Optimization of Machining Parameters of Inconel-718 Super Alloy

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Abstract: This study is to determine the influence of controllable parameters on machining characteristics of Inconel-718 and to achieve the optimum parameters for sustainable and efficient turning, understanding the consequences of tool materials together with higher cutting speeds on the formation of residual stresses controllable cutting parameters such as cutting speed, feed rate and depth of cut were selected at different level for experimentations in accordance with the Taguchi L9 array method using cutting tool as carbide tip tool. Extensive study is to be on the resulting surface roughness, material removal rate, tool wear and chip formation. With (MINI TAB) ANOVA software is analyzed and provides the optimized parameters for efficient machining of Inconel 718.

I. INTRODUCTION

At 70% of alloys used in the aerospace engine are nickel-based alloys and others are titanium alloys. Super alloy Inconel 718 has large number of applications in different fields of manufacturing sector due to its unique properties like high thermal resistance, high creep and corrosion resistance and retains toughness and strength at elevated temperatures. It is very important that Inconel 718 has excellent yield strength (550 MPa) even at elevated temperature (700-800°C). Almost about 70% by weight in the case of aerospace applications and 50% by weight in the case of aero-engines components are made of Inconel 718.Further Inconel 718 applications are not limited to aerospace industry but it includes ship engines, nuclear power plants and petro-chemical plants. The use of Inconel 718 alloy in such destructive environments ensures that it up holds high corrosion resistance. High fatigue resistance, withstand them at high mechanical and thermal shock, creeps, and erosion at elevated temperature. Aero engines Inconel-718 is normally used for manufacturing of gas turbine blades, which operates at very high temperature and pressure. Inconel 718 retains high toughness and strength over a wide temperature range, striking for high temperature applications: where other aluminum and steel alloys would get soften. But on other hand Inconel 718 offers serious challenge as a work material during turning machining due to their exceptional combined properties such as high temperature strength and toughness, hardness and chemical wear and creep resistance. Although these properties are attractive for design requirements, they create a bigger challenge to manufacturing engineers due to high temperatures and stresses generation during machining. There are two main problems in machining of super alloy Inconel 718 a less tool life due to the work hardening and abrasion properties of the Inconel718, b metallurgical and surface damages to the work piece due to very high cutting pressure and temperature, which also contributes towards work hardening, surface tearing, and deformation.

Many researchers have investigated the machining characteristics of Inconel 718 by considering the general machining/cutting conditions and ordinary tool materials. Hence, there is still a scope and challenge to study and understand the nature, surface integrity and chip formation during machining Cutting pressure and temperature decrease with increase in cutting speed in high speed machining Therefore it is important to understand how the change of cutting speed affects on the surface integrity in inconel 718 alloy machining. According to literatures, it is found that the assessment for high speed turning of inconel 718 with three different tool materials with MQL cutting condition has not been done completely. In the present study, the effects of controllable cutting parameters (cutting speed, feed rate and depth of cut) on the surface roughness and cutting force during turning Inconel 718 with, Carbide cutting tools have been investigated. The design of experiments was selected from Taguchi's L9 orthogonal arrays. Subsequent to the experiments, the effect of turning parameters on surface quality, tool wear, and Material removal rate have been analyzed

II. LITERATURE REVIEW

Investigated effect of Boron Nitride Coating on Wear Behavior of Carbide Cutting Tools in Milling of Inconel 718, Surface roughness and tool wear was recorded in relation with cutting length. Wear mechanisms on the coated carbide tools were determined using scanning electron microscopy in combination with energy dispersive spectroscopy with Cutting speed - 30 m/min, Feed rate - 0.05 mm/tooth, Axial depth of cut - 0.1mm & Abrasive and adhesive wear was found as main failure mechanisms on the worn tools. Approximately two times longer tool life was obtained with the BN coated carbide tools [1]. This sutdy the effects of cutting speed on tool wear and tool life when machining Inconel 718 with ceramic tools, A series of tool life experiments has been carried out using silicon nitrite based and whisker reinforced ceramic tools which have two different geometries and three different ISO qualities with 10% water additive cutting fluid. The experiment results show that crater and flank wears are usually dominant wear types in ceramic square type (SNGN) inserts while flank and notch wear are dominant in round type (RNGN) inserts. Minimum flank wear is seen with SNGN tools at low cutting speeds while it is seen with RNGN tools at high cutting speeds [2]. An Experimental Study of Tool Wear and Cutting Force Variation in the End Milling of Inconel 718 with Coated Carbide Inserts, with cutting speed of 600 rpm, 900 rpm & Damage observed on the rake surface, such as crater wear, was quite limited. The development of the flank wear of the coated carbide inserts used for both the down milling and the up milling under the spindle speed of 600 rpm [3]. Investigated High speed machining of Inconel 718: tool wear and surface roughness analysis, Turning trials are conducted at various speed ranging from low to high (60 m/min, 90 m/min, 190 m/min, 255 m/min). Tool wear and surface roughness, which are two major aspects of machinability, have been discussed in this investigation; Wear patterns observed at these cutting speeds are uniform along the nose radius along with some traces of peeling coating [5, 6]. Comparatively at high cutting speeds tool gets worn out at very faster rate with major tool failure patterns like heavy notching. Also at high speed because of very high amount of heat is generated in cutting zone while machining Inconel 718 burns marks are visible on the tool [4].

III. METHODOLOGY

A. Experimental Setup

Turning operations were carried out on lathe Machine. This lathe is provided with a high quality feed mechanism which maintains the set feed accurately. To examine the influence of machining parameters on process meters, experiments are carried out on Inconel 718 bar (of length 200mm and diameter of 17 mm) using carbide tip tool inserts (Insert: SNMG 120408; Grade: TS2500). Preliminary experiments were carried out to fix the limits of cutting speed for different cutting tool materials based on the available data for machining Inconel 718 from hand books and literature.
The Cutting conditions selected for the experiments are shown in the table 1.According to Taguchi's full factorial Design of Experiments an L9 Orthogonal Array was selected, Where number of factors are 3 (Cutting speed, Feed, Depth of cut), number of levels of each factor is 3 and number of experiments to be conducted are 9. The experiments were performed on Lathe machine. Various input parameters varied during the experimentation are cutting speed, feed rate, and depth of cut.

Table 1: L9 Orthogonal array

COLUMN / CONDITION	L_9 1	2	3
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 2: L9 orthogonal array with all values selected for the experimental

	Level		
Control Factors	I	II	III
Cutting speed	40	90	140
Feed rate	4	5	6
Depth of cut	2	3	4

The effects of these input parameters are studied on MRR; following steps were followed in the cutting operation:

- The work piece was made horizontal with the help of dial indicator.
- The work piece is facing at one side and center hole with 8 mm diameter drill bit.
- The experiment was made for cutting operation of the work piece and a profile of different depth of cuts 0.2, 0.3, 0.4 and 4, 5, 6 cm turning length.

Figure 3.1: Experimental setup

For the present experimental work three process parameters each at three levels have been decided. It is desirable to have minimum three levels of process parameters to reflect the true behavior of output parameters under study. The L9 orthogonal array with all values selected for the experimental run is shown in table 2. There are 9 parameter combinations that need to be tested. Each parameter combination is tested for replications for effective error reduction and for accurate S/N ratio. The levels of the individual process parameters / factors are given in and show L9 Orthogonal Array of Process Parameter.

B. Material Composition and Properties

Table 3: Material composition Components Ni

Components	Ni	Cr	Mo	Co	Nb	C	Al	Mn	Ti
Percentage (%)	50-55	17-21	3.2	1	5.3	0.08	0.6	0.35	1.23

Table 4: Work piece properties

Work specimens	Inconel 718
Hardness	35 HRC
Size	17 x 200 mm
Density	8.19 g/cm³
Young's modulus	208 × 103 Mpa
Workpeice holder	Jaw Chuck

C. Minitab 16

MINITAB 16 is a computer program designed to perform basic and advanced statistical functions. It combines the user-friendliness of Microsoft Excel with the ability to perform complex statistical analysis. The Figure - 5.1 shows the MINITAB 16 work sheet with the Taguchi design selected for the design. MINITAB 16 calculates response tables and generates main effects and interaction plots for Signal-to-noise rations (S/N ratios) vs. the control factors.

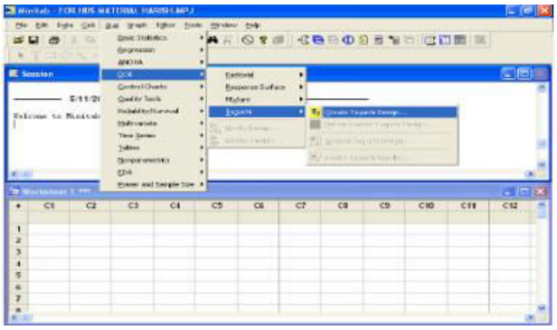

Figure 3.2: The MINITAB 16 Work Sheet with the Taguchi Design

IV. EXPERIMENTAL PROCEDURE

The major problem with the turning process is setting the parameters for different materials for different thickness. The different values of the parameters set for machining some material for the same work piece will give different values of accuracy. So it not possible to randomly select the parameters, which give the wrong values of the performance measures. But the machine operator may choose some good parameters based on his experience on that machine, which may give better output. Every operator will choose different parameters which may or may not give the good responses. The objective of any company is to give good products to the customer so that it should not damage or lose its function thereby avoiding the loss to the customer. After conducting the matrix experiment, responses such as Inconel 718 alloy material is calculated and tabulated.

Table 5: L9 orthogonal array (model/Assigned values)

S.No	Cutting Speed	Feed Rate	Depth Of Cut
1	1	1	1
2	1	2	2
3	1	3	3
4	2	2	1
5	2	3	2
6	2	1	3
7	3	3	1
8	3	1	2
9	3	2	3

S. No	Cutting Speed	Feed Rate	Depth Of Cut
1	40	40	0.20
2	40	50	0.30
3	40	60	0.40
4	90	50	0.20
5	90	60	0.30
6	90	40	0.40
7	140	60	0.20
8	140	40	0.30
9	140	50	0.40

V. RESULT AND DISCUSSION

The statistical analysis of variance is to determine which design parameters significantly effects the surface roughness and MRR. Based on the ANOVA the relative importance of machining parameters with respect to surface roughness and MRR investigated and machining parameters table 4 shows the result of the ANOVA analysis of MRR. An analysis of variance (ANOVA) table is commonly used to summarize the tests performed. The ANOVA is applied to test adequacy of the developed models. The purpose of the ANOVA is to investigate which parameters significantly affect the response characteristics. The test for significance of the regression model and the test for significance on individual model coefficients are performed. Table 4.1 shows ANOVA for MRR of the Inconel718.The purpose of ANOVA to find the process parameters which affect the performance characteristic. It absorbed that the depth of cut has insignificant effect on surface roughness.

A. Material Removal Rate:

MRR is the rate at which the material is removed the work piece. The MRR is defined as the ratio of the difference in weight of the work piece before and after machining to the machining time. MRR is the rate at which the material is removed the work piece. The MRR is defined as the ratio of the difference in weight of the work piece before and after machining to the machining time. Metal removing rate (mm3/sec), Turning is most common process in whole manufacturing, for turning process the lathe is selected. Material Specification. Ø17mm and length 200mm

Table 6: L9 orthogonal array (calculated values)

Run	CUTTING SPEED (rpm)	FEED (mm/rev)	DEPTH OF CUT (mm)	MACHINING TIME (seconds)	MRR (mm^3/Min)	Surface finish (µm)
1	40	40	0.20	130	193.065	0.88
2	40	50	0.30	165	144.297	1.02
3	40	60	0.40	204	186.183	1.12
4	90	50	0.20	20	789.75	0.42
5	90	60	0.30	24	1162.19	0.62
6	90	40	0.40	18	1389.97	0.9
7	140	60	0.20	14	1326.97	0.42
8	140	40	0.30	10	1844.27	0.59
9	140	50	0.40	12	2559.1	0.64

B. Analysis of experimental Data using Taguchi

The data obtained after measuring the response variables were tabulated and discussed in the previous sections. In this section, obtained data has been analyzed based on Taguchi analysis using MINITAB 16 software.

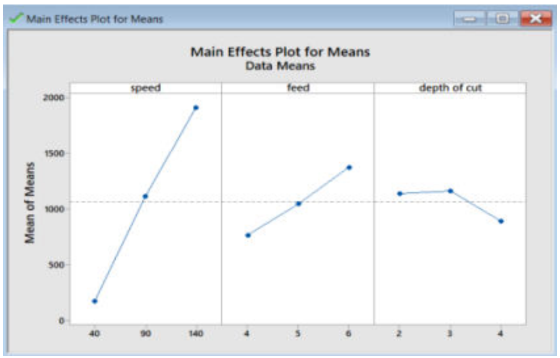

Figure 5.1: Mean vs Mean graph

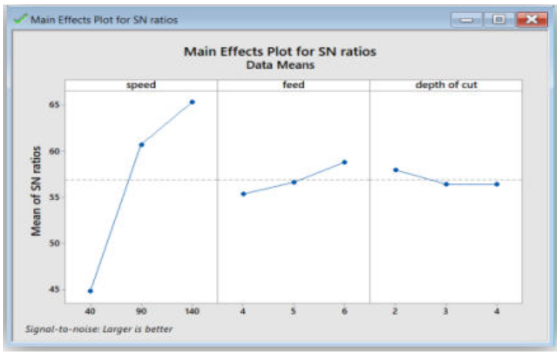

Figure 5.2: Graph for signal to noise ratio

VI. CONCLUSION

The effect of feed is maximum MRR followed by cutting speed and depth of cut has least effect on MRR. The optimum parameters are cutting speed 140 rpm, feed rate 60 mm/rev and depth of cut 0.2 mm. The parameters are ranked as 1, 2, 3 for feed rate, cutting speed, depth of cut. The developed regression equation is used to predict the MRR with 4.59% error. The developed regression equation is used to predict the MRR with 96.40% accuracy. The maximum % of contribution in feed rate is 1.42 %, cutting speed is about 60.22 %, Depth if cut is about 28.35 % and also error is 10.1 % are obtained by ANOVA calculations.

VII. FUTURE SCOPE OF WORK

The work can be extended by considering the other parameters like different tool materials, conditions and by changing tool angle, Tool flank wear, voltage etc. The work may be continued, for machining various materials for finding optimal combination of parameters and also by varying the work materials to find out the best material of the work. During the experiment, some noise factors were ignored like temperature, vibrations, etc which can be included. The present work is carried out using simple CNC machine. The experiment can also be conducted using fully automatic CNC machine.

REFERENCES

1. V. Bushlya, J. Zhoua, and J.E. Ståhl. 2012. Effect of cutting conditions on machinability of super alloy Inconel 718 during high speed turning with coated and uncoated PCBN tool. 45th CIRP Conference on Manufacturing Systems. Procedia CIRP 3. pp. 370375.

2. A. Devillez, G. Le Coz, S. Dominiak and D. Dudzinski. 2011. Dry machining of Inconel 718, workpiece surface integrity. Journal of Materials. Processing Technology. 211: 1590-1598.

3. M. Nalbant, A. Altin, and H. Gokkaya. 2007. The effect of cutting speed and cutting tool geometry on machinability properties of nickel-base Inconel 718 super alloys. Material Design. 28 4. 1334-1338.

4. A. Devillez, F. Schneider, S. Dominiak, D. Dudzinski, and D. Larrouquere. 2007. Cutting forces and wear in dry machining of Inconel 718 with coated carbide tools. Wear. 262 (7-8): 931-942.

5. A. Altin, M. Nalbant, and A. Taskesen. 2007. The effects of cutting speed on tool wear and tool life when machining Inconel 718 with ceramic tools. Material Design. 28: 2518-2522. 6. R.S. Pawade, S. Joshi, P.K. Brahmankar, and M. Rahman. 2007. An investigation of cutting forces and surface damage in high-speed turning of Inconel 718. Journal of Material Processing Technology. 192-193: 139-146.