Some Experimental Investigations on Turning of Nimonic 80A using Sialon Ceramic Inserts

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Abstract: The main objective of this study is to analyze the effect of cutting speed, feed, and depth of cut on response variables such as surface roughness, tool wear, and material removal rate (MRR). Turning of NIMONIC 80A was carried out at three levels of cutting speed, feed, and depth of cut. Analysis of variance (ANOVA) is used to find which factor is significant for the output parameters. From experimental analysis it is observed that mainly major factor responsible for flank wear is cutting speed,for surface roughness is feed and to get maximum material removal rate is depth of cut. It is found from experimental results that the ceramic inserts gives better surface finish compared to carbide inserts.

Keywords:***ANOVA; MRR; NIMONIC 80A; Surface roughness; Taguchi method***

1 Introduction

In rapid growing industries scenario, automation and optimization of the manufacturing process improves productivity and quality of products. Superalloys are extensively used in aerospaces due to its superior properties. This superior properties are in terms of it's good oxidation and corrosion resistance at higher temperature. The tensile and creep rupture point is large at elevated temperature (815°C). NIMONIC 80A is a nickel based super alloy which contains mainly nickel and chromium. It is strengthened by the addition of titanium and aluminium. It is widely used in gas turbine engines, automobile exhaust valves, die casting inserts and cores, and nuclear boiler tube parts. Hence an attempt, of studying these characteristics is to increase the product rate in minimum time and cost.

To overcome the above difficulties while machining of nickel based super alloys the selection of machining parameters is an important task. Many researchers carried out the machining of NIMONIC alloys. X. D. Guo et al. [2] and P. Subhash et al. [5] found that the depth of cut and feed rate has more influence on surface topography and residual stress. J. L. Li et al. [3] observed that the periodic fracture and ASB (adiabatic shear band) were simulated at different cutting speeds for determining the root cause of saw tooth chip formation during machining of Nimonic C 263 with uncoated carbide inserts. Danish khan et al. [4] investigated that the feed rate was most important factor to determine surface roughness.

M.V.R.D. Prasad et al. [6] found that feed rate is the most significant factor affecting the surface roughness with thehelp of ANN approach. Bin Zou et al. [7] studied the surface damages caused by turning NiCr20TiAl nickel based super alloy for different cutting speed, feed rate and depth of cut. It was found that, at cutting speed of 100 m/min, feed rate of 0.15 mm/rev and depth of cut of 1 mm, good surface finish is obtained with less work-hardening layer, also lower cutting forces are generated.

2 Experimental work

An experimental setup consists of a brief description of the materials and equipments used for machining of Nimonic 80A using Sialon ceramic inserts. Also, the design procedure used for experiments is outlined.

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2.1 Equipments used

The machine used for the turning of Nimonic 80A is ACE CNC Lathe Jobber XL (See Fig. 3). The instrument used for measuring the surface roughness and flank wear are SJ 301stylus type Surface roughness tester (see Fig. 1) and Nikon microscope (see Fig. 2) respectively.

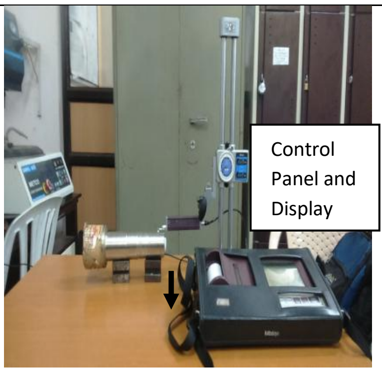

Fig. 1. Photographic view of surface roughness tester

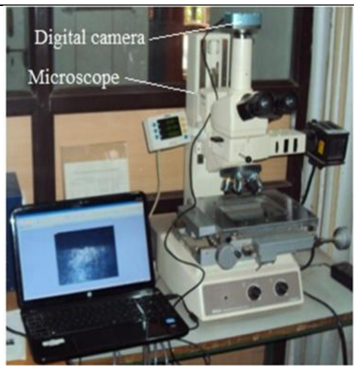

Fig. 2. Nikon Microscope

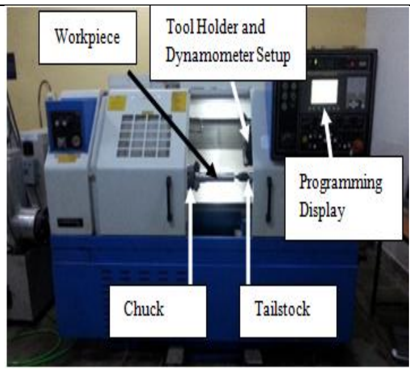

Fig. 3. Experimental set up

2.2 *Work Material and Tool used for Experimentation*

The nickel-based superalloy Nimonic 80A (Length 250mm and Diameter 65 mm)has been taken for turning with Sialon ceramic inserts. 9 experimental runs have taken. Each pass is taken of 30 mm length of Nimonic 80A rod. Specification of material and tool is given in Table 1. Selection of input parameters and their levels is shown in Table 2.

Table 1 Material properties

Work material	Nimonic 80A
Chemical composition	(Ni 73.74%,Cr 18.88%,Ti 1.98, Al 1.33%, Co 1.34%, Fe 1.99%, Si 0.68%, Cu 0.11%, C 0.045%, Mn 0.77%, B 0.041%, Zn 0.09%)
Hardness (HV)	300
Yield Strength (MPa)	780
UTS (MPa)	1250
Density (kg/m3)	8165
Specific heat (J/kgk)	212
Ceramic insert	CNGA 120408 SN800
Tool holder	PCLNL 2525 M12

Table 2 Selection of input parameters and their levels

Process parameters	Cutting speed, Vc (m/min)	Feed, f (mm/rev)	Depth of cut, d (mm)
Level 1	400	0.10	0.25
Level 2	450	0.15	0.50
Level 3	500	0.20	0.75

3 Results and Discussion

L_9 orthogonal array was used to find out the effect of cutting speed, feed, and depth of cut on surface roughness, material removal rate (MRR) and flank wear. Table 3, illustrates the experimental results for surface roughness, flank wear, and MRR.

Table 3 Experimental results for R_a, MRR and flank wear

Expt. no.	Factors			Performance measures		
	Cutting speed (m/min)	Feed (mm/rev)	Depth of cut (mm)	Surface roughness Ra (µm)	MRR (mm^3/min)	Flank wear Vb (µm)
1	400	0.10	0.25	0.43	9963.3	109.54
2	400	0.15	0.50	0.49	29783.6	114.52
3	400	0.20	0.75	1.03	59349.7	121.01
4	450	0.10	0.50	0.31	22337.7	122.93
5	450	0.15	0.75	0.60	50076.3	130.38
6	450	0.20	0.25	0.85	22417.4	125.55
7	500	0.10	0.75	0.42	37093.6	170.17
8	500	0.15	0.25	0.48	18681.2	145.3
9	500	0.20	0.50	0.52	49639.3	150.94

3.1 *Analysis of Surface roughness*

ANOVA is used to find out which factor is significant for the output parameters. From the ANOVA Table 4 it is found that the major contributing parameters for roughness in turning operation of NIMONIC 80A, is feed which has slightly more important than other cutting parameters. The percentage contribution of feed is 63.72 and for depth of cut and cutting speed contributes 21.38 and 11.74 respectively towards the surface roughness.

Table 4 Results of the analysis of variance for surface roughness

Symbol	Cutting parameter	Degrees of freedom	Sum of squares	Mean Square	F	Contribution (%)	P
A	Cutting speed	2	0.04895	0.024475	3.71	11.74	0.212
B	Feed	2	0.26576	0.132879	20.15	63.72	**0.047**
C	Depth of cut	2	0.08920	0.044601	6.76	21.38	0.129
Error		2	0.01319	0.006594		3.16	
Total		8	0.41710				

Fig. 4 shows the main effect plot for surface roughness. The main effect plot gives the variation of surface roughness with respect to cutting speed, feed, and depth of cut. The surface roughness decreases with increase in cutting speed. The minimum surface roughness was observed at cutting speed of 500 m/min. As the cutting speed is increased, the conditions promoting the built up edge formation is also reduced due to a rise in temperature, which leads to a corresponding reduction in the height of the micro irregularities (roughness). Along with the rise in temperature, the reduced friction and plastic deformation could also have caused the reduction in the surface roughness when the cutting speed is increased.

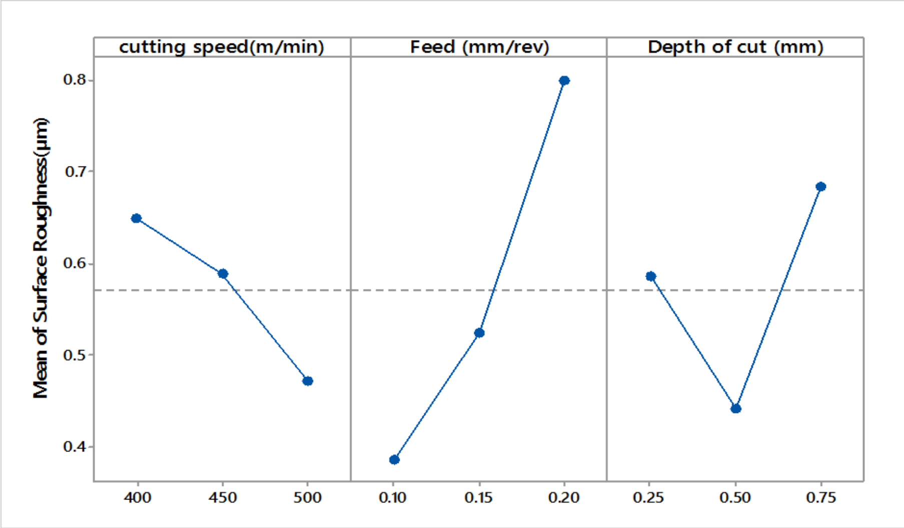

Fig. 4. Main effect plot for surface roughness

The surface roughness first decreases then increases with increase in depth of cut. The minimum surface was observed at depth of cut of 0.50 mm. This might be due to an increase in the deformation volume with the increase in depth of cut. Thus, severe deformation of work material leads to generation of more irregularities on the surface and hence poor surface finish.The optimum parameters for better surface finish obtained from ANOVA are cutting speed of 500 m/min, feed of 0.10 mm/rev and depth of cut of 0.50 mm.

3.2 Analysis of MRR

The material removal rate is an important factor in machining of any component because it decides the production rate. It is desirable to have higher material removal rate so that less time is required for the machining of any component. The material removal rate is given by the following formula (Boothroyd et al., 2013).

$$\text{MRR} = \frac{\pi}{4} \times (D^2 - d^2) \times f \times N$$

Where, D = Diameter of work piece before turning (mm)

d = Diameter of work piece after turning (mm)

N = Spindle speed (rpm)

f = feed (mm/rev.)

3.3 Analysis of Flank Wear by using ANOVA

Tool wear has a significant problem in metal cutting process. Usually,two types of wear occur while machining (flank wear and crater wear). Flank wear is mostly affected by hardness and low thermal conductivity of the materials. This is originated due to its high chemical affinity. Flank wear occurs on the relief face of the cutting tool and is generally attributed to the rubbing of the tool along the machined surface and high temperatures causing abrasive and/or adhesive wear, thus affecting tool material properties as well as work piece surface. An apparent sticking layer formed on the tool face near cutting edge layer indicates that bonding between chip-tool interfaces had occurred. Which factor is statistically significant for flank wear is determined by using analysis of variance. The contribution of each parameter is calculated with the help of ANOVA. The results of analysis of variance are given in Table 5.

Table 5 Results of the analysis of variance for Flank wear

Symbol	Cutting parameter	Degrees of freedom	Sum of squares	Mean Square	F	Contribution (%)	P
A	Cutting speed	2	2614.46	1307.23	28.72	85.74	**0.034**
B	Feed	2	26.05	13.03	0.29	0.85	0.777
C	Depth of cut	2	317.69	158.85	3.49	10.42	0.223
Error		2	91.02	45.51		2.99	
Total		8	3049.23				

Analysis of variance is used to determine which factor is statistically significant for flank wear. The contribution of each cutting parameter is calculated with the help of ANOVA. Table 5gives the ANOVA results.it is seen that p value for cutting speed is 0.034, which indicates that cutting speed is most significant factor for flank wear. The percentage contribution of cutting speed, feed and depth of cut is 85.75, 0.85 and 10.42 respectively. Cutting speed has more influence on flank wear as compared to the feed and depth of cut.

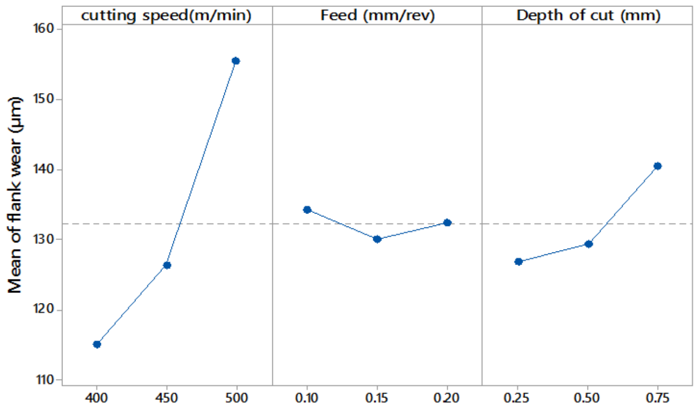

Fig. 5. Main effect plot for flank wear

Figure 5 shows the deviation of flank wear with cutting parameters. Highest flank wear is seen at cutting speed of 500 m/min. NIMONIC 80A has poor thermal conductivity due to which temperature in the cutting region goes up to 1200 ºC and accumulates at the rake face at higher cutting speed.Flank wear first decreases and then increases with increasing feed. Because chip cross section area increases hence more heat is dissipated through the chips which reduce the temperature at cutting zone. Further with increasing feed flank wear goes on increasing, because forces generated at the cutting edge of tool increases. This heavy force produces higher stress on the cutting edge of tool. Due to this stress the flank wear increases rapidly. Similarly as depth of cut increases, very high stresses developed at the tool nose because of higher cutting force. In addition, higher temperature developed some distance behind the cutting edge may lead to catastrophic failure when the cutting conditions are set at higher values. In order to get minimum flank wear cutting speed should be taken at lower level, feed at medium level and depth of cut at lower level.

4 Conclusions

The experiments were conducted to examine the effect of process variables on turning of NIMONIC 80A using SiAlON ceramic inserts. From the experimental investigations following conclusions are drawn:

- It is observed that SiAlON ceramic inserts gives better results for surface roughness compared to carbide insert. At lower cutting speed, notching is predominant and it is decreasing as cutting speed increases. As ceramic inserts are used at much higher cutting speed, higher MRR are obtained while turning of NIMONIC 80A.

- Most significant factor for surface roughness is feed. Maximum contribution of feed towards the surface roughness is 63.72%. Optimized parameters for less surface roughness are cutting speed of 500 m/min, feed of 0.1 mm/rev and depth of cut of0.50 mm.
- It is found that tool wear progresses rapidly during machining of NIMONIC 80A. Statistical ANOVA shows that the most significant factor for flank wear is cutting speed, which has P-value of 0.034, and the next influencing factor is depth of cut which is above 95% CL. The optimum condition to get lower flank wear is cutting speed of 400 m/min, feed of 0.15 mm/rev and depth of cut of 0.25 mm.

References

[1]. E.O. Ezugwo, J,Bonney, Y.Yamane "An Overview of Machinability of Aero-engine Alloys", Journal of Materials Processing Technology 134(2003) 233-253.
[2]. Bin Zou, Ming Chen, Shasha Li "Study on Finish-turning of NiCr20TiAl Nickel-based Alloy using Al2O3/TiN-coated Carbide Tools" International Journal of Advanced Manufacturing Technology (2011) 53:81–92.
[3]. C. Ezilarasan, V.S. Senthil kumar, A. Velayudham "Theoretical Predictions and Experimental Validations on Machining the NIMONIC C-263 Super Alloy", Simulation Modelling Practice and Theory 40 (2014) 192–207.
[4]. E. O. Ezugwu & C. I. Okeke "Performance of PVD Coated Carbide Inserts When Machining a Nimonic (C-263) Alloy at High Speed Conditions", Tribology Transactions, 43:2, (2000)332-336.
[5]. C.Ezilarasan, V. S. Senthil Kumar, A. Velayudham, K. Palanikumar "Modeling and Analysis of Surface Roughness on Machining of NIMONIC C-263 Alloy by PVD Coated Carbide Insert", Trans. Nonferrous Met. Soc. China 21(2011) 1986-1994.
[6]. E. O. Ezugwu & C. I. Okeke "Effects of Coating Materials on the Machinability of a Nickel Base, C-263, Alloy", Tribology Transactions, 43:3, (2000)549-553.
[7]. C. Ezilarasan, V.S. Senthil kumar, and A. Velayudham "Effect of Machining Parameters on Surface Integrity in Machining NIMONIC C-263 Super Alloy Using Whisker-Reinforced Ceramic Insert", Journal of Materials Engineering and Performance, Volume 22(6) June 2013,1619-1628.
[8]. C. Ezilarasan, V.S.Senthil kumar, and A.Velayudham "An Experimental Analysis and Measurement of Process Performances in Machining of NIMONIC C-263 Super Alloy", Measurement 46 (2013) 185–199.
[9]. W.H. Yang, Y.S. Tarng "Design Optimization of Cutting Parameters for Turning Operations based on the Taguchi Method", Journal of Materials Processing Technology 84 (1998) 122 – 129.
[10]. M. Nalbant, H.Gokkaya, G.Sur "Application of Taguchi Method in the Optimization of Cutting Parameters for Surface Roughness in Turning", Materials and Design 28 (2007) 1379–1385.
[11]. G. Boothroyd, "Fundamentals of Machining and Machine Tools, Marcel Dekker, Inc., First edition.