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Thermomechanical Analysis of Cutting Tool Used for Minimizing Tool Wear During Machining of Inconel 718

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Abstract

During the CNC machining process, high stresses and temperatures are created at the cutting edge during machining of Inconel 718 due to severe tool wear. Inconel 718, one of the most often used Ni alloys, has a low machinability. Hence, determination of proper cutting tool to minimize tool wear and reduce surface roughness becomes an important aspect. Considering the scenario, the model-ling of dry turning of Inconel 718, a 3-Dimensional (3D) numerical model based on Finite Element (FE) is used. Turning tests were used to validate the model. The main wear modes that were dis-covered experimentally (chipping, notching, and built up edge BUE) were linked to variables predicted by the computational model, such as temperature and plastic strain at the chip. In this study, response surface methodology is used to design four features, matrix for a flexible composite design consisting of 5 repetitive levels; planning, implementation, implementation and development of mathematical models. Medium cutting strength is determined by the different feed values in the tangential, radial, and axial directions during the tooth by maintaining immersion and axial depth of the cut as constant. A comparison is shown between modeling and experimentation. In this paper, the principal stress and displacement strain has been seen at the tool-work interface region of three cutting tools during machining Inconel 718. Three directions i.e tangential, radial, and axial directions these stress and displacement has been applied to observe the changes and determine the selection of the suitable cutting tool for optimal machining conditions and parameter selection. It is observed that titanium cutting tool can prove to be a better tool to be used for machining Inconel 718 for longer tool life and improve productivity.

Major Findings: *The principal stress and Von-Mises stress in the thermomechanical analysis during Machining of Inconel 718 is found to be less in titanium cutting tool. This is the most suitable tool that can be used for machining hard to cut material Inconel 718.*

Keywords: *CNC Machining, Cutting Tool, Modelling, Thermomechanical Analysis, Tool Wear*

1.0 Introduction

Machining of hard-to-reduce substances with traditional approaches continues to be taken into consideration as a difficult, because the unique works of those substances regularly result in speedy device put on and decreased floor integrity. For that reason, it's far superior to mix traditional machining approaches with different technology so as to conquer the troubles of machining those substances[1].

In the prevailing work, laser assisted turning experiments on a Ti-6Al-4V work piece had been carried out the usage of AlTiN lined reducing equipment so as to analyze the impact of laser heating on reducing forces, reducing temperature, device put on and micro structure alterations. Two collections of experiments

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had been carried out beneath various reducing speed, laser spot diameter and work piece diameter values; the primary collection worried simplest laser heating of the work piece and the second one each laser heating and reducing. The findings found out the impact of parameters on reducing forces and temperature figuring out the significance of work piece diameter size, indicated the formation of martensite segment on the pinnacle of the heat- affected area of the work piece and additionally confirmed that excessive temperatures can result in in-depth device put on, as an alternative of getting a useful impact for the reducing device. Finally, finite element (FE) simulations had been performed if you want to take a look at the time evolution of the temperature subject and calculate the heating and cooling fees in the course of the manner[2].

From the FE results, highly excessive heating and cooling fees had been discovered for smaller work piece diameters and decrease reducing speed, while the excessive value of those fees justified the advent of the martensite segment *via* diffusion less transformation. Here three cutting tools are taken on work piece and checked for multiple conditions like feed rate and thermal temperature at around 500° C and end up getting the material which suits up the job[3]. A large amount of heat is produced during the mechanical process and in a separate process where transformation takes place. Temperature built into the surface of the cutting tool when a cutting tool meets a piece of work to cut the temperature of the tool. Heat is a factor that greatly influences the performance of a tool during operation.

The energy used in metal cutting is often converted into heat[4]. Built-in temperature of the cutting time depends mainly on the connection between the tool and the chip, cutting mechanism and the friction generated between chip and tool. In particular, all the heat generated is transferred to the cutting tool and the part is cut off with a chip. In between machining temperatures produced in the deformation area affect both the piece and the work tool. A major source of error in the manufacturing process occurs at high temperatures as well contributes to the temperature change of the cutting tool and greatly influences the wear of the tool, tool health, integrity of the work part of the work, method of chip design[5].

Many research activities are dedicated to developing analytical and numerical models, mimicking metal cutting processes and the effects of mechanical flexibility such as cutting speed, feed and cutting depth. Numerical models are very important in predicting power, chip composition, weight distribution, degree of weight, temperature and pressure on the cutting edge[6]. Due to excessive heat and built in temperature at the tool-work interface region which is seen as important parameter in describing the longetivity of the tool. The present study is to determine the important factors which describes the impact of the heat, temperature, stress and strain in bringing down the tool life. Even the study investigates the selection of better cutting tool to machine Inconel 718. To read the impact on the geometric edges and cutting edges in the area of integrity especially in mechanical stress using advanced simulation techniques.

2.0 Methodology

Analysis of the finished result of the multi-point cutting tool is done using Ansys 23.1, a comprehensive limitation analysis package. Ansys 23.1 is a limited-value analysis package to numerically solve many mechanical, structural and non-structural problems. These problems include static or dynamic analysis of the structure (both direct and indirect), heat transfer and fluid problems as well as acoustic and electromagnetic problems[7].

In this paper, analysis of thermo-mechanical of Inconel 718 is done using single point cutting tool. The thermal analysis is used to determine the temperature distribution and value such as heat distribution, heat loss or gain, heat gradient, temperature fluctuations *etc*. The problem of analysis here is basically structural - thermal[8]. Usually, the combination of physics is ignored or simplified. Simulation engineers often use single-physics. Because integrated analysis is more computer-based. However, integrated analysis yields more realistic results. The Ansys 23.1 Workbench is designed to facilitate simulation of multiphysics integration. In terms of integration, integration of multiphysics can be divided into two. They are a series of interactions and direct combinations.

In successive connections, integration is considered in one direction only and in direct integration, integration is considered in both directions[9]. The thermal way to structural integration can be easily defined in workbench. However, one method of thermal integration formation is not possible. Direct integration is available, but not from the workbench interface. To represent direct integration,

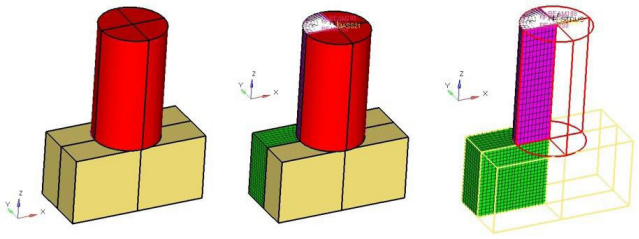


Figure 1. Quarter symmetry model for consideration in FEA.

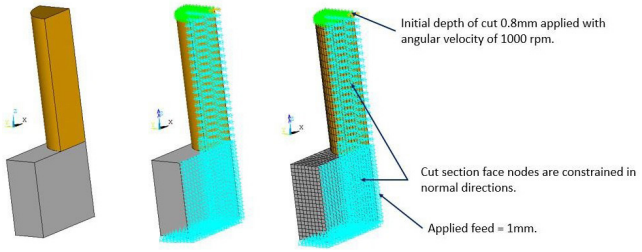


Figure 2. Loads and boundary conditions applied in the quarter symmetry model

APDL commands should be applied[10]. The user must select the features of the integrated field. One method of thermal bonding formation is usually represented by direct bonding with it. Structural analysis is better than thermal analysis in terms of mesh and out-comes[11].

Three cutting tools which are Titanium, Carbide and Ceramic are taken under consideration on work piece Inconel 718. The geometry and finite element model is shown in Figure 1.

Once the geometry is done the boundary conditions are applied that is the cut sections are constrained in normal direction and bottom phases in all direction. Then with the fixed work piece, cutting tool is moved for feeding the initial parameters depth of cut which is 0.5 mm and feed rate as 0.08 mm/min. In Figure 2, it is observed the conditions for the boundary.

Figure 3 below describes the meshing of the work piece and cutting tool which is taken for quarter symmetric in order to save time. Once the meshing for quarter symmetric is done then mirroring is done to get the total 3-D geometry[12].

2.1 Carbide Cutting Tool

For carbide cutting tool the stress developed in the tool is gradually increasing towards the tip of the cutting tool, this shows that there will a tool wear at the tool work interface region when the tool is being acting on the work piece. The work piece Inconel 718 is also same to develop max stress throughout the work piece[13]. This can be due to surface irregularity being formed when the tool is acting which is worn out however this tool cannot be taken at this 1000 rpm cutting speed and 0.8 m/min and depth of cut 0.2. The properties of carbide cutting tool is shown in Table 1.

Table 1. Properties of carbide cutting tool

Properties	Values
Cutting speed	75 m/min
Feed rate	0.8 mm/rev
Depth of cut	0.05 mm
Boiling point	6000°C
Melting point	2785°C

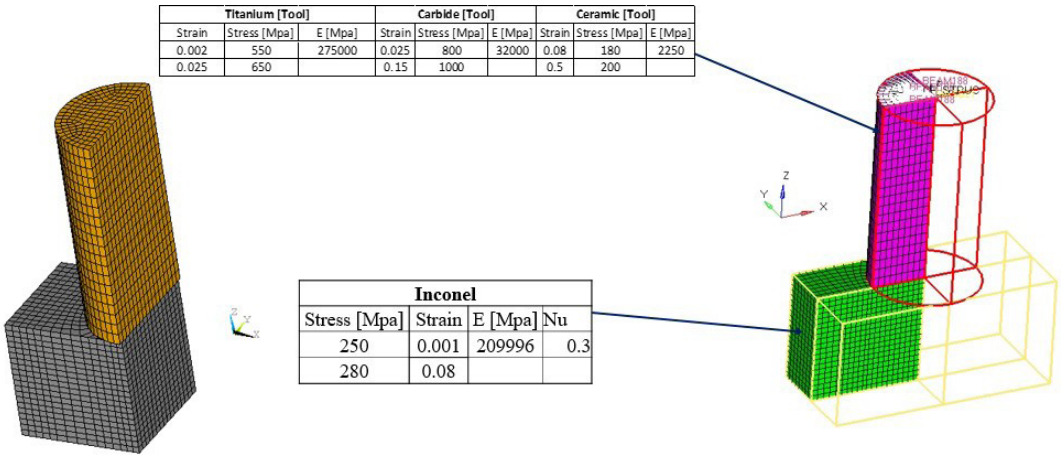


Figure 3. Material properties used in the quarter symmetry model.

2.2 Titanium Cutting Tool

For titanium cutting tool less stress has been developed within the tool when it is acting on the Inconel 718 the stress developed on the work piece is accurately being done at the tool work interface region and then stress gradually distributed throughout the work piece so the machinability of the work piece will be done smoothly with this cutting tool. The titanium tool has following data shown in Table 2.

2.3 Ceramic Cutting Tool

For ceramic cutting tool the stress developed at the tool work interface region is found to be highest than the other cutting tool, also the tip of tool cutting has stress higher than the other tool. This shows the wear condition of the cutting tool, also the stress developed at the work piece which is due to the irregular stress on the surface done by wear off cutting tool is not recommended to be used at the parametric condition of cutting at speed 1000 rpm, feed rate 1mm/min and depth of cut 0.8 mm. The work piece is Inconel-718 on which the feed rate Principle-1 stress is taken and with scaling it has been considerable distribution of principle stress in the feed rate is slower than the other tool[14]. The properties of titanium cutting tool is shown in Table 3.

Table 2. Properties of titanium cutting tool

Properties	Values
Cutting speed	50 m/min
Feed rate	0.05 to 0.51mm/rev
Depth of cut	0.2 mm
Boiling point	3287°C
Melting point	1668°C

Table 3. Properties of ceramic cutting tool

Properties	Values
Cutting speed	450 rpm
Feed rate	0.75 mm/rev
Depth of cut	0.15 mm
Boiling point	1800°C-2000°C
Melting point	1500°C

3.0 Results

After finding the characteristics properties of all the cutting tool then the average out of it was taken and to the conclusion of the standard parameters to be taken which came up is shown in Table 4.

3.1 X Displacement

The X displacement for all three cutting tools on the work piece is applied and the stresses developed is noticed. When the titanium cutting tool is moving across the feed rate direction as shown in Figure 4, the considerable amount of stress is seen among the feeds and the displacement is also minimum. This shows effective machining been carried out along feed rate direction[15]. Stress minimum = -0.35044 MPa. Stress maximum =1.01076 MPa, Maximum displacement = 1.17547 MPa. These parameters shows the value of stress that can be withstand with this cutting tool to machine,

Table 4. Standard parameters of cutting tool on Inconel 718

Properties	Values
Cutting speed	1000 rpm
Feed rate	0.08 mm
Depth of cut	0.5 mm
Temperature	500°C

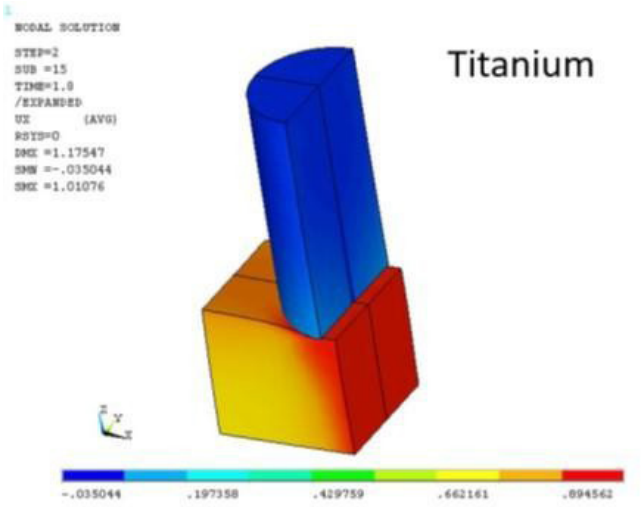


Figure 4. X Axis displacement for titanium cutting tool.

the cutting tool with better accuracy and good surface finish[16].

When the ceramic cutting tool is moving across the feed rate direction as shown in Figure 5, the considerable amount of stress is seen among the feeds and the displacement is also minimum. This shows effective machining been carried out along feed rate direction. It is observed that Stress maximum = 1.00027 MPa, Stress minimum = -0.066866 MPa and Displacement maximum = 1.00028 MPa. These parameters of ceramic cutting tool shows the value of stress that can be withstand with this cutting tool to machine the cutting tool with better accuracy and good surface finish. The red zone indicates that these parameters though ideal for machining Inconel 718 cannot withstand the temperature generated at the tool-work interface and hence this tool should not be selected for machining the work piece[17].

When the carbide cutting tool is moving across the feed rate direction as shown in Figure 6, the considerable amount of stress is seen among the feeds and the displacement is also minimum. This shows effective machining been carried out along feed rate direction. It is observed that Stress maximum = 1.00365 MPa, Stress minimum = -0.063188 MPa, Displacement maximum = 1.00394 MPa. This cutting tool proves that the parameters selected can machine Inconel 718 but the tool will lose the longetivity of being machined the cutting tool and hence not to select this tool for these parameters[18].

In the Table 5, it can be observed that the titanium cutting tool can handle maximum stress and displacement in X-direction during the machining of Inconel 718 which is required, since Inconel 718 is a hard to cut material.

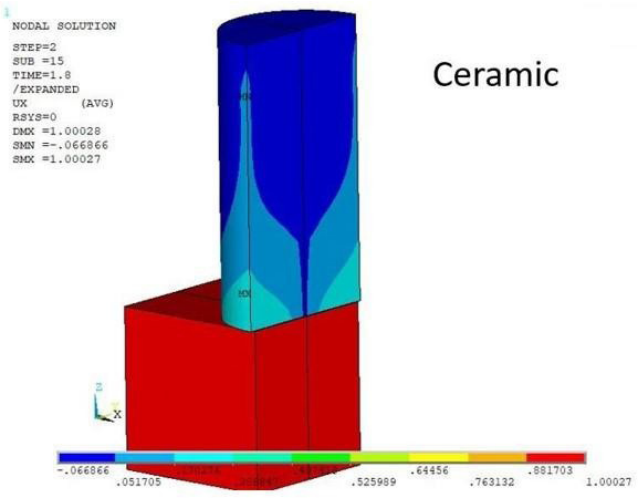


Figure 5. X Axis displacement for ceramic cutting tool.

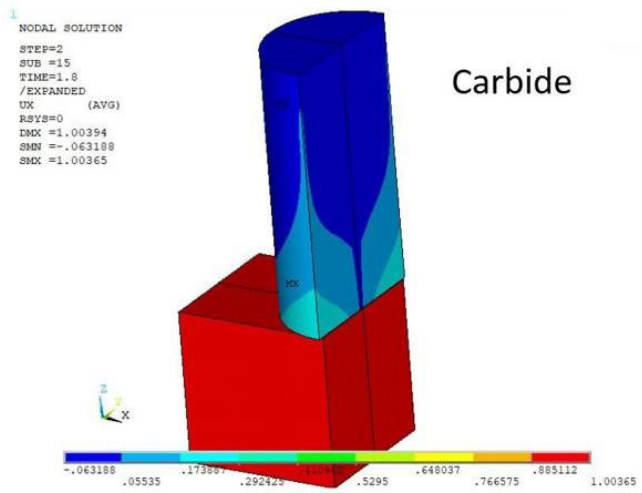


Figure 6. X Axis displacement for carbide cutting tool.

Table 5. Optimal parameters of X-displacement of cutting tool on Inconel 718

Cutting Tool or Parameter	Titanium	Ceramic	Carbide
Stress minimum	–0.35044 MPa	–0.066866 MPa	–0.063188 MPa
Stress maximum	1.01076 MPa	1.00027 MPa	1.00365 MPa
Displacement Maximum	1.17547 MPa	1.00028 MPa	1.00394 MPa

3.2 Y Displacement

The Y displacement for all three cutting tools on the work piece is applied and the stresses developed is noticed. When the tool is moving along Y-direction as shown in Figure 7, the maximum stress is being generated at the starting point which shows that the machining can be carried out. It is observed that Stress maximum = 1.17547 MPa, Stress minimum = 0.461336 MPa, Displacement maximum = 1.17547 MPa. This parameters predict the selection of titanium as the better cutting tool since the red zone is only seen at the tool work interface region, than the entire work piece and also can generate better machining features[19].

When the carbide cutting tool is moving along Y-direction as shown in Figure 8, the maximum stress is

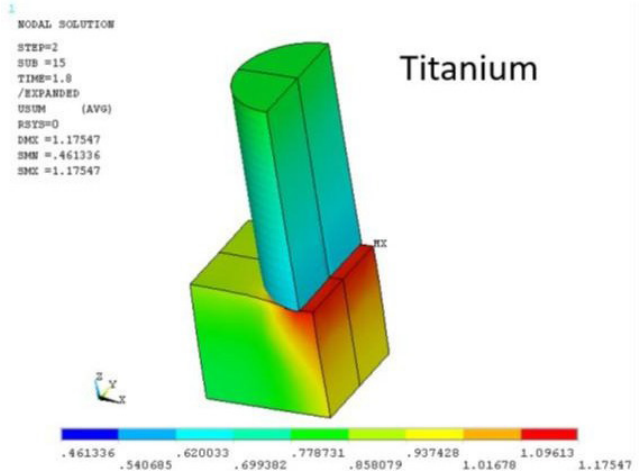


Figure 7. Y Axis displacement for titanium cutting tool.

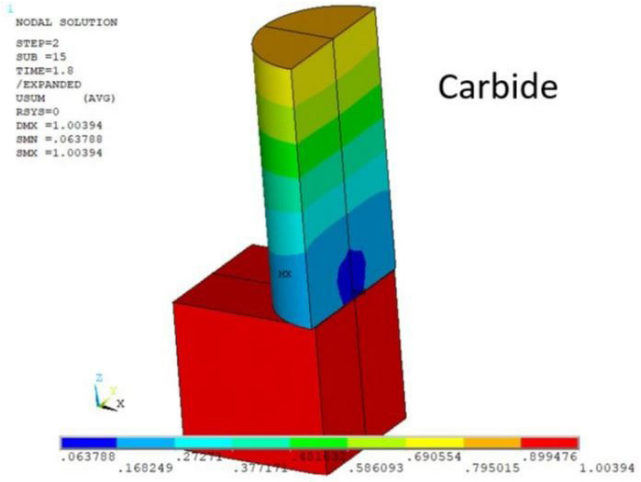


Figure 8. Y Axis displacement for carbide cutting tool.

being generated at the starting point which shows that the machining can be carried out. It is observed that Stress maximum = 1.00394 MPa, Stress minimum = 0.063788 MPa, Displacement maximum = 1.00394 MPa. The red zone shows that the tool selection is inappropriate at these parameters and not to be chosen for the machining of Inconel 718 for good surface finish.

When the ceramic cutting tool is moving along Y-direction as shown in Figure 9, the maximum stress is being generated at the starting point which shows that the machining can be carried out. It is observed that Stress maximum = 1.00028 MPa, Stress minimum = 0.022078 MPa, Displacement maximum = 1.00028 MPa. The parameters chosen for the cutting tool cannot produce better machining features and not to be selected for optimal parameters to machine Inconel 718. The tool

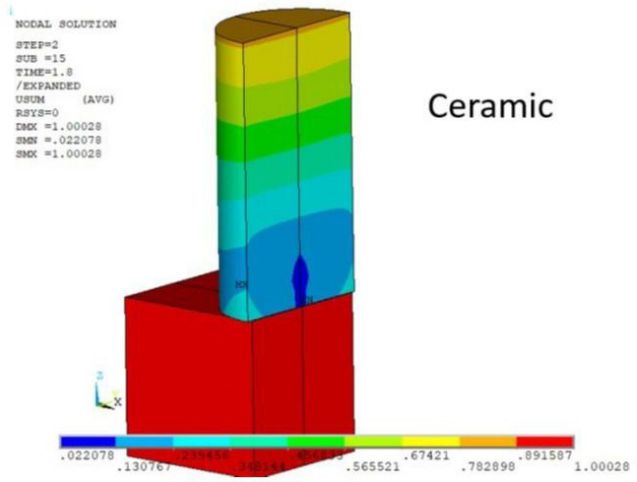


Figure 9. Y axis displacement for ceramic cutting tool.

Table 6. Optimal parameters of Y-displacement of cutting tool on Inconel 718

Cutting Tool or Parameter	Titanium	Ceramic	Carbide
Stress minimum	0.461336 MPa	0.022078 MPa	0.063788 MPa
Stress maximum	1.17547 MPa	1.00028 MPa	1.00394 MPa
Displacement maximum	1.17547 MPa	1.00028 MPa	1.00394 MPa

machining parameters are not ideal to be chosen due to the red zone appearing over the entire work piece[20].

In the Table 6, it can be observed that the titanium cutting tool can handle maximum stress and displacement in X-direction during the machining of Inconel 718 which is required since Inconel 718 is a hard to cut material.

3.3 Z Displacement

When the titanium cutting tool is penetrating the work piece as shown in Figure 10, there is maximum displacement seen at the tool work interface region which shows the machining been carried out effectively. It is observed that Stress maximum = 0.01083 MPa, Stress minimum = - 0.8MPa, Displacement maximum = 1.17547 MPa. The tool has shown considerable machining features over the entire work piece.

When the carbide cutting tool is penetrating the work piece as shown in Figure 11, there is maximum

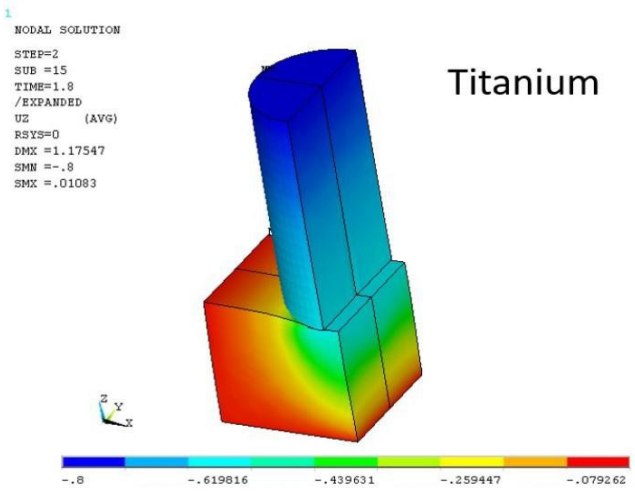


Figure 10. Z axis displacement for titanium cutting tool.

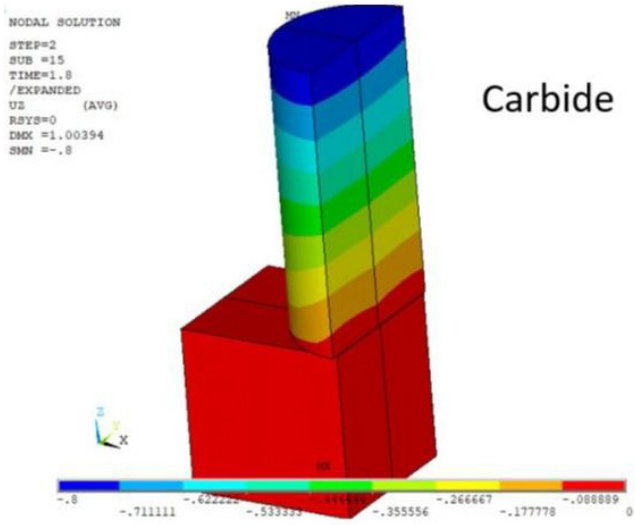


Figure 11. Z axis displacement for carbide cutting tool.

displacement seen at the tool work interface region which shows the machining been carried out effectively. It is observed that Stress maximum = 0 MPa, Stress minimum = -0.8 MPa, Displacement maximum = 1.0035 MPa. The dissipation of heat energy at the work piece is very high which can reduce the tool life.

When the ceramic cutting tool is penetrating the work piece as shown in Figure 12, there is maximum displacement seen at the tool work interface region which shows the machining been carried out effectively. It is observed that Stress maximum = 0 MPa, Stress minimum = -0.8 MPa, Displacement maximum = 1.0028 MPa. The tool cannot be chosen for the machining of Inconel 718.

Table 7. Optimal parameters of Z-displacement of cutting tool on Inconel 718

Cutting Tool or Parameter	Titanium	Ceramic	Carbide
Stress minimum	–0.8 MPa	–0.8 MPa	–0.8 MPa
Stress maximum	0.01083MPa	0 MPa	0 MPa
Displacement maximum	1.17547MPa	1.0028 MPa	1.0035 MPa

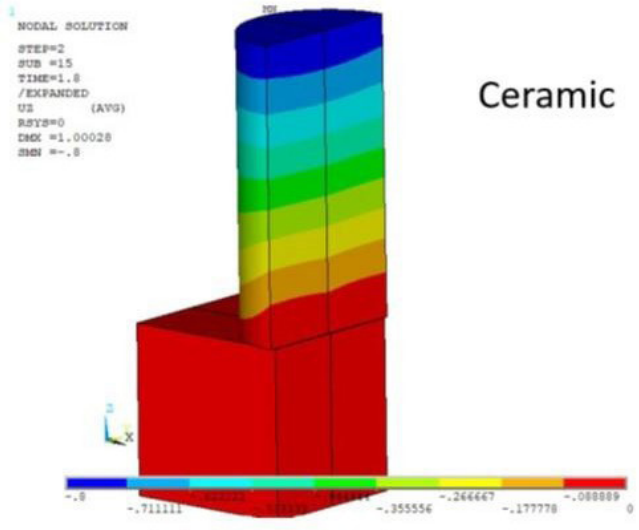


Figure 12. Z axis displacement for ceramic cutting tool.

In the Table 7, it can be observed that the titanium cutting tool can handle maximum stress and displacement in Z-Direction during the machining of Inconel 718 which is required since Inconel 718 is a hard to cut material.

4.0 Discussion

4.1 Von Mises Stress

When the Von Mises stress is applied in the modeling of the three cutting tools- titanium, carbide and ceramic during machining of the work piece Inconel 718. It is observed that work piece chipping is smooth during titanium cutting tool application seen in Figure 13, but when carbide or ceramic cutting tool is used on Inconel 718 the stress developed in the work piece may create uneven roughness on the work piece owing to the disintegration of the grains on the surface of the work piece after machining, in Figure 14 is observed and also in

Figure 15 respectively. It is observed that the cutting tool titanium produces better surface finish in the work piece which can be noticed by the red zone whereas in ceramic and carbide cutting tools it is very high and hence cannot be selected for machining Inconel 718 at the parameters considered.

In Figure 13, Von Mises stress has developed at the tool-work interface region resulting in the chipping of the work piece and the machining of Inconel 718 occurring effectively. The light blue region shows the stress that has been developed due to the titanium cutting tool acting on the work piece Inconel 718. Hence, machining will be done.

In Figure 14, Von Mises stress has developed very low at the tool-work interface region resulting in the less

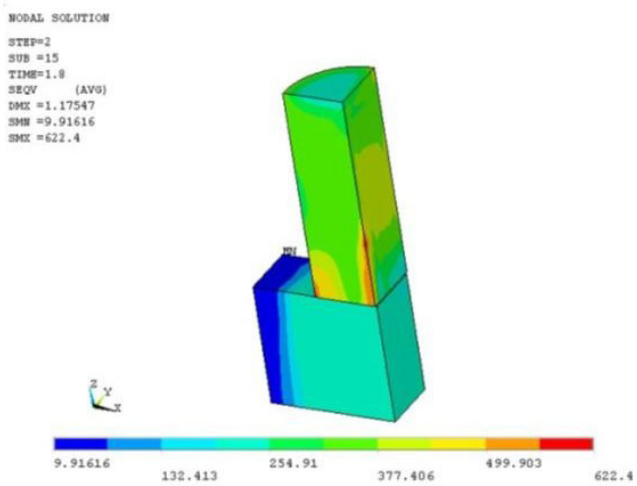


Figure 13. Von Mises stress for titanium cutting tool.

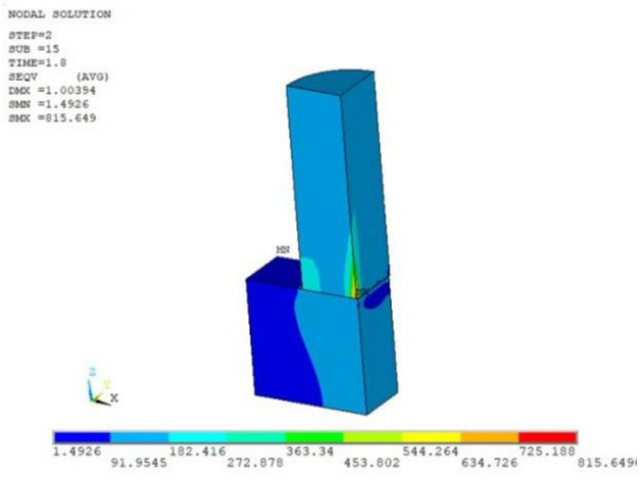


Figure 14. Von Mises stress for carbide cutting tool.

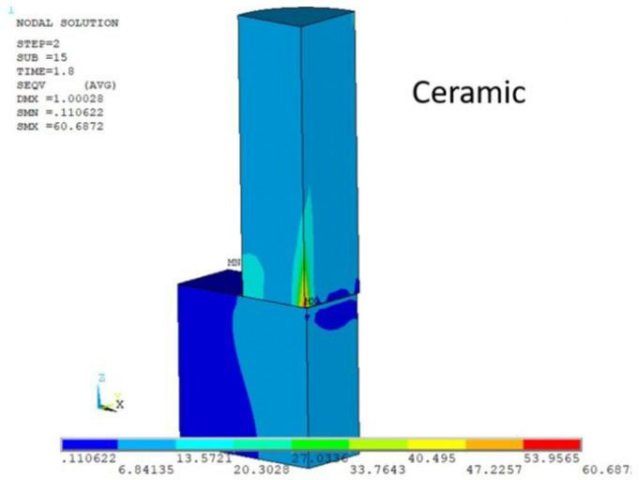


Figure 15. Von Mises stress for ceramic cutting tool.

chipping effect of the work piece owing to the machining condition of Inconel 718. The dark blue region shows the stress that has not been developed due to the carbide cutting tool acting on the work piece Inconel 718. Hence, machining will not be done effectively and will impact the wear on the tool.

In Figure 15, Von Mises stress has developed very small at the tool-work interface re-gion resulting in the minimal chipping effect of the work piece owing to the machining condition of Inconel 718. Hence, machining will not be done very effectively and will impact the wear on the tool and also decrease the tool life.

4.2 Principle Stress

There has been considerable distribution of principle stress on the cutting speed along the feed rate direction which shows lower tool wear on the cutting tool. The distribution of principle stress along carbide, titanium and ceramic is shown in Figures 16, 17 and 18 respectively. Titanium cutting tool showing less tool wear during principle stress analysis proving to be the better in choice than the other two cutting tools taken into consideration. The titanium cutting tool shows a remarkable feature in machining Inconel 718 with good considerable parameters while the other two cutting tools ceramic and carbide cutting tool are not able to machine Inconel 718 which can be seen by the red zone in the work pieces.

In Figure 16, principle stress seems to be building at the tool work interface region. Light blue region shows the stress that has been built up in the entire tool owing

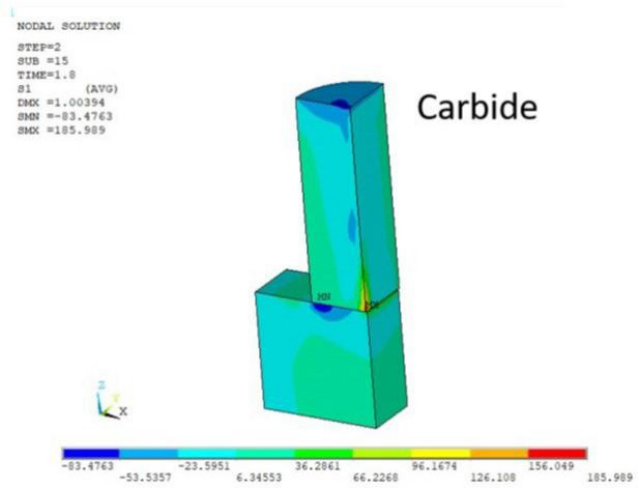


Figure 16. Principle stress for carbide cutting tool.

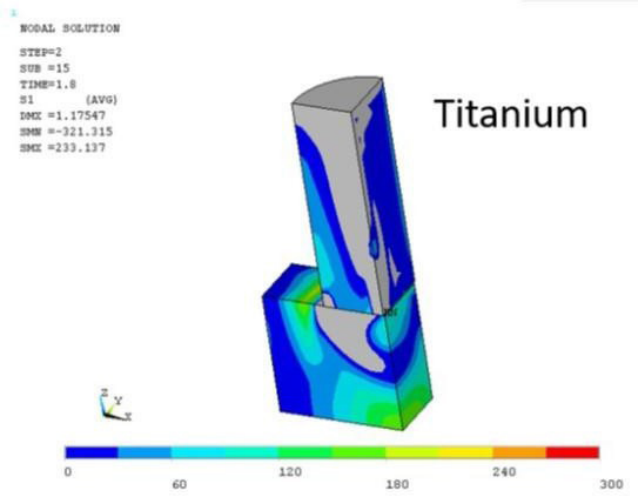


Figure 17. Principle stress for titanium cutting tool.

to the increase of temperature at the interface region resulting in increasing tool wear.

In Figure 17, principle stress seems to be low and distributed uniformly at the tool work interface region. Dark blue region shows the little stress that has been built up in the entire tool owing to the low temperature at the interface region resulting in reduction in tool wear. Also, the grey region shows no stress has been built up by the principle stress showing the stability of the titanium cutting tool to be used for machining Inconel 718.

In Figure 18, principle stress seems to be building rapidly at the tool work interface region. Light blue region shows the stress that has been built up all over the entire tool owing to the increase of temperature at the tool-work

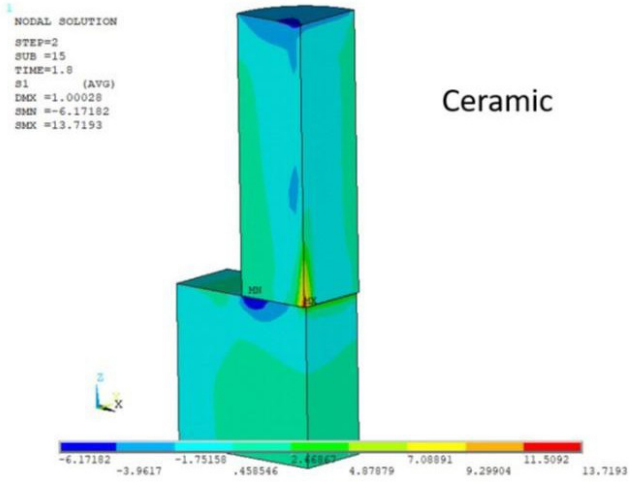


Figure 18. Principle stress for ceramic cutting tool.

interface region resulting in high tool wear than all the other cutting tools taken into consideration.

5.0 Conclusion

After carrying out the analysis by the 3 cutting tools during machining of Inconel 718, the following conclusions were observed by the thermo mechanical analysis.

1. Titanium cutting tool is found to be better than other two cutting tools due to high stress resistance acting on higher cutting parameters.
2. Titanium cutting tool is seen to have less Von Mises stress distribution inside its grains due to which it has the capability to withstand higher temperature and machining condition.
3. Titanium cutting tool is seem to have less principal stress distribution than the other two cutting tools due to which it can have a prolong tool life and better heat resistance.
4. Carbide cutting tool is seem to be better than ceramic but less effect than the titanium cutting tool due to its stress developed at Von Mises region and principle stress region.
5. Ceramic cutting tool seems to have the most less effective in machining Inconel 718 which can be seen because of the highest stresses being developed at Von Mises region and principle stress region.
6. While comparing the three cutting tools, the maximum stress developed is found to be less in titanium. Thus, making it the obvious choice to perform machining on Inconel 718 if the cutting speed is 1000 rpm, feed rate is 1mm/min, depth of cut is 0.8 mm and temperature around 500° C.

6.0 Author Contribution

Conceptualization, I. S. R; methodology, A. R., F. X. and A. M. R.; software, F. X.; validation, A. R and A. M. R.; formal analysis, A. R.; investigation, F. X.; resources, I. S. R.; data curation, A. R. and A. M. R.; writing-original draft preparation, I. S. R.; writing-review and editing, I. S. R.; visualization, P. P. P and F. X.; supervision, P. P. P.; project administration. All authors have read and agreed to the published version of the manuscript.

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