International Journal of Engineering Science Invention (IJESI)
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org ||Volume 7 Issue 6 Ver II || June 2018 || PP 21-32

Finite Element Analysis of Optimization for Turning Parameters of Super Alloy Inconel 718

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Abstract:*Alloy Inconel 718, a nickel based super alloy, developed initially for use in rotating parts in aerospace and gas turbine applications, has become the preferred material for the manufacture of important Components and Auxiliary Tools and Sub-Surface Safety Valves. Super alloy Inconel 718 is mostly used in sophisticated applications due to its unique properties desired for the engineering applications. Due to its peculiar characteristics machining of Super alloy Inconel 718 is difficult and costly. The present work is an attempt to make use of Taguchi optimization technique to optimize the cutting parameters during high speed turning of Inconel 718 using Cubic Boron Nitride and Alumina Ceramic KY 1615.The cutting parameters are cutting speed, feed rate and depth of cut for turning of work piece material Super Alloy Inconel 718. In this work, the optimal parameters are cutting speed, feed rate and depth of cut. The parametric model of cutting tool and work piece assembly is done in Pro/Engineer and analysis is done in Ansys. The cutting parameters considered are Cutting Speed – 2000rpm, 3500rpm and 5500rpm, Feed Rate – 250mm/min, 500mm/min and750mm/min and Depth of Cut is0.3mm, 0.6mm and 0.9mm.It is a powerful design of experiments (DOE) tool for engineering optimization of a process. It is an important tool to find the critical parameters and predicts optimal settings for each process parameter. Taguchi method is used to study the effect of process parameters and establish correlation among the cutting speed, feed and depth of cut with respect to the machinability factor, cutting forces such as cutting force and feed force. Process used in this project is turning process. Modeling is done in Pro/E and anasis is done in ANSYS.*
Keywords: *Cutting force, Feed force, Chip analysis, Taguchi method*

Date of Submission: 25-05-2018 Date of acceptance: 11-06-2018

I. Introduction To Turning

Turningis a machining process in which a cutting tool, typically a non-rotary tool bit, describes a helical tool path by moving linearly while the work piece rotates. The tool's axes of movement may be literally a straight line, or some set of curves or angles but they are essentially linear (in the nonmathematical sense). Usually the term "turning" is means for the creation of external surfaces by this cutting action. The cutting of faces on the work piece (that is, surfaces perpendicular to its rotating axis), is called "facing", and may be lumped into either category as a subset.

Turning can be done manually, in a traditional form of lathe, which requires continuous supervision by the operator, or by using an automated lathe which does not. Today the most common type of such automation is computer numerical control, better known as CNC. (CNC is also commonly used with many other types of machining besides turning.)

When turning, a piece of relatively rigid material (such as wood, metal, plastic, or stone) is rotated and a cutting tool is transversed along 1, 2, or 3 axes of motion to produce precise diameters and depths. Turning can be either on the outside of the cylinder or on the inside (also known as boring) to produce tubular components to various geometries. Although lathes could even be used to produce complex geometric figures, even the platonic solids; although since the advantage of CNC it has become unusual to use non-computerized toolpath control for this purpose.

1.3 INTRODUCTION TO FEA

Finite Element Analysis (FEA) was first developed in 1943 by R. Courant, who utilized the Ritz method of numerical analysis and minimization of variational calculus to obtain approximate solutions to vibration systems. Shortly thereafter, a paper published in 1956 by M. J. Turner, R. W. Clough, H. C. Martin, and L. J. Top established a broader definition of numerical analysis. The paper centered on the "stiffness and deflection of complex structures".

1.4 Work Piece Materialnickel Alloy Inconel 718
Inconel 718 – Nickel-Chromium Alloy

II. Literature Survey

Optimization of Process Parameters of Turning Parts: A Taguchi Approach
Neeraj Sharma, Renu Sharma
Abstract

The present study applied extended Taguchi method through a case study in straight turning of mild steel bar using HSS tool for the optimization of process param. The study aimed at evaluating the best process environment which could simultaneously satisfy requirements of both quality as well as productivity with special emphasis on reduction of cutting tool flank wear, because reduction in flank wear ensures increase in tool life. The predicted optimal setting ensured minimization of surface roughness. From the present research of ANOVA it is found the Depth of cut is most significant, spindle speed is significant and feed rate is least significant factor effecting surface roughness.

The Effect of Tool Construction and Cutting Parameters on Surface Roughness and Vibration in Turning of AISI 1045 Steel Using Taguchi Method
Author(s) Rogov Vladimir Aleksandrovich, GhorbaniSiamak
ABSTRACT

This paper presents an experimental investigation focused on identifying the effects of cutting conditions and tool construction on the surface roughness and natural frequency in turning of AISI1045 steel. Machining experiments were carried out at the lathe using carbide cutting insert coated with TiC and two forms of cutting tools made of AISI 5140 steel. Three levels for spindle speed, depth of cut, feed rate and tool overhang were chosen as cutting variables. The Taguchi method L_9 orthogonal array was applied to design of experiment. By the help of signal-to-noise ratio and analysis of variance, it was concluded that spindle speed has the significant effect on the surface roughness, while tool overhang is the dominant factor affecting natural frequency for both cutting tools. In addition, the optimum cutting conditions for surface roughness and natural frequency were found at different levels. Finally, confirmation experiments were conducted to verify the effectiveness and efficiency of the Taguchi method in optimizing the cutting parameters for surface roughness and natural

PARAMETRIC INVESTIGATION OF TURNING PROCESS ON MILD STEEL AISI 1018 MATERIAL
J. M. Gadhiya L. D. College of Engineering Mechanical Department, Navrangpura,Ahmedabad-15
P. J. Patel L. D. College of Engineering Mechanical Department, Navrangpura,Ahmedabad-15

Turning is widely used machining process in today's industrial requirement. In the present research, the effect of CNClathe machine processing parameters such as speed, feed and depth of cut effect on measured response such as surface roughness. The experiment was designed according to full factorial with three different level of each input parameter.For result interpretation, analysis of variance (ANOVA) was conducted and optimum parameter is selected on the basis of the signal to noise ratio,which confirms the experimental result. The result indicated that cutting speed and Feed play important role in surface roughness.

Conclusions
From conducted experiment of Turning cutting on Mild steel, varying Speed, feed and depth of cut gives following conclusion.
1. Cutting speed and feed have high contribution on surface roughness for Mild steel.
2. Depth of cut had less effect for surface roughness.
3. The S/N ratio suggests the optimum parameter setting for selected operating rage of experiment.

Aim Of The Project
- The effect of parameters cutting speed, feed rate and depth of cut while turning of Super Alloy Nickel 718 are formulated mathematically. The cutting tools are tungsten carbide, Cubic Boron Nitride and Alumina Ceramic KY 1615. The cutting parameters considered are spindle speed – 2000rpm,3500rpm, 5500rpm, feed rate – 250mm/min, 500mm/min,750mm/min and depth of cut –0.3mm,0.6mm, 0.9mm.
- A parametric model of cutting tool and workpiece is designed using 3D modeling software Pro/Engineer.
- Analytical investigations are made on the model by applying the forces by taking different values of cutting speed, feed rate and depth of cut. Analysis is done in Ansys.
- Optimization is also done using Taguchi technique by taking the experimental values. Taguchi method is a powerful design of experiments (DOE) tool for engineering optimization of a process. It is an important tool to identify the critical parameters and predict optimal settings for each process parameter.
-

III. Methodology

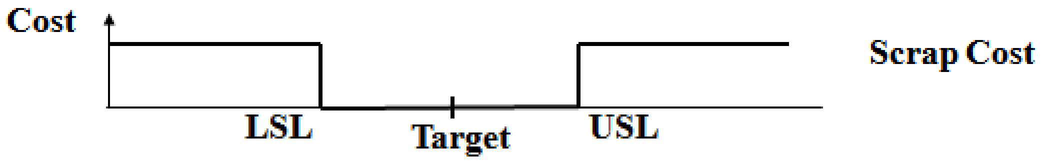
Robust Design – The Taguchi Philosophy

Overview

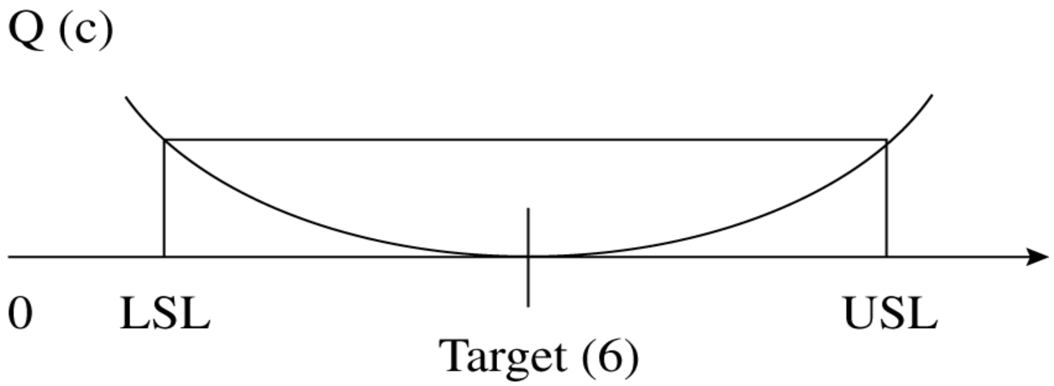
- Taguchi Design of Experiments
- Background of the Taguchi Method
- The Taguchi Process

The Taguchi Quality Loss Function

- The traditional model for quality losses
- – No losses within the specification limits!

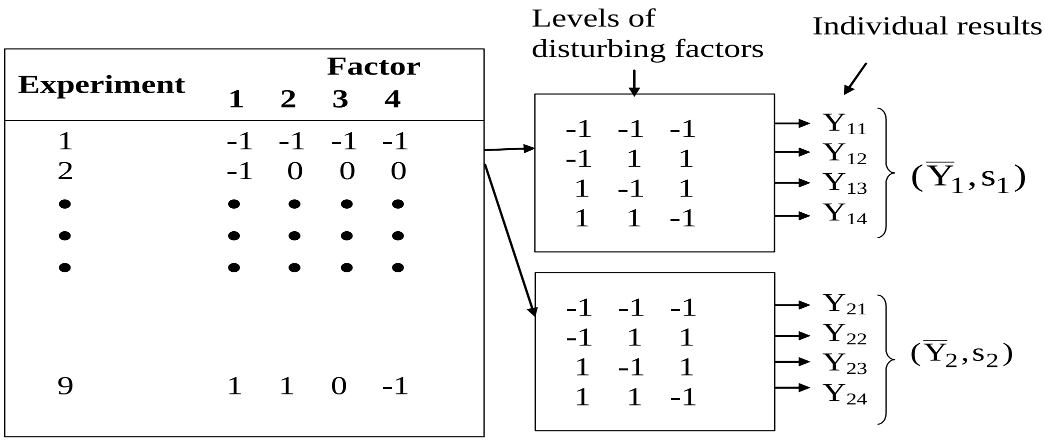


- The Taguchi loss function
- – the quality loss is zero only if we are on target



The Taguchi Approach to DOE

- Traditional Design of Experiments (DOE) focused on how different design factors affect the **average** result level
- Taguchi's perspective (robust design)
- – variation is more interesting to study than the average
- – Run experiments where controllable design factors **and** disturbing signal factors take on 2 or three levels.
- For each combination of the design variables a number of experiments are run covering all possible combinations of the signal variables.
- – Can estimate average effects and the variation different design factor levels imply
- – choose factor levels that minimize the sensitivity against disturbances
- From every trial series we can obtain an average result level and a measure of the variation, si, i=1,2, … ,9. These values can then be used as a basis for choosing the combination of factor levels that provides the most robust design.



5.2 Finite Element Analysis:

Results of Finite Element Analysis

FEA has become a solution to the task of predicting failure due to unknown stresses byshowing problem areas in a material and allowing designers to see all of the theoreticalstresses within. This method of product design and testing is far superior to the manufacturingcosts which would accrue if each sample was actually built and tested.

In practice, a finite element analysis usually consists of three principal steps:

1.pre-processing

2.analysis

3.pre-processing

IV. Experimental Analysis

Statistical Design Ofexperiment: Taguchi Method:

Taguchi designs provide a powerful and efficient method for designing products that operate consistently and optimally over a variety of conditions. , the primary goal is to find factor settings that minimize response variation, while adjusting (or keeping) the process on target. . A process designed with this goal will produce more consistent output. A product designed with this goal will deliver more consistent performance regardless of the environment in which it is used.

Taguchi method advocates the use of orthogonal array designs to assign the factors chosen for the experiment. The most commonly used orthogonal array designs are L8, L16, L9 (i.e. eight experimental trials), L16 and L18. The power of the Taguchi method is that it integrates statistical methods into the engineering process.

Table 2.1: CONTROL FACTORS AND THEIR RANGE OF SETTING FOR THE EXPERIMENT

CONTROL FACTOR	LEVEL-1	LEVEL-2	LEVEL-3
Cutting speed	2000rpm	3500rpm	5500rpm
Feed	250mm/min	500mm/min	750mm/min
Depth Of Cut	0.3	0.6	0.9
Tool material	Tungsten carbide	Cubic boron nitride	Alumina ceramic

The above table represents the control factors for hot machining of high manganese steel. As we have four control factors and three levels per factor, according to taguchi method we choose L_9taguchi design. In L_9taguchi design, we use orthogonal arrays instead of standard factorial design. This design reduces the number of experiments from 24 (i.e. factorial 4*3*2*1) to a designed set of 9 experiments.

SIGNAL-TO- NOISE RATIO:

The control factor that may contribute to reduce variation can be quickly identified by looking at the amount of variation present as response. Taguchi has created a transformation of the repetition data to another value which is response measure of the variation present. The transformation is signal-to-noise ratio(S/N).There are three S/N ratios available depending upon the type of characteristics.

1) LOWER IS BETTER: $(S/N)_{LB}$
$= -10 \log (\sum 1/y_i^2)$

2) NOMINAL IS BETTER: $(S/N)_{NB1} = -10 \log V_e$

$(S/N)_{NB2} = 10 \log ((V_m - V_e)/r\, V_e)$

3) HIGHER IS BETTER:

$(S/N)_{HB} = -20 \log (\sum 1/y_i^2)$

Where,y_i = each observed value.

V. Results

Using randomization technique, specimen was turned and cutting forces were measured with the three – dimensional dynamometer. The experimental data for the cutting forces have been reported in Tables. Feed and radial forces being 'lower the better' type of machining quality characteristics, the S/N ratio for this type of

$$\text{S/N ratio} = -10 \log\left[\frac{1}{n}(y_1^2 + y_2^2 + ... + y_n^2)\right] \qquad ... (1)$$

response was and is given below: Where $y_1, y_2, ..., y_n$ are the responses of the machining characteristics for each parameter at different levels.

Table 3.1: EXPERIMENTAL OBSERVATIONS

	CONTROL FACTORS				
TRAIL NUMBER(RUNS)	**CUTTING SPPED(1)**	**FEED(2)**	**DEPTH OF CUT(3)**	**TOOL MATERIAL(4)**	CUTTING FORCE
1	2000	250	0.3	TC	1395.00
2	2000	500	0.6	CBN	369.21
3	2000	750	0.9	AC	163.25
4	3500	250	0.6	AC	417.60
5	3500	500	0.9	TC	139.60
6	3500	750	0.3	CBN	282.55
7	5500	250	0.9	CBN	178.32
8	5500	500	0.3	AC	267.54
9	5500	750	0.6	TC	86.73

In our case the response is cutting force. It would be the best if cutting force is minimum. So as the objective is to minimize cutting force, we select Signal-to-Noise ratio to Smaller the Better (STB) quality.
For Lower the Better the Signal to Noise ratio is given as,
$(S/N)_{LB} = -10 \log (\sum 1/y_i^2)$

With the help of MINITAB software we draw the average SNR table and also plot the Main Effect Plot.

Trial number	**S/N values**
1	-62.8915
2	-51.3455
3	-44.2571
4	-52.4152
5	-42.8977
6	-49.0218
7	-45.0240
8	-48.5478
9	-38.7634

FACTOR'S SNR	**CUTTING SPEED**	**FEED**	**DEPTH OF CUT**	TOOL MATERIAL
SNR1	-52.83	-53.44	-53.49	-48.18
SNR2	-48.11	-47.60	-47.51	-48.46
SNR3	-44.11	-44.01	-44.06	-48.41
DELTA	8.72	9.43	9.43	0.28
RANK	3	1	2	4

Fea Analysis Using Ansys
Force Calculations
1. Cutting Parameters
Speed – 2000rpm
Feed – 250mm/Min
Depth Of Cut - 0.3mm
Cutting Force
N_e = (Depth X Feed X Cutting Speed X Ks) / (60 X 10^3 X Coefficient of Efficiency)
Ne = 4.65KW

Ks = (Ne X60 X 10^3 X Coefficient of Efficiency)/ (Depth X Feed X Cutting Speed)
Coefficient of Efficiency = 0.8
Ks= (4.65X60 X 10^3 X0.8)/(0.3X250 X2000)
Ks=1488N

2. Cutting Parameters
SPEED – 3500rpm
FEED – 500mm/Min
DEPTH OF CUT - 0.9mm
Ks = (4.65X60 X 10^3 X0.8)/(0.9X500 X3500)
Ks=141.71N

3. Cutting Parameters
SPEED – 5500rpm
FEED – 750mm/Min
DEPTH OF CUT - 0.6mm
Ks = (4.65X60 X 10^3 X0.8)/(0.6X750 X5500)
Ks= 90.1818N

4. Cutting Parameters
SPEED – 2000rpm
FEED – 500mm/min
DEPTH OF CUT - 0.6mm
Ks = (4.65X60 X 10^3 X0.8)/(0.6X500 X2000)
Ks= 372N

5. Cutting Parameters
SPEED – 3500rpm
FEED – 750mm/min
DEPTH OF CUT - 0.3mm
Ks = (4.65X60 X 10^3 X0.8)/(0.3X750 X3500)
Ks= 283.422N

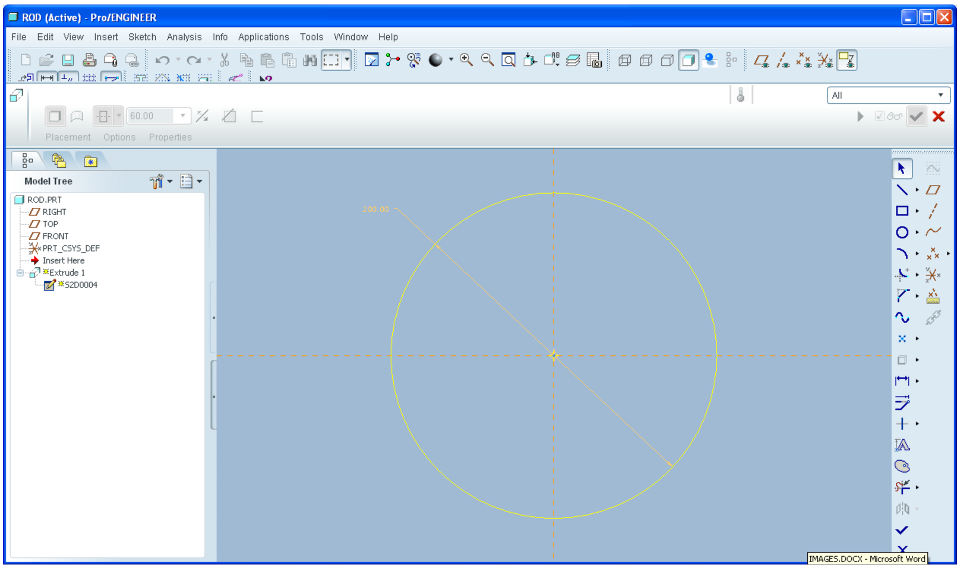
6. Cutting Parameters
SPEED – 5500rpm
FEED – 250mm/min
DEPTH OF CUT - 0.9mm
Ks = (4.65X60 X 10^3 X0.8)/(0.9X250 X5500)
Ks= 180.36N

7. Cutting Parameters
SPEED – 2000rpm
FEED – 750mm/min
DEPTH OF CUT - 0.9mm
Ks = (4.65X60 X 10^3 X0.8)/(0.9X750 X2000)
Ks= 165.33N

8. Cutting Parameters
SPEED – 3500rpm
FEED – 250mm/min
DEPTH OF CUT - 0.6mm
Ks = (4.65X60 X 10^3 X0.8)/(0.6X250 X3500)
Ks= 425.14N

9. Cutting Parameters
SPEED – 5500rpm
FEED –500mm/min
DEPTH OF CUT - 0.3mm
Ks = (4.65X60 X 10^3 X0.8)/(0.3X500 X5500)
Ks= 270.544N

7.2 3DMODEL USING PRO-E SOFTWARE
WORK PIECE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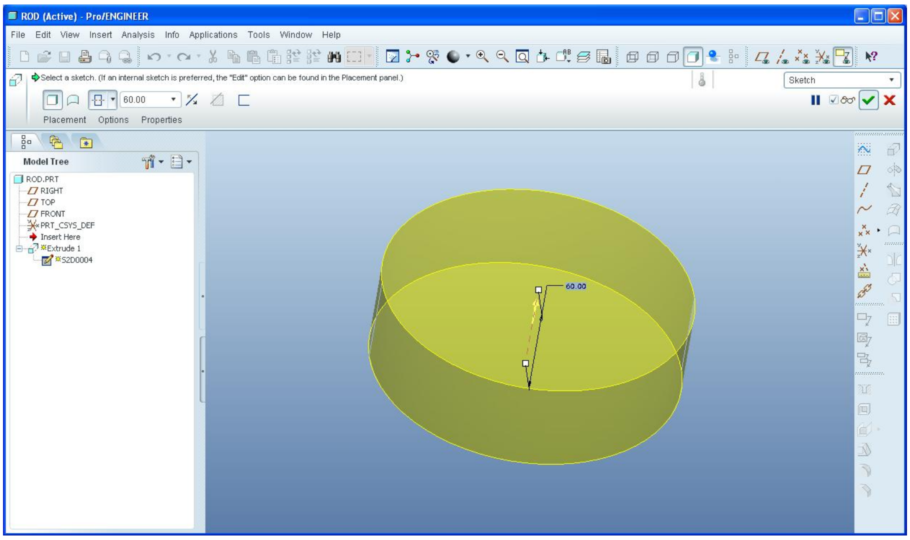
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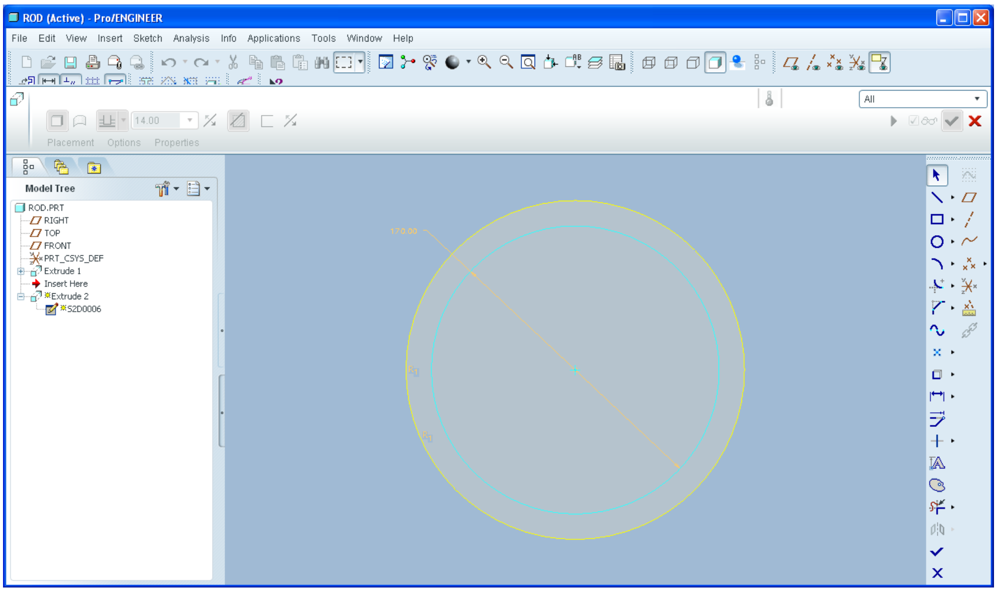
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Extrude 2
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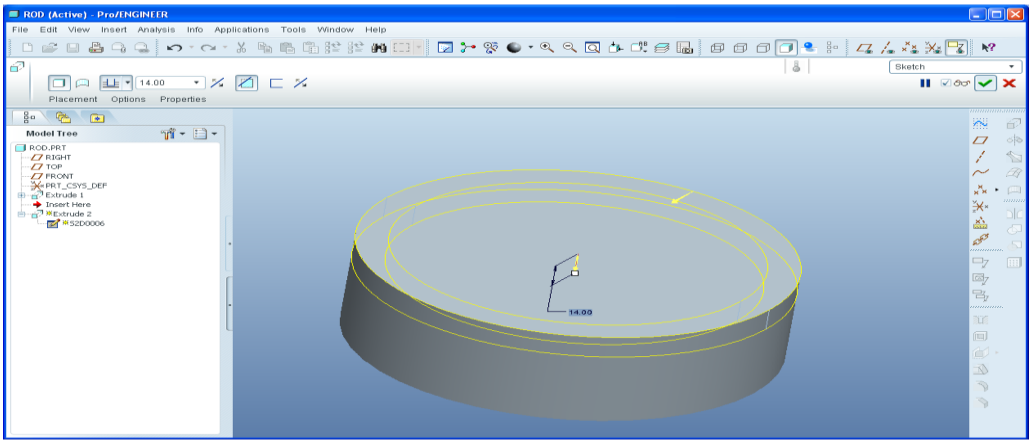
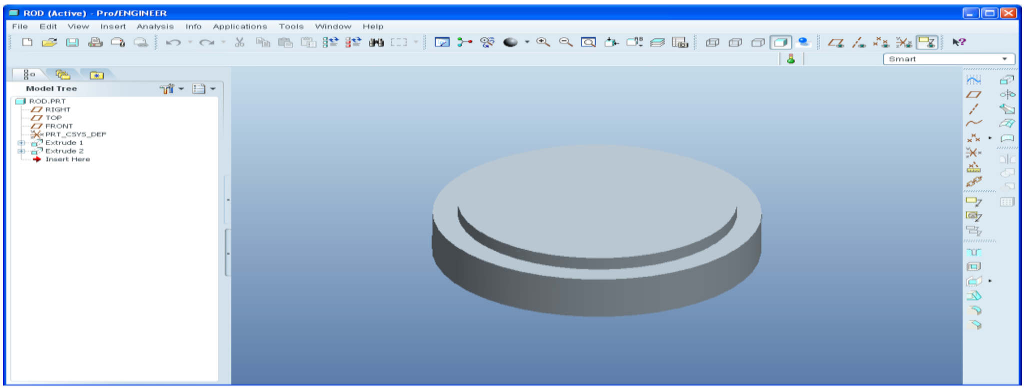
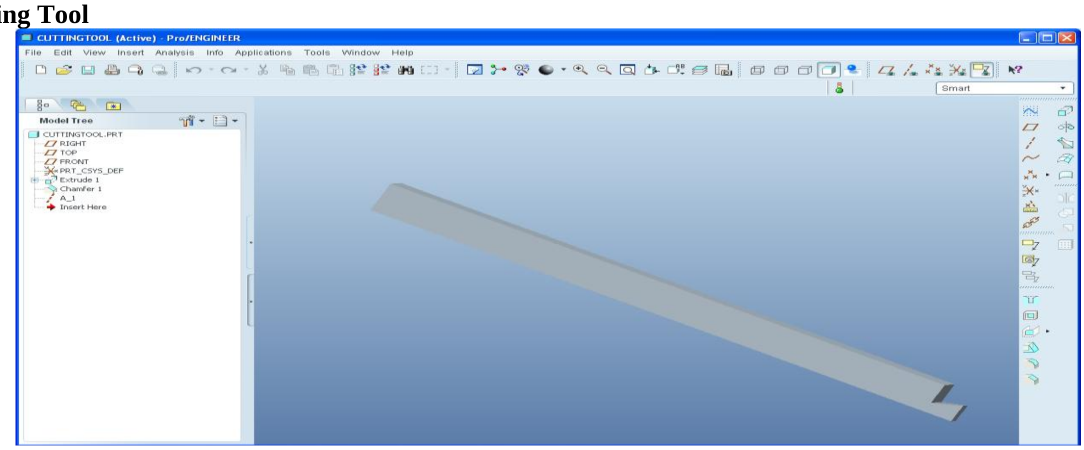
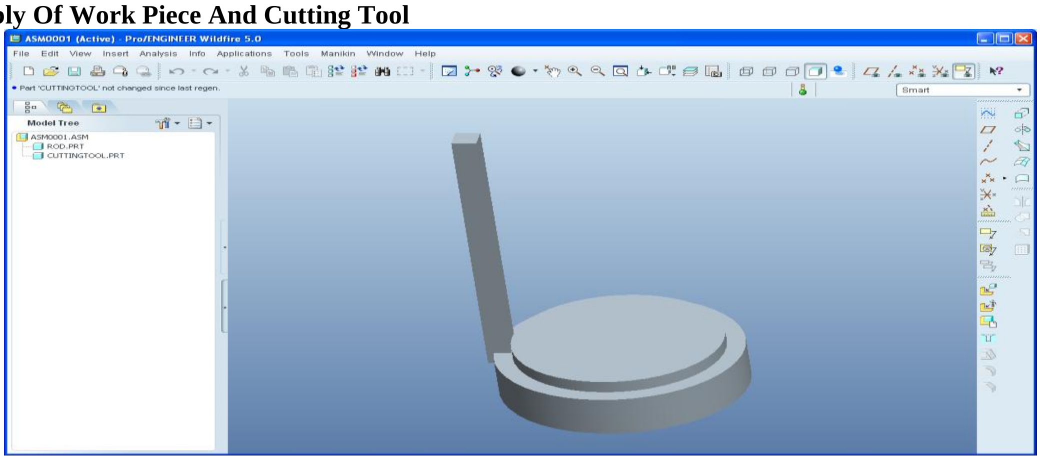




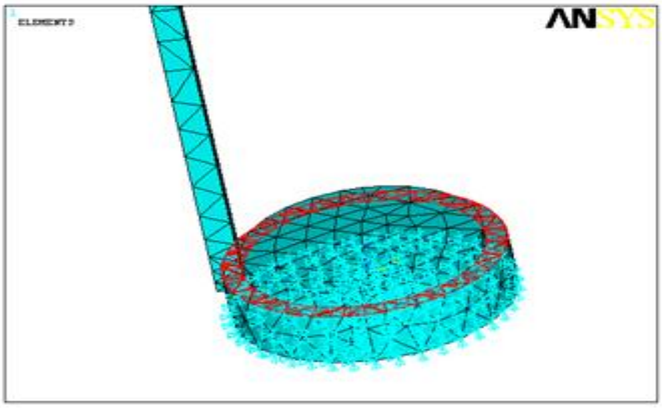
Cutting Tool



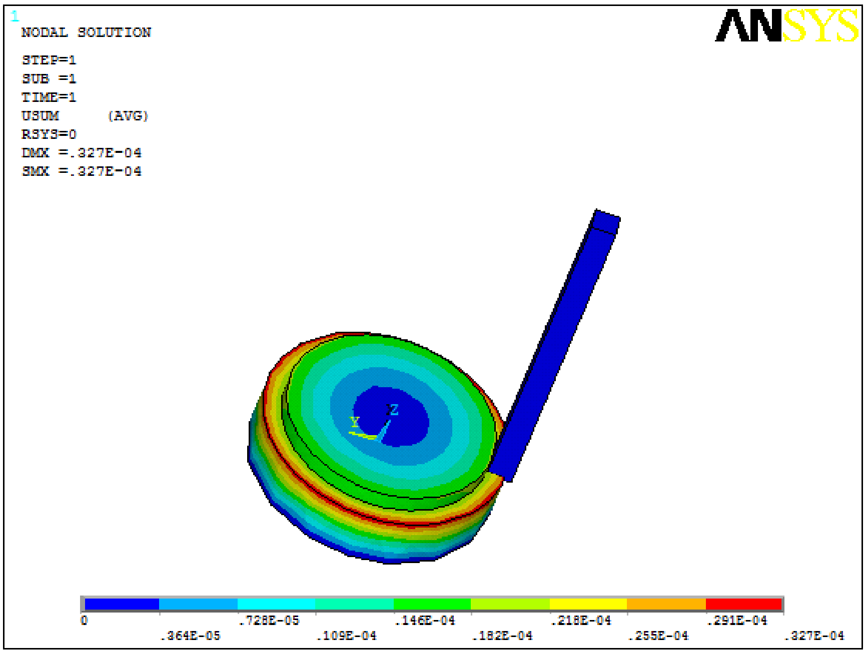
Assembly Of Work Piece And Cutting Tool



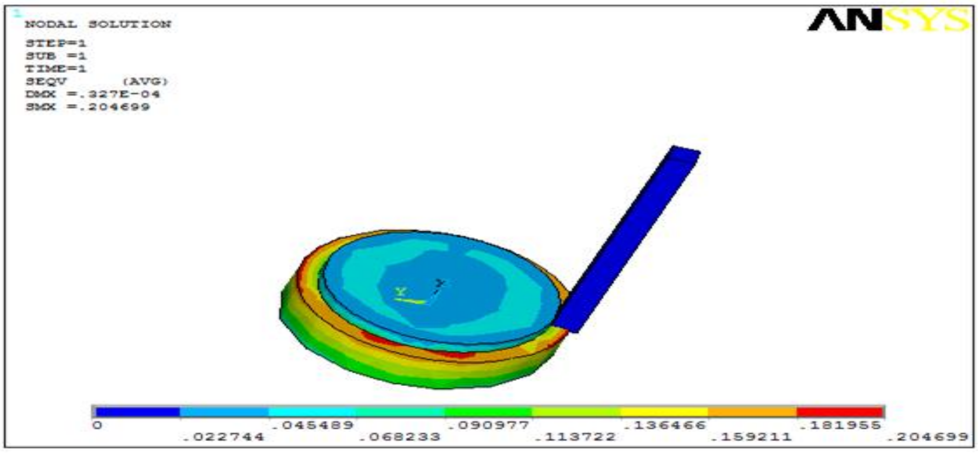
7.3 Analysis Of Cutting Tool And Workpiece
7.3.1 Work Piece – Inconel 718, Cutting Tool – Tungsten Carbide
Material Properties
Work Peice-
YOUNG MODULUS- 200GPa
POISSON'S RATIO - 0.294
DENSITY- 8.19 g/cc
CUTTING TOOL – TUNGSTEN CARBIDE
YOUNG MODULUS – 713.82 GPa
POISSON'S RATIO - 0.24
DENSITY- 0.00000158 kg/mm
CUTTING PARAMETERS
CUTTING SPEED-2000rpm
FEED RATE- 250mm/min
DEPTH OF CUT-0.3 mm
Loads- define loads- apply- structural- displacement – on Areas-ok
Pressure –on Areas- 0.170 N/mm^2-ok.



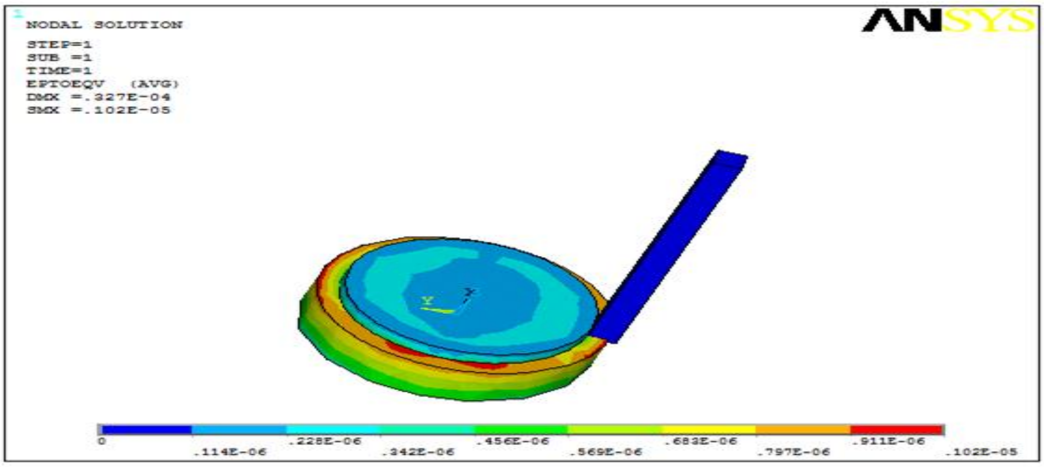
Solution- solve – current l.s – ok
General postprocessor-plot results- contour plots- nodal solutions- displacement vector sum-ok



General postprocessor-plot results- count our plots nodal solution- stress- von mises stress

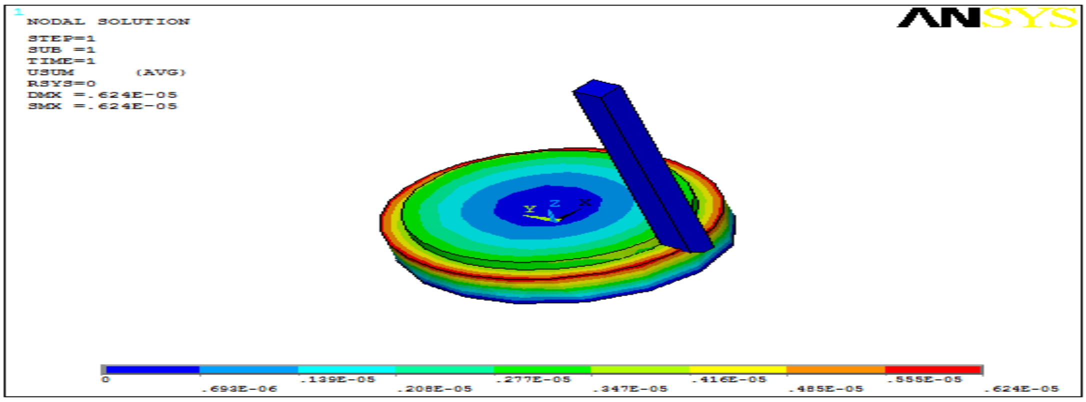


General postprocessor-plot results- contour plots nodal solution- strain- total strain intensity

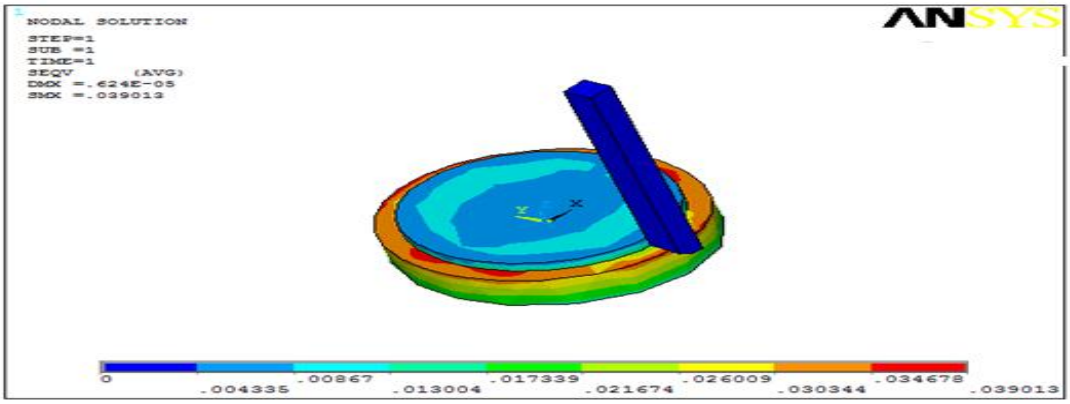


Cutting Parameters
CUTTING SPEED-3500rpm
FEED RATE- 750mm/min
DEPTH OF CUT-0.3mm
Loads- define loads- apply- structural- displacement – on Areas-ok
Pressure –on Areas- 0.0324N/mm^2-ok.
Solution- solve – current l.s – ok

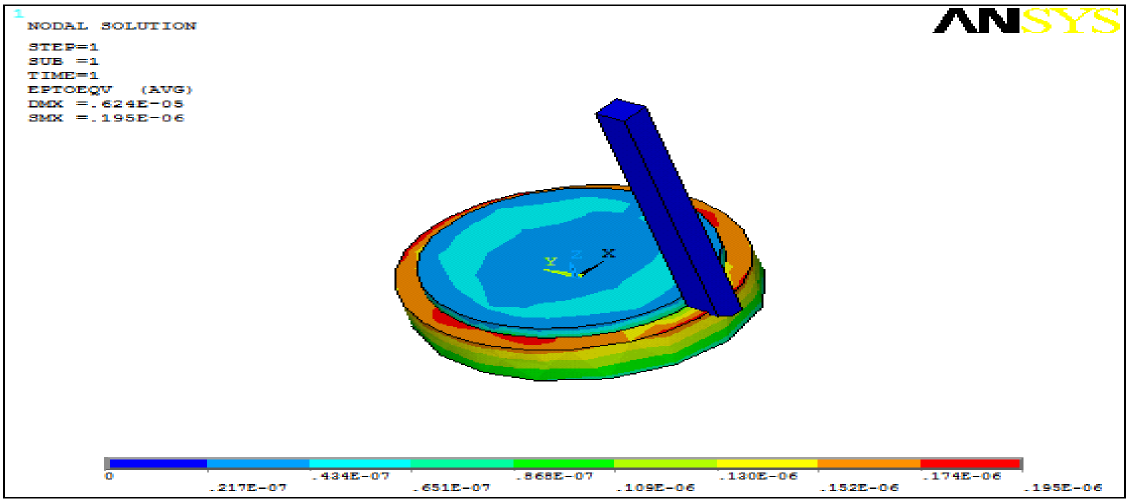
General postprocessor-plot results- contour plots- nodal solutions- displacement vector sum-ok



General postprocessor-plot results- count our plots nodal solution- stress- von mises stress



General postprocessor-plot results- contour plots nodal solution- strain- total strain intensity



Results Table

8.1 Cutting Tool – Tungsten Carbide

	Displacement (mm)	Stress (N/mm^2)	Strain
CUTTING SPEED-2000rpm FEED RATE- 250mm/min DEPTH OF CUT-0.3mm	0.327 e^{-04}	0.204699	0.102 e^{-05}
CUTTING SPEED-3500rpm FEED RATE- 500mm/min DEPTH OF CUT-0.9mm	0.328 e^{-05}	0.019266	0.965 e^{-07}
CUTTING SPEED-5500rpm FEED RATE- 750mm/min DEPTH OF CUT-0.6mm	0.199 e^{-05}	0.012438	0.623 e^{-07}

8.2 Cutting Tool – Cubic Boron Nitride

	Displacement (mm)	Stress (N/mm^2)	Strain
CUTTING SPEED-2000rpm FEED RATE- 500mm/min DEPTH OF CUT-0.6mm	0.821 e^{-05}	0.051295	0.257 e^{-06}
CUTTING SPEED-3500rpm FEED RATE- 750mm/min DEPTH OF CUT-0.3mm	0.039013	0.195 e^{-06}	0.624 e^{-05}
CUTTING SPEED-5500rpm FEED RATE-250mm/min DEPTH OF CUT-0.9mm	0.397 e^{-05}	0.024805	0.124 e^{-06}

8.3 Cutting Tool – Alumina Ceramic Ky 1615

	Displacement (mm)	Stress (N/mm^2)	Strain
CUTTING SPEED-2000rpm FEED RATE- 7250mm/min DEPTH OF CUT-0.9mm	0.364 e^{-05}	0.022758	0.114 e^{-06}
CUTTING SPEED-3500rpm FEED RATE- 250mm/min DEPTH OF CUT-0.6mm	0.938 e^{-05}	0.05864	0.294 e^{-06}
CUTTING SPEED-5500rpm FEED RATE-500mm/min DEPTH OF CUT-0.3mm	0.595 e^{-05}	0.037207	0.186 e^{-06}

VI. Conclusion

In this thesis, the effect of parameters cutting speed, feed rate and depth of cut while turning of Nickel alloy Inconel 718 are formulated mathematically using three different cutting tools Tungsten carbide,Alumina Ceramic KY1615 and Cubic Boron Nitride. A parametric model of cutting tool and work piece is designed using 3D modeling software Pro/Engineer.Experimental investigations are done to determine the cutting forces. By observing the results, spindle speed of 5500rpm, feed rate of 750mm/min and depth of cut 0.6mm yields better results as the cutting forces are less. The cutting tool is Tungsten Carbide.Analytical investigations are made on the model by applying the forces by taking different values of cutting speed, feed rate and depth of cut. The parameters considered are: Spindle Speed – 2000rpm,3500, 5500rpm; Feed Rate – 250mm/min, 500mm/min,750mm/min;Depth of Cut – 0.3mm,0.6mm,0.9mm.Tool Material-TC,CBN,AC. Structural Analysis is done in ANSYS.By observing the structural analysis results, the analyzed stress values are less than the yield stress values of the respective materials for all speeds and feed rates. The displacement values are also very less.

And also while using Tungsten Carbide as cutting tool, the optimal parameters are 5500rpm, feed rate 750mm/min and 0.6mm depth of cut has less stress values. While using Cubic Boron Nitride as cutting tool, the optimal parameters are 5500rpm, feed rate 250mm/min and 0.9mm depth of cut has less stress values. And also while using Alumina Ceramic as cutting tool, the optimal parameters are 2000rpm, feed rate 450mm/min and 0.9mm depth of cut has less stress values. So comparing all the results, the better parameters are 5500rpm, feed rate 750mm/min and 0.6mm depth of cut by using Tungsten Carbide tool.By experimental observations, Using randomization technique, specimen was turned and cutting forces were measured with the three – dimensional dynamometer. The experimental data for the cutting forces have been reported in Tables. Feed and radial forces being 'lower the better' type of machining quality characteristics.so we can conclude, the optimised parameters are 5500rpm, feed rate 750mm/min and 0.6mm depth of cut by using Tungsten Carbide tool.

References

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Peta.Anil Kumar"Finite Element Analysis of Optimization for Turning Parameters of Super Alloy Inconel 718 "International Journal of Engineering Science Invention (IJESI), vol. 07, no. 06, 2018, pp 21-32