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AN INVESTIGATION ON EFFECT OF CUTTING PARAMETERS ON MACHINING FORCE AND CHIP MORPHOLOGY IN CNC TURNING OPERATION OF INCONEL 718

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ABSTRACT

Inconel 718 is widely used in space, nuclear and thermal industrial components due to its ability to maintain strength at elevated temperatures. The exploration of the machining parameters of the material can provide a data to the manufacturing engineer to understand the machinability of the Inconel 718. The effect of cutting parameters on machining force can provide required strength from the cutting tool and machine tool to provide stable cutting operation. Also, effect of cutting parameters on chip morphology can provide insight stability of the operation and safety of the operation.

This paper presents the results of experimental investigation on the effect of cutting parameters on machining force and chip morphology in CNC Turning Operation of Inconel 718.The results show that the feed is the most significant parameter followed by cutting speed, depth of cut. The results also show that the chips thickness keep on increasing as the cutting speed and depth of cut are increased. The chip formation is mostly affected by the change of cutting speed followed by the depth of cut and the feed rate.

KEYWORDS: Inconel 718, Machining, chip morphology, machining forces.

1. INTRODUCTION

The selection of work material is at the center of machining process design as it influences the operating parameters of the process. Inconel 718 is a nickel based alloy known for is heat resistant abilities. Inconel has wide range of operating temperature (-250 to 705^{0}C) in which it maintains its mechanical properties [1]. This wide operating temperature range along with high strength and corrosion resistance makes it suitable for different industrial applications like pump rotors, pressure vessels, shafts, fasteners, heat exchangers etc. The cutting and machining characteristics of the materials should be properly explored in order to provide sufficient data to the production engineer which can be helpful for the development of production plan. In order to generate this data the parameters like cutting force and chip shape are needed to be finding out as these factors can effectively asses the performance of material [2]. Researchers are working on the exploration of different operating parameters in machining of Inconel 718 like mechanical properties of surface layers [3], cutting edge characteristics [4], rake angle, tool life [5] etc. The machining of Inconel 718 is a challenging task due to its high strength, high chemical affinity to tool material and adhesion on cutting edge. In order to improve machining technique efforts are mounted by the researchers, this research is mainly classified into two section namely surface quality and tool life [6]. The machining force in the machining has direct relation with the tool life. The machining forces are required to design or machine tools and cutting tools, the components of machine tools should be able to withstand these forces to provide a reliable and accurate cutting process. The machine tool should also be withstand these forces without generating abnormal noise, mechanical failures and vibrations. Along with cutting forces chip morphology is also an important tool to determine the machine tool performance and product quality. The type and form of the chip is an indicator of the quality of material, stability of the cutting process and safety of the operation [7]. Also, the undesirable size and forms of chips can lead to safety and storage issues. The cataloguing of these chip based on shape, size, color and direction will give an indication of the behavior of the cutting process [8].

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This research work gives presents the effect of cutting parameters on machining force in in CNC Turning Operation of Inconel 718; this paper also provides chip morphology of the Inconel 718 material at different cutting parameters.

2. METHODOLOGY

Following methodology in followed for the conducting this research work;

a) Preparation of work specimen.
b) Formation of design of experiments.
c) Framing the working conditions as per the feasibility of the machine tools.
d) Conducting numbers of trials.
e) Study of chip morphology by changing cutting parameters (cutting speed (v), feed (f), Depth of cut (DOC)) and obtaining high quality photographs. The photographs will be examined for curliness, length.
f) Measurement of cutting forces by three channel digital strain gauge type dynamometer.

Machine tool

The experimental investigation was carried out on a CNC lathe machine (shown in figure 1) under dry and wet conditions.

Figure 1 The CNC lathe

Specification of the CNC lathe machine

CNC - 3000
Manufactured by: Colchestor
Power of the motor: 7 KW, 5 HP
Centre height: 230 mm
Swing over Bed: 510 mm
Swing over cross slide: 255 mm
Range of spindle speed: 20-2200 rpm.
Tool type: TiCN+TiC+TiCN+Al_2O_3+TiN-PVD coated carbide tool (TT 5080)

Force measurement

The cutting forces were measured with a strain gauge dynamometer mounted on the CNC lathe, shown in figure 2.

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Figure 2 Strain gauge dynamometer

Dynamometer Specifications:
The Lathe tool dynamometer enables to measure cutting or tangential force (F_t), axial or feed force (F_f) and radial or thrust force (F_r) in different cutting conditions. This dynamometer consists of a tool holder held rigidly in the dynamometer body. Sensing is done using strain gauges fixed on the Mechanical set up, enclosed in the box. This dynamometer is mounted directly on the Tool Post of Lathe Machine, as shown in figure 3.


Figure 3 Experimental set up

Forces were measured and recorded for the different cutting conditions both for dry and wet conditions.

Procedure for measurement of cutting forces:
To investigate the performance of cutting tool during metal cutting the measurement of cutting force is essential.

This helps the analysis of effect speeds and feeds on the surface roughness of work piece material.

a) Mount a work piece in the chuck of the machine. The workpiece should be a polished one or preferably machined one, so that the tool comes in contact with the workpiece continuously during cutting operation. There should not be any lateral vibration while cutting operation.
b) Adjust the speed and feed of the lathe machine and start the lathe machine.
c) Feed the tool manually to start cutting and then put the machine in auto feed mode.
d) Adjust the Feed in steps of 0.2, 0.25, 0.3 mm/rev respectively.
e) Wait for some time to stabilize the output of the bridges and measure the maximum forces for tangential (F_t), feed (F_f) and Radial (F_r).
f) Measure the output for vertical and horizontal forces. The vertical and horizontal forces on the dynamometer should not exceed a limit 250 Kg.
g) Before taking next readings, again ensure that bridge is in balanced condition that is zero reading on the indicator.

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3. RESULTS AND DISCUSSION

Table 1 Factors and levels used in the experiment

Sr. No.		Factors	Levels		
			1	2	3
1	A	Cutting speed (mm/min)	50	70	90
2	B	Feed (mm/rev.)	0.1	0.2	0.3
3	C	Depth of cut (mm)	0.1	0.2	0.3

The orthogonal array is designed to reduce the number of experimental trials to explore this research work. The Taguchi method is employed and each parameter is categorized in three levels namely low (1), medium (2) and high (3). The required numbers of formulas are calculated by using following formula;
N Taguchi = 1+ NV (L – 1)
N Taguchi = Number of experiments to be conducted
NV = Number of parameters
L = Number of levels
In this work NV = 3 and L = 3, Hence N Taguchi = 1+ 4 (3-1) = 9

The table 2 shows orthogonal array used for the experiments.

Table 2 Process parameters used Taguchi L9 Orthogonal Array

Expt. No.	Levels		
	Cutting speed (V_c)	Feed (f)	Depth of cut (DOC)
1	50	0.1	0.1
2	50	0.2	0.2
3	50	0.3	0.3
4	70	0.1	0.2
5	70	0.2	0.3
6	70	0.3	0.1
7	90	0.1	0.3
8	90	0.2	0.1

Effect of cutting parameters on machining force

Table 3 Table for machining forces and surface roughness

Expt No.	Cutting speed (m/min) V_c	Feed (mm/ rev.) f	DOC (mm)	Tangential force F_t (N)	Feed force F_f (N)	Radial force F_r (N)	Machining force M_f (N)
1	50	0.1	0.1	147.15	117.72	117.72	222.19
2	50	0.2	0.2	137.34	122.62	117.72	218.53
3	50	0.3	0.3	196.2	156.96	176.58	307.10

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4	70	0.1	0.2	201.10	161.86	171.67	310.03
5	70	0.2	0.3	235.44	201.10	206.01	371.91
6	70	0.3	0.1	294.32	206.01	250.15	437.76
7	90	0.1	0.3	235.44	166.77	206.01	354.52
8	90	0.2	0.1	210.91	161.86	171.67	316.48
9	90	0.3	0.2	309.01	235.44	284.49	481.52

Cutting forces provide a better understanding of the machining process as they relate directly to the cutting conditions and tool condition during machining. The results in the table 3 shows that the cutting speed has highest statistical significant (57.67%) followed by feed (41.41%). whereas depth of cut (0.93%) was found to be less. Therefore, cutting speed and feed are the most significance factors. Depth of cut is not significant. It can be observed that the increase in machining force caused with the increase in cutting speed and feed. The increase in the feed rate induces a larger volume of the cut material in a same unit of time.

Main effect plots for machining forces

Main effect plots for forces shown in the figure 4 main effects plot shows the variation of forces with respect to cutting speed, feed and depth of cut. X axis represents change in level of the variable and Y axis represents the change in the resultant response. The mean line is shown by the straight horizontal line. It observed from figure 4 that machining force slightly increases when turning wet environment than dry environment. At lower cutting speed lower machining forces are observed. At the cutting speed 50 m/min. cutting forces are lower. As feed rate and depth of cut increases the machining forces continuously increases.

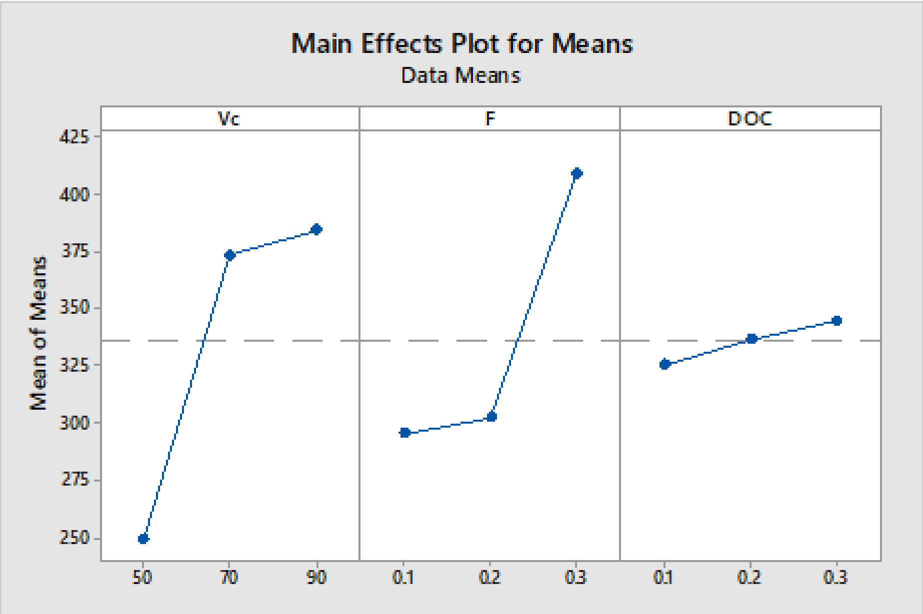

Figure 4 Main effects plot for means of machining forces

It is seen from figures 5 and 6 that the residuals follow an appropriate straight line in normal probability plot. Residuals possess constant variance as they are scattered randomly around zero in residuals versus the fitted values. Since residuals exhibit no clear pattern, there is no error due to time or data collection order.

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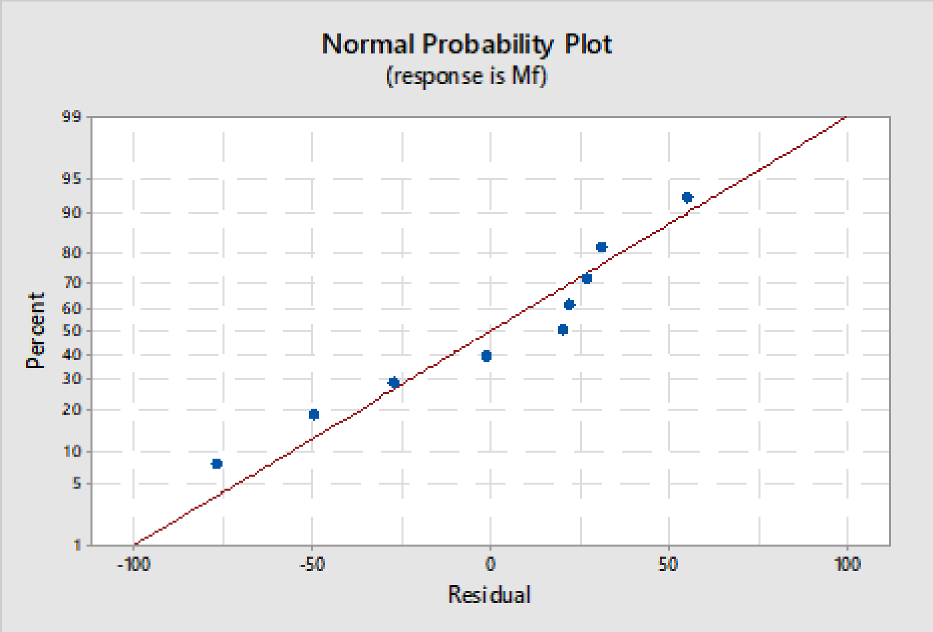

Figure 5 Normal probability plot of the residuals for machining force

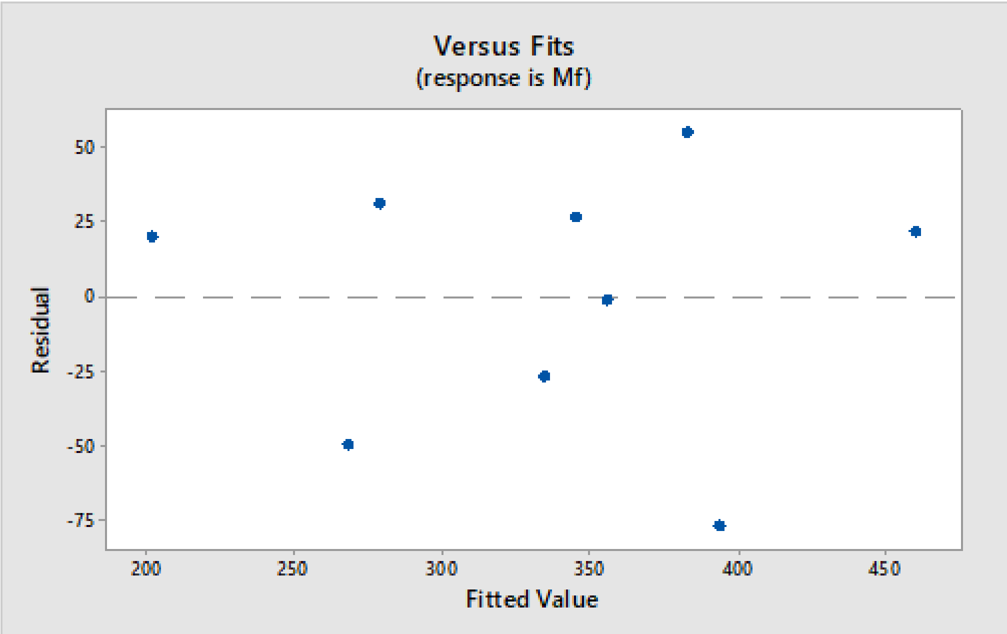

Figure 6 Residuals versus fitted values plot for machining force

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Chip morphology

Table 4 Types of Chip pattern during machining

Sr. No.	Cutting parameters	Shape	Color	Type of chip formed
1	V_c = 50 f = 0.1 DOC =0.1	Snarled tubular type chips	Metalic	
2	V_c = 50 f = 0.2 DOC = 0.2	Snarled tubular type l chips	Metalic	
3	V_c = 50 f = 0.3 DOC =0.3	Snarled tubular type chips	Metalic	
4	V_c = 70 f = 0.1 DOC =0.2	long tubular type chips	Metalic	
5	V_c = 70 f = 0.2 DOC = 0.3	Snarled tubular type chips	Metalic	
6	V_c = 70 f = 0.3 DOC =0.1	Snarled Tubular chips	Blue	

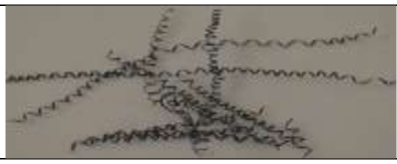
7	V_c = 90 f = 0.1 DOC =0.3	Snarled tubular type chips	Blue	
8	V_c = 120 f = 0.2 DOC = 0.2	Snarled tubular type chips	Blue	
9	V_c = 120 f = 0.2 DOC = 0.25	Long tubular type chips	Blue	

Table 5 Chip morphology

Expt No.	Chip Thickness (mm)	Width (mm)	Curliness	Surface Roughness (µm)	Machining Force (N)
01	0.06	0.49	High	0.151	222.19
02	0.08	0.44	Less	0.256	218.53
03	0.08	0.60	High	1.951	307.10
04	0.09	0.34	High	0.245	310.03
05	0.09	0.58	Less	0.689	371.91
06	0.10	0.49	Less	2.041	437.76
07	0.10	0.42	Less	0.567	354.52
08	0.10	0.46	Less	1.343	316.48
09	0.08	0.43	Less	2.241	481.52

Table 4 shows types of pattern of the chips during machining and Table 5 shows effect of cutting parameters on the chip formation. It is found that the chips having loose arc and connected arc type morphology with silver colored appearance showing lower machined roughness values (0.48 Ra mm). The corresponding magnitude of thrust forces is also low in these cases. On the other hand, the chip forms such as snarled ribbon type highly torn, with partially or highly burnt appearance show higher machined roughness values (Ra ¼ 1.62 mm) and higher values of the radial force components. Analysis of chip thickness ratio shows that the cutting speed influences the chip thickness ratio, which in turn governs chip morphology. Thus, physical form of the chips shows significant differences at lower (125 m/ min) and higher (475 m/min) cutting speeds. A change in feed rate controls the ability of chips to dissipate heat to the surroundings and hence govern the chip morphology, too. Cutting edge geometry influences the chip thickness ratio. The application of chamfered and honed edge insert (CH) reduces chip thickness ratio but the value is higher in case of 30 chamfered edge insert (CW1). The statistical analysis of results shows that the following parameter combination produces lower chip thickness ratio and the loose arc.

From the experiment, the chips were collected with successive machining time and examined its shapes and colors by digital camera to identify the nature of chip. For the turning speed at 50 m/min the chips are regularly tubular at the start of the cut as the turning progresses towards the end the chips formed are snarled continuously ribbon-like. At higher turning speed of 90 m/min the chips are consistent and snarled washer type helical chips.

4. CONCLUSION

The following conclusions are drawn from the study. The process parameters cutting condition and depth of cut are significant and velocity, feed are insignificant for surface roughness. From response table it is found that depth of cut has greatest effect on surface roughness and it followed by cutting condition, feed and velocity.
From Taguchi's DOE, it is observed that first level of cutting speed, first level of feed and first level of depth of cut (A1-B2-C1) result in minimum value of machining force. For this parametric combination prediction of thrust force is done according to Taguchi and it is 213.2N. For this experiment machining force is 222.19N. This is very close to predicted value, indicating that the use of Taguchi Design for analysis and optimization of control parameters is appropriate.

The process parameters feed is the most significant parameter followed by cutting speed, depth of cut. At lower cutting speed higher machining forces are observed. As feed rate and depth of cut increases the machining forces continuously increases.

It is also observed that the chips thickness keep on increasing as the cutting speed and depth of cut are increased to the next level. The chip formation is mostly affected by the change of cutting speed followed by the depth of cut and the feed rate.

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