electronic based instrument, whose function is to detect the non-uniformity of miscellaneous machine elements and find the surface roughness based on standards of roughness and show the results up to two place of decimal integer. The stylus of the roughness tester is in vertical direction only. The displacement throughout the mark is controlled and digitally displayed on the LCD of it.

Fig. 4MItutoyosurftest SJ-201P

Specification of Surftest SJ-201P

Detector unit

Method of detecting	Differential inductance
Stylus tip material	Diamond
Skid force	400mN or less
Radius of curvature of skid	40 mm
Radius of stylus tip	5µm for 4mN type and 2µm for 0.75mN type SJ-201
Measuring force	4mN for 4mN type and 0.75 for 0.75mN type SJ-201
Measurement range	12.5 mm in x-axis and (350µm) in z-axis
Conical taper angle	90^o
Measuring speed	0.25, 0.50 mm/second

Properties (Measuring and Resolution) of SJ-201P

Measuring range	**Resolution of SJ-201P**
Auto	0.01 µm-0 .04 µm depends on the measuring range
14000 µinch (350 µm)	12.8 µinch (0.4 µm)
4000 µinch (100 µm)	3.2 µinch (0.1 µm)
2000 µinch (50 µm)	1.6 µinch (0.05 µm)
400 µinch (10 µm)	0.4 µinch (0.01 µm)

3.5 Taguchi based orthogonal array experimental design

It is obvious that for designing and selecting of orthogonal Array of Taguchi method, following prerequisites must be required:

- Parameters of machining and their interactions should be selected and evaluated.
- Level of each parameters should be selected.

The total degree of freedom depends on total number of trials and levels of parameter. It increases with the increase in number of levels of a parameter because the DOF of a parameter is calculated by the formula: (no. of levels-1). Hence, the total DOF is depends directly on the levels of a parameter, that is, if levels of a parameter decrease the total DOF also increases and vice versa. With increasing DOF the total number of trials increased automatically in an experiment. If each parameters have two level, the the size of an experiment is reduced.For higher order relationships and curved relationships, three levels or more than three levels of each parameter should be selected. Number of level of a factor also depends on design of orthogonal array. For higher order equations, minimum three levels of each factor should be chosen. The standard 2-level and 3-level orthogonal arrays are given below:

a) 2-level arrays: L_4, L_8, L_{12}, L_{16}, L_{32}
b) b) 3-level arrays: L_9, L_{18}, L_{27}

In this work, three factors at three levels each except nose radius have been used. Nose radius can also be taken as input process variables but here it is constant. In our work, we use two solid carbide end mill of 0.8 mm and 0.4 mm corner radius. In this research, the three factors are: cutting speed, depth of cut and feed rate. L_{27} orthogonal array of Taguchi method is used. This method is picked because of its ability to examine the interaction between factors. A total of 27 runs are needed to use L_{27} orthogonal array of Taguchi method. 27 experiments is done by one tool on Inconel work-pieces and other 27 experiments has been done by another tool.

Table 5. Process parameters with their levels

Process parameters	symbol	Unit	Level		
			Level 1	Level 2	Level 3
Cutting speed	v	m/min	30	60	90
Depth of cut	d	Mm	0.5	0.7	0.9
Feed rate	f	mm/revolution	0.06	0.09	0.12

4 Experimental Results

4.1 Conducting phase

A Taguchi method or an orthogonal array technique is planning the hypothetical procedure for employing non-identical set of design similar to 2-level design to 5-level design & mixed level design. In this work, we used three factors at three level each apart from nose radius. The software used, MINITAB, gives the dynamic & static responses on the scale of static response demonstration. The main features of amusement keep a highly secured level and the purpose of Taguchi & robust design are used to determine an optimum conjunction of process parameters covering those attain robustness to differentiate with noise factors. It helps to evaluates response tables for the experiments and creates interaction plots & main effects.

In this work, I have used MINITAB 17 to design L27 orthogonal array of Taguchi method and to conclude and analyse the result. The interaction plots between two factors and find out the optimal values of factors are also drawn to conclude results.

The S/N ratios for the surface roughness have been found by the formula (1). The S/N ratios criteria ‘smaller is better characteristic’ have been used to find and analyse the result and also for checking the quality of experiment.

$$\frac{S}{N} = -10 * \log[\frac{1}{n}\sum_{i=1}^{n} yi^2]......(1)$$

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Where $y_i$denotes the experimentally noted value of the i^{th} run &number of iterations is denoted byn

Fig. 5 Experimental setup

Table 6. Response table for surface roughness and S/N ratios

Run	V (cutting speed) in m/min	F (feed rate) in mm/rev	D (depth of cut) in mm	R_a (SR) in µm for tool A	R_a (SR) in µm for tool B	S/N ratios for R_a for tool A	S/N ratios for R_a for tool B
1	30	0.06	0.5	0.23	0.16	12.7654	15.9176
2	30	0.06	0.7	0.31	0.13	10.1728	17.7211
2	30	0.06	0.9	0.18	0.15	14.8945	16.4782
4	30	0.09	0.5	0.43	0.27	7.3306	11.3727
5	30	0.09	0.7	0.39	0.30	8.1787	10.4576
6	30	0.09	0.9	0.48	0.17	6.3752	15.3910
7	30	0.12	0.5	0.37	0.47	8.6360	6.5580
8	30	0.12	0.7	0.55	0.39	5.1927	8.1787
9	30	0.12	0.9	0.52	0.45	5.6799	6.9357
10	60	0.06	0.5	0.38	0.28	8.4043	11.0568
11	60	0.06	0.7	0.29	0.23	10.7520	12.7654
12	60	0.06	0.9	0.40	0.22	7.9588	13.1515
13	60	0.09	0.5	0.52	0.42	5.6799	7.5350
14	60	0.09	0.7	0.49	0.45	6.1961	6.9357
15	60	0.09	0.9	0.50	0.39	6.0206	8.1787
16	60	0.12	0.5	0.76	0.61	2.0206	4.2934
17	60	0.12	0.7	0.65	0.60	2.3837	4.4370
18	60	0.12	0.9	0.70	0.55	3.7417	5.1927
19	90	0.06	0.5	0.44	0.34	3.09880	9.3704
20	90	0.06	0.7	0.39	0.29	7.1309	10.7520
21	90	0.06	0.9	0.37	0.54	8.1787	5.3521
22	90	0.09	0.5	0.60	0.52	8.6360	5.6799
23	90	0.09	0.7	0.62	0.46	4.4370	6.7448
24	90	0.09	0.9	0.55	0.81	4.1522	1.8303
25	90	0.12	0.5	0.89	0.72	5.1927	2.8534
26	90	0.12	0.7	0.92	0.70	0.7242	3.0980
27	90	0.12	0.9	0.76	0.64	2.3837	3.8764

4.2 Analysis phase

The analysis work in our research of variance table for tool A & B is also designed by using Minitab 17. The analysis of variances (ANOVA) table for tool A & B for the machining parameters is shown in Table 7& 8, which indicates that depth of cut has no significant or minimum effect on surface roughness whereas feed rate & cutting speed have significant influence on response, that is, surface roughness. Onlyinteraction of cutting feed rate*cutting (f*v), has significant effect on response. Other parameters and their interaction are found to be not significant .The delta values (for SN ratios) for tool A for cutting speed, depth of cut and feed rate are, 4.131, 0.328 and 6.205respectively, as described in Table 7. The delta values for tool B for depth of cut ,feed rate and cutting speed & are 0.717 , 7.460 and 6.606 respectively. The results indicated thatcriteria of surface roughness are “smaller is better”. Therefore, from this table it is concluded that feed rate has more influence on surface roughness than two other parameters.

Table 7. ANOVA table for SN ratios for SR for tool A

Terms	DOF	Adj. SS	Adj. MS	F	P
v	2	79.835	39.9175	20.78	0.001
d	2	0.529	0.2647	0.12	0.873
f	2	177.318	88.6588	46.15	0.000
v*d	4	10.001	2.5003	1.30	0.347
f*d	4	2.646	0.6614	0.34	0.841
v*f	4	6.484	1.6210	0.84	0.535
Error	8	15.369	1.9211		
Total	26	292.182			

Significance level (α=0.05)

Table 8. ANOVA table for SN ratios for SR for tool B

Terms	DF	Adj. SS	Adj. MS	F	P
v	2	198.810	99.570	36.52	0.000
d	2	2.475	1.233	0.45	0.650
f	2	252.202	126.101	46.33	0.000
v*d	4	20.001	5.003	1.84	0.215
f*d	4	6.060	1.515	0.56	0.701
v*f	4	16.700	4.175	1.53	0.281
Error	8	21.773	2.722		
Total	26	518.032			

Significance level (α=0.05)

The feed rate (f) is directly proportional to surface roughness in the range of 0.06 to 0.09 mm/rev. Also, it is also evident that the other factors do not effect much as compared to feed rate and closer results were shown by Lohitaksha M. Mayer [2]. But, if the feed rate is increased from 0.09 to 0.12 surface roughness again increases moderately.

It has also been found that depth of cut has approximately no significant effect on surface roughness. The interaction plot of surface roughness for tool A & tool B is shown in fig 10 & fig. 11, where each plot shows the interaction between two factors, that is, feed rate & cutting speed, depth of cut & feed rate and cutting speed & depth of cut. This means that the influence of one factor is dependent on another factor. This is also proved by the ANOVA table shown in Tables 7 & 8.

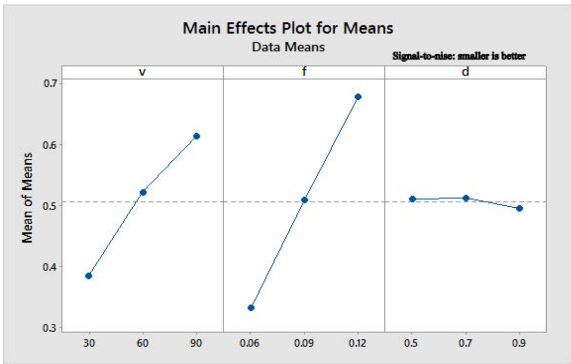

Fig. 6Graph showing means for tool A

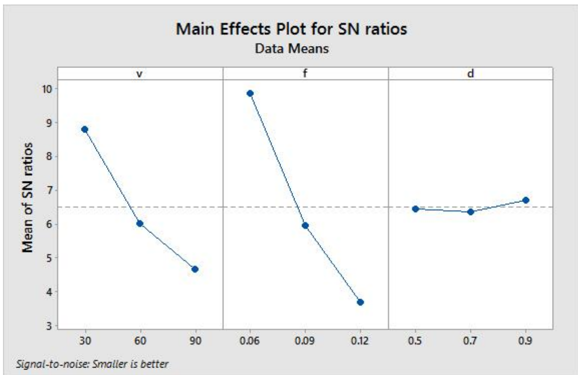

Fig. 7Graph showing S/N ratios for tool A

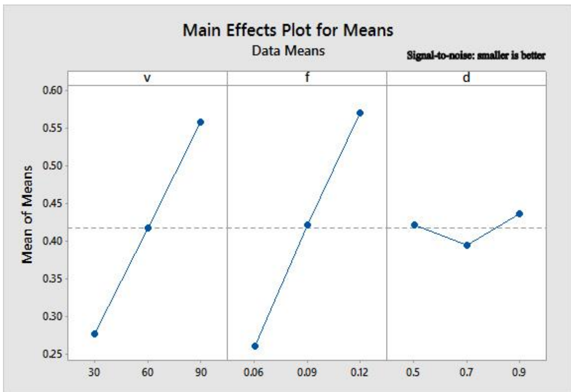

Fig. 8 Graph showing means for tool B

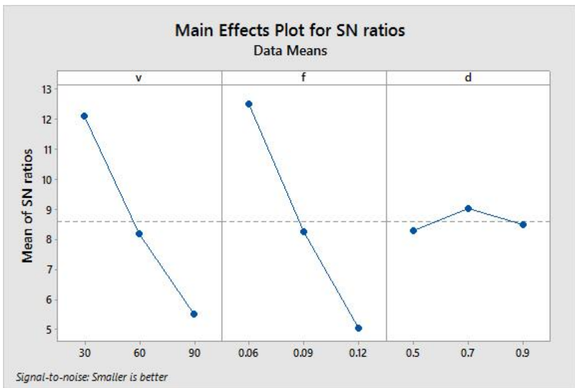

Fig. 9Graph showing S/N ratios for tool B

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Table 9. Response for surface roughness: smaller is better for tool A

Level	v	F	d
1	0.3844	0.3322	0.5111
2	0.5211	0.5089	0.5122
3	0.6133	0.6778	0.4956
Delta	0.2289	0.3456	0.0167
Rank	2	1	3

Table 10. Response for SN Ratios: smaller is better for tool A

Level	v	F	d
1	8.803	9.877	6.442
2	6.026	5.951	6.363
3	4.672	3.672	6.693
Delta	4.131	6.205	0.328
Rank	2	1	3

Table 11. Response for surface roughness: smaller is better for tool B

Level	v	F	d
1	0.2767	0.2600	0.4211
2	0.4167	0.4211	0.3944
3	0.5578	0.5700	0.4356
Delta	0.2811	0.3100	0.0411
Rank	2	1	3

Table 12. Response for SN Ratios: smaller is better for tool B

Level	v	F	d
1	12.112	12.507	8.293
2	8.172	8.236	9.010
3	5.506	5.047	8.487
Delta	6.606	7.460	0.717
Rank	2	1	3

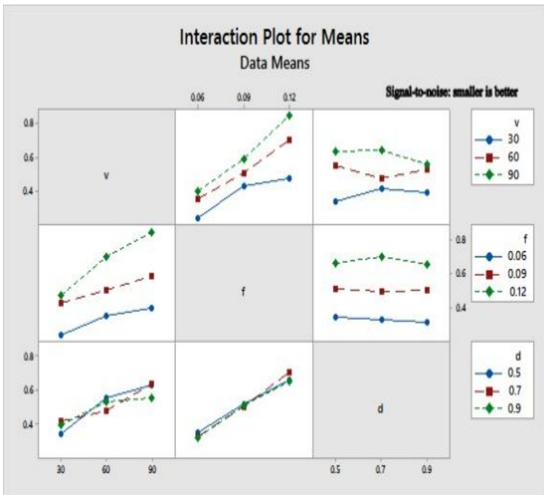

Fig. 10 Interaction plot for means of SR for tool A

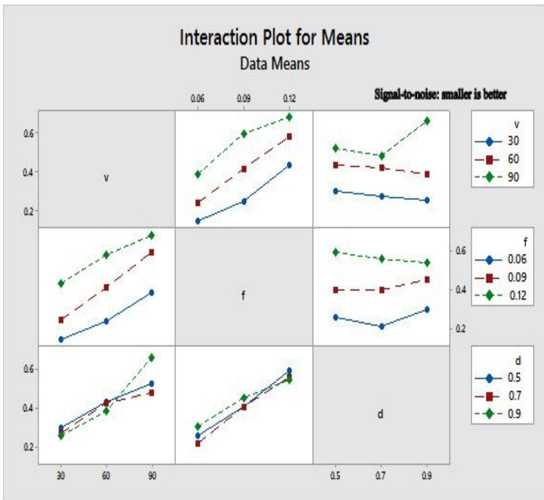

Fig. 11 Interaction plot for means of SR for tool A

4.3Effect of nose radius on surface roughness

Fig. 12 shows themain impact or effect plot for nose radius on surface roughness with respect to cutting speed. Results conclude that tool with higher nose radius has higher roughness than the tool with lower nose radius or conversely it can be stated that surface roughness is directly proportional to nose radius.

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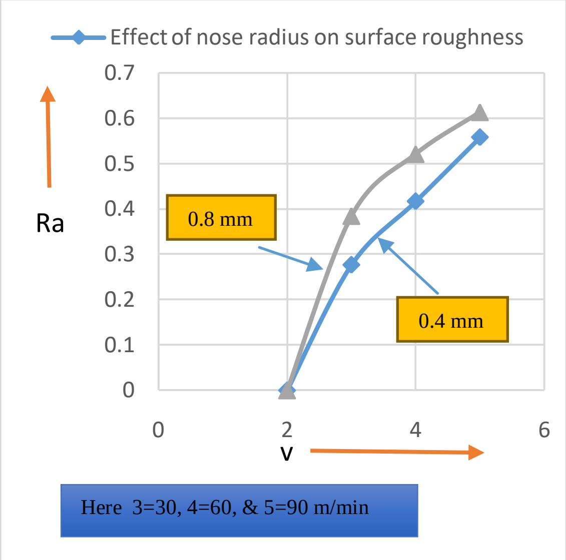

Fig. 12 Plot for main effect of nose radius on SR

4.4 Computation of optimal surface roughness

4.4.1 for cutting tool A

The optimum surface roughness is found at level E3, F3 and G2 respectively which is concluded from the graph, henceattribute smaller is better applies.
Where-
E3=Surface roughness for level 3 (0.6133 µm) cutting speed.
F3 =Surface roughness for level 3 (0.6778 µm) feed rate.
G3 = Surface roughness for level 3 (0.5122 µm)depth of cut.
U=Average result for 27 runs of surface roughness

$$U = \frac{\sum_{i=1}^{27} Ra}{27} = 0.50037\ \mu m$$

SR_{opt}=U + (E3-U) + (F3-U) + (G2-U) = 0.80256 µm

4.4.2 for cutting tool B

The optimum surface roughness is found at level H3, I3 and J3 respectively which is concluded from the graph, hence smaller is better attribute applies. Where-
H3=Surface roughness for level 3 (0.5578µm) cutting speed.
I3= Surface roughness for level 3 (0.5700 µm) feed rate.
J3 = Surface roughness for level 3 (0.4356 µm)depth of cut.
V=Average result for 27 runs of surface roughness= 0.417037 µm

SR_{opt}= V + (H3-V) + (I3-V) + (J3-V) = 0.729326 µm

5 Conclusion

- Surface roughness is directly proportional to the cutting speed and feed rate. In this research, feed rate has been found to be the most prominent effect on surface roughness. The second most significant factor which affects the surface roughness is cutting speed.
- The most significant parameters along with their interactions are feed rate, cutting speed in context of predicting surface roughness in end milling operation.

- It has been also concluded that the low surface roughness (0.18 micron) for tool A is achieved at cutting speed of 30 m/min, feed rate of 0.06 mm/rev and 0.9 mm depth of cut whereas for tool B the lowest value of roughness is achieved at cutting speed of 30 m/min, at feed rate of 6 mm/rev and 0.7 mm of depth of cut.
- Optimal value of surface roughness for tool A is 0.80256 µm and optimal value of surface roughness for tool B is 0.729326.
- Larger nose radius, that is, 0.8 mm nose radius has higher roughness than 0.4 mm nose radius.

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