International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 5 (2018) pp. 2158-2162

Optimization of Process parameters in hot machining of Inconel 718 alloy using FEM

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Abstract

Nickel-based alloys can be found in applications particularly in aircraft engines, gas turbines because of its high strength, strong corrosion resistance and excellent thermal fatigue properties and thermal stability compared to conventional materials. Nickel-based alloy is one of the extremely difficult-to-cut materials. Preheating of work piece reduces the yield strength which makes machining easier. To describe plastic behavior of material Johnson-cook material model is used. The Johnson–Cook material model is most widely used and the simplest model in metal cutting simulation which can relate the material behavior at high temperatures, high strains and high strain rates. In the present paper, finite element based simulation of heat assisted machining of Inconel 718 alloy has been carried out using ABAQUS software. Finally simulation results of vonmises stress at different influential parameters combination of speed, feed and preheating temperatures are presented and of optimum parameters combination is determined.

Keywords: Hot machining, Abaqus/Explicit, FEM, Orthogonal metal cutting. Inconel 718

INTRODUCTION

Nickel based super alloys play the prominent role in aerospace industry due to its good mechanical properties, chemical resistance and thermal conductivity at elevated temperatures. However, due to these outstanding properties, these alloys are difficult to machine and the surface integrity of a machined component can be affected if suitable machining conditions are not taken. In several research studies, many authors carried out the machining of hard materials using finite element simulation. A K Parida et al. [1] analyzed the effect of nose radius on temperature distribution in the tool and observed the increase of cutting force and thrust force with increase of nose radius at both room and heated conditions. Liu et al [2] studied the effect of edge roundness on residual stresses in AISI304 steel using FE model. Moaz H Ali et al. [3] predicted surface roughness with effective feed rate of the cutting force components and surface finish during the face milling operation of titanium alloy. Diaz et al. [4] focused on prediction of temperature and its measurement during the machining of Ni-based super alloys as it is crucial to control the cutting process, avoiding work piece damage. Muthu Elangovan et al. [5] suggested that J-C model is still the most popular model for simulating machining due to its robustness and its ease of application in the FE codes. Temperature generation and distribution during chip formation has been formulated and solved using Abaqus FEM software and stress analysis also carried out by B.V.R.M Kumar et al [6]. Abhushawashi Y et al [7, 12, 13] Selected suitable J-C model parameters which provide best fit between predicted and measured results. Arvind J et al [8] focused on chip morphology during orthogonal machining using numerical model and compared with experimental results. M. H. Miguelez et al [9] and M. Nasar et.al [10] studied the residual stress induced in work piece of different materials has been simulated by FEM. Woon et al [11] studied the effect of nose radius on chip formation, stress distribution using finite element simulation. Many researchers carried out machining simulations to study the influence of machining parameters, tool geometry on cutting forces and temperature distribution and residual stresses but little work was found in heat assisted machining using FEM simulation. The main objective of this paper is to predict the influence of machining parameters in heated condition on stresses using FEM simulation and to find optimum parameters. The predictive model was developed and simulated under different values of cutting parameters i.e. cutting speed, feed rate and temperature.

FINITE ELEMENT MODELING

The FEM simulation software Abaqus/Explicit was used to study the heat assisted machining of Inconel 718 alloy. The 3D model of work piece and cutting tool were developed based on Johnson-Cook Model (Eq.1) which can relate the material behavior at high temperatures, high strains and high strain rates. Figure 1 shows the solid model of work piece and tool and Figure 2 shows the FEM model.

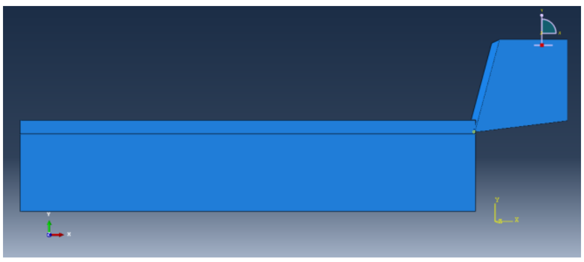

Figure 1. Solid model of tool-work piece

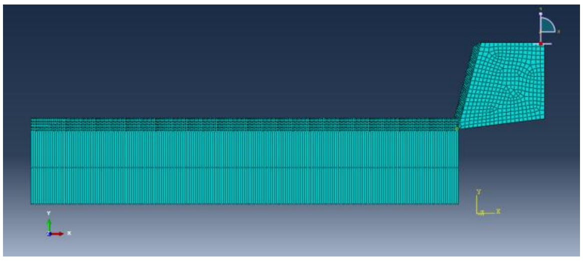

Figure 2. FEM model of tool-work piece

$$\sigma_{eq} = \left[A + B\varepsilon_p{}^n\right]\left[1 + C\ln(\dot{\varepsilon}^*)\right]\left[1 - T^{*m}\right] \qquad (1).$$

$$\varepsilon_f = [D_1 + D_2 \exp(D_3\sigma^*)][1 + D_4 \ln(\dot{\varepsilon}_P{}^*)][1 + D_5T^*] \qquad (2)$$

Material deformation studies are also conducted based on J-C failure model (Eq.2). J-C model parameter values for Inconel 718 alloy considered are listed in Table 1. The J-C model parameters are very much suitable for dynamic simulation applications.

Nomenclature

A - Yield stress (MPa)

B - Strain hardening parameter (MPa)

n - Strain hardening exponent

C - Strain rate sensitivity parameter

m -Temperature exponent

ε_p - Plastic strain

$\dot{\varepsilon}^* = (\dot{\varepsilon}_p{}^* / \dot{\varepsilon}_0)$ is dimensionless strain rate

$T^{*m} = (T-T_0) / (T_m - T_0)$; T, T0 and T_m being the working temperature, room temperature and melting temperature respectively.

ε_f = fracture strain

D_1 to D_5 are coefficients of Johnson-Cook material shear failure initiation criterion

$\sigma^* = \sigma_m / \sigma_{eq}$ is the stress

σ_{eq} = equivalent stress

σ_m =mean stress

Table 1. J-C model parameters of Inconel 718 alloy

A(MPa)	B(MPa)	n	m	C
980	1370	0.164	1.03	0.020
D_1	**D_2**	**D_3**	**D_4**	**D_5**
0.11	0.75	-1.45	0.04	0.89

The Tungsten Carbide (WC) cutting tool is selected for this simulation studies based on work piece material properties. The properties of Inconel 718 alloy and WC and the tool geometry are listed in Table 2 and 3.

Table 2. Geometry of cutting Tool

Rake angle, α	Clearance angle	Nose radius (mm)
15^0	7^0	0.8

Table 3. Properties of Work piece and Tool

S. No	Parameter	Inconel 718	WC
1	Density(kg/m^3)	8195	15700
2	Young's Modulus(GPa)	200	705
3	Poisson ratio	0.3	0.23
4	Thermal conductivity(W/m^{0}C)	11.4	24
5	Specific heat(J/Kg/^{0}C)	430	178

Friction at tool-chip interface influences the formation of chip, temperature and tool wear. The coefficient of friction between tool and work piece is considered as 0.15. The work piece deformation is assumed as elastic in nature and the interaction between tool-chip and tool-work piece is considered as general contact. Boundary conditions applied are shown in Figure 3 as work piece bottom is fixed and the tool is constrained to move along x-direction. Pre heating temperature is applied at the top of the work piece.

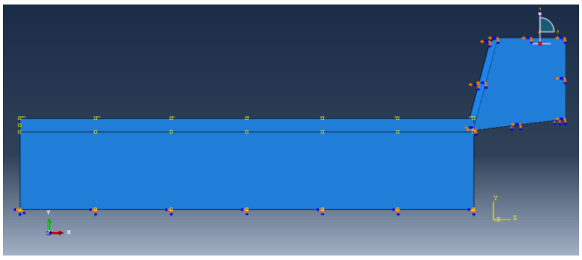

Figure 3. Boundary conditions applied to tool and work piece

Simulation Runs

The layout of simulation runs are designed based on full factorial method by considering the machining parameters speed, feed and temperature shown in Table 4 keeping depth of cut as constant.

Table 4. Process parameters and their levels

parameters	speed	feed	temperature
Level 1	50	0.25	25
Level 2	100	0.5	300
Level 3	150	0.75	600

Table 5. Results Table

S. No	Speed (m/min)	Feed(mm/rev)	Temp. (^{0}C)	Stress (Moises)GPa
1	50	0.25	25	2.8
2	50	0.25	300	2.7
3	50	0.25	600	2.4
4	50	0.50	25	2.8
5	50	0.50	300	2.6
6	50	0.50	600	2.3
7	50	0.75	25	2.9
8	50	0.75	300	2.6
9	50	0.75	600	2.4
10	100	0.25	25	2.8
11	100	0.25	300	2.7
12	100	0.25	600	2.3
13	100	0.50	25	2.7
14	100	0.50	300	2.6
15	100	0.50	600	2.3
16	100	0.75	25	2.75
17	100	0.75	300	2.6
18	100	0.75	600	2.4
19	150	0.25	25	2.8
20	150	0.25	300	2.6
21	150	0.25	600	2.4
22	150	0.50	25	2.7
23	150	0.50	300	2.6
24	150	0.50	600	2.1
25	150	0.75	25	2.7
26	150	0.75	300	2.6
27	150	0.75	600	2.3

Table 6. S/N values at different machining conditions

S. No	Speed (m/min)	Feed(mm/rev)	Temp. (^{0}C)	S/N Ratio
1	50	0.25	25	-7.94
2	50	0.25	300	-8.01
3	50	0.25	600	-8.25
4	50	0.50	25	-7.94
5	50	0.50	300	-8.09
6	50	0.50	600	-8.33
7	50	0.75	25	-7.87
8	50	0.75	300	-8.07
9	50	0.75	600	-8.25
10	100	0.25	25	-7.94
11	100	0.25	300	-8.01
12	100	0.25	600	-8.33
13	100	0.50	25	-8.01
14	100	0.50	300	-8.07
15	100	0.50	600	-8.33
16	100	0.75	25	-7.98
17	100	0.75	300	-8.07
18	100	0.75	600	-8.25
19	150	0.25	25	-7.94
20	150	0.25	300	-8.07
21	150	0.25	600	-8.25
22	150	0.50	25	-8.01
23	150	0.50	300	-8.07
24	150	0.50	600	-7.33
25	150	0.75	25	-8.01
26	150	0.75	300	-8.09
27	150	0.75	600	-8.33

RESULTS AND DISCUSSION

The vonmises stress value and signal-to-noise ratio(S/N) at different machining conditions are simulated and listed in Table 5 and Table 6.

The S/N ratios are calculated for the simulation results. The S/N ratio method is used to measure the deviation of the performance characteristics from the targeted values. The categories of performance characteristics in the analysis of the S/N ratio depend on output parameters which are either smaller-the-better or higher-the-better.

Irrespective of the category of the performance characteristic, a larger S/N ratio value corresponds to better performance. Therefore, the optimal level of the machining parameters is the level with the highest S/N ratio.

Some vonmises stress plots observed during the simulation at different conditions is shown in figure 4(a) to figure 4(g).

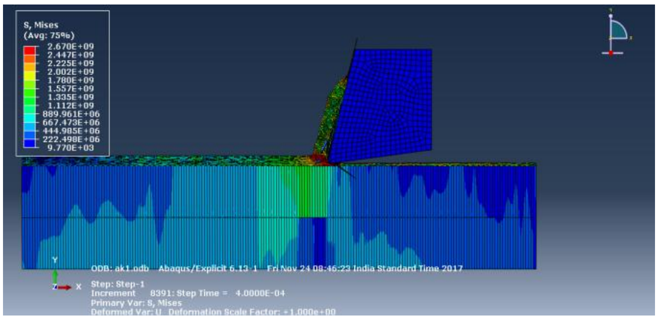

Figure 4a: V=50m/min, f=0.25mm/rev, T=25^{0}C

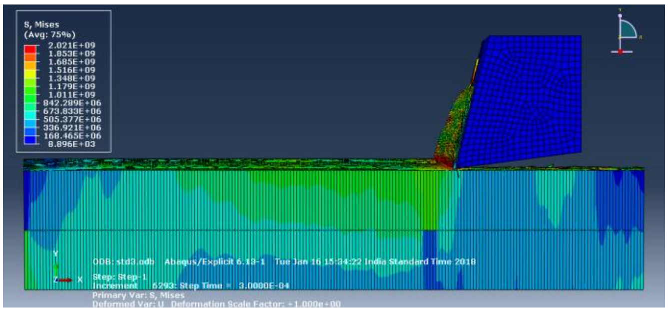

Figure 4b: V=50m/min, f=0.25mm/rev, T=600^{0}C

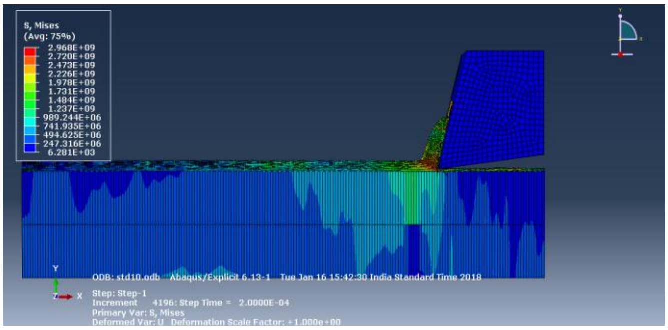

Figure 4c: V=100m/min, f=0.25mm/rev, T=25^{0}C

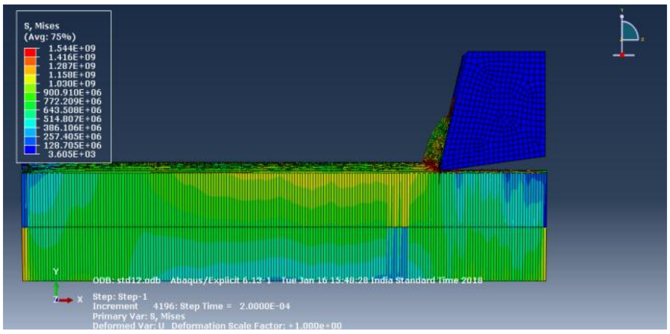

Figure 4d: V=100m/min, f=0.25mm/rev, T=600^{0}C

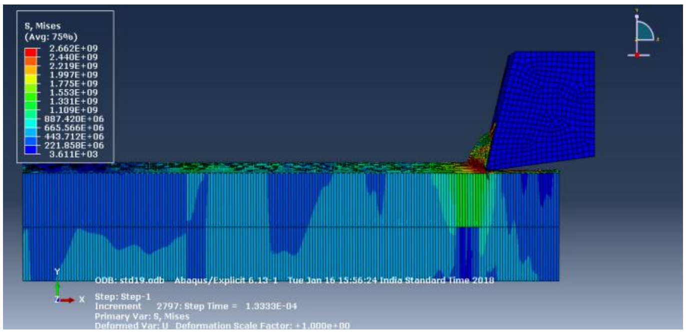

Figure 4e: V=150m/min, f=0.25mm/rev, T= 25^{0}C

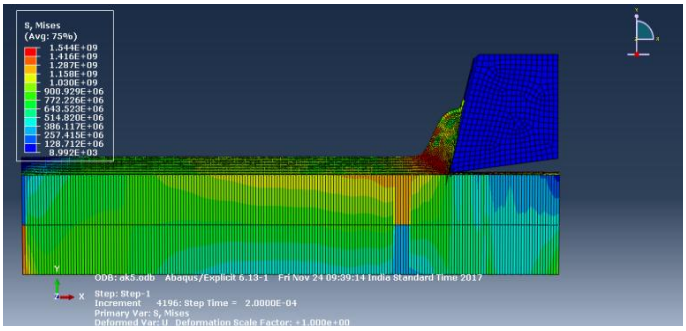

Figure 4f: V= 100m/min, f=0.50mm/rev, T= 600^{0}C

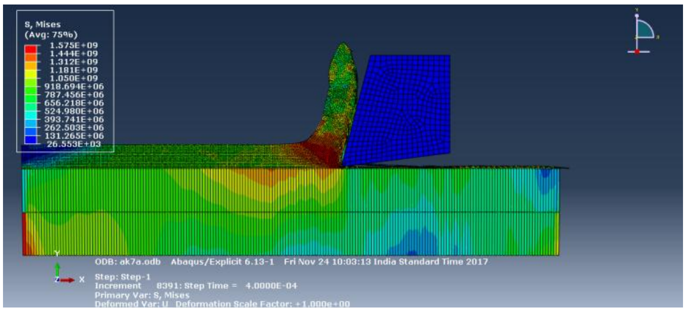

Figure 4g: V= 150m/min, f=0.75mm/rev, T= 600^{0}C

For stresses, the smaller the better approach is considered. The optimum combination of parameters obtained at V=150m/min, f=0.5mm/rev., T= 600^{0}C. Finally, the optimum parameters combination is verified with developed model.

Table 7: Response table of S/N ratio of Vonmises Stress

Level	Speed	feed	Temperature
1	0.055	0.053	0.175
2	0.025	0.004	0.074
3	0.013	0.003	0.159
Delta(Max-Min)	0.042	0.05	0.101
Rank	3	2	1

Table 7: ANOVA for Vonmises stress

Source	DF	Seq SS	Seq MS	F-Value	P-value	%Contribution
V	2	0.007	0.003	3.37	0.05	77.5
f	2	0.010	0.005	5.15	0.015	21.13
T	2	0.529	0.264	250.76	0.001	0.14
Error	20	0.021	0.001			
Total	26	0.568				100

Response values of S/N ratio are shown in Table 7. ANOVA results for Vonmises stress is given in Table 8, which shows that preheating temperature has more influence on stress induced during machining, followed by feed and cutting speed.

CONCLUSIONS

It is clear from the simulation tests that stress reduces with increase of cutting speed, preheating temperature and decrease of feed rate. We got the optimum parameters obtained from the simulation are V=150m/min., f=0.5mm/rev, T= 600^0C. From ANOVA table, it is can concluded that the pre heating temperature has more influence on stress. Irrespective of different speed, feed combination, pre heating temperature has more influence on stress; the stress value is reduced during preheating condition compared to room temperature condition. The results are not validated with experimental values but similar trend in stress values is obtained.

REFERENCES

[1] Asit Kumar P, K Maity, 2016, Effect of nose radius on forces, and process parameters in hot machining of Inconel 718 using finite element analysis. Engineering Science and Technology, an International Journal 20 (2017) 687–693

[2] Liu and Guo, Finite element modeling the influence of edge roundness on the stress and temperature fields induced by high-speed machining. The international journal of advanced Manufacturing technology, pp.255-267, 2006

[3] Moaz H. Ali, Basim A. Khidhir, M.N.M. Ansari, Bashir Mohamed, 2013, FEM to predict the effect of feed rate on surface roughness with cutting force during face milling of titanium alloy. HBRC Journal (2013) 9,263-269

[4] Diaz-Alvarez J, Cantero J L, Miguelez H, Soldani X, Numerical analysis of thermo mechanical phenomena influencing tool wear in finishing turning of Inconel 718. Int. J. Mech. Sci. 2014, 82, 161-169.

[5] Muthu Elagovan, K Senthamarai, S Jayabal, Finite element simulation in machining of Inconel 718 nickel based super alloy. International Journal of Advanced Engineering Applications, Vol.5, Iss.3, pp.22-27(2012)

[6] B.V.R.M Kumar, K Hemachandra Reddy, Ch. R. Vikram Kumar, Finite Element Model Based On Abaqus / Explicit To Analyze The Temperature Effects Of Turning. International Journal of Applied Engineering Research ISSN 0973-4562 Volume 11, November 8(2016) pp 5728-5734

[7] Abushawashi Y, Xiao. Astakhov V. FEM Simulation of Metal cutting using a New Approach to model chip formation. Int. J. Adv. Mach. Form. Oper2011; 3:71-92

[8] Arvind J, Raja Hussain, process modelling, simulation and experimental validation for prediction of chip morphology during high speed machining of Al 2024-T3. SAS TECH Journal volume 13, Issue1, April 2014

[9] M. H. Miguelez, R. Zaera, A. Molinari, R. Cheriguene, and A. Rusinek, Residual stresses in orthogonal cutting of metals: The effect of thermo mechanical coupling parameters and of friction. Journal of thermal stresses, 2009, vol.32, n. 3, p.269-289

[10] M. Nasar, E.G Ng, and M.A. Elbestawi, Modelling the effects of Tool-Edge Radius on Residual stresses when orthogonal cutting AISI316L. International Journal of Machine Tools Manufacturing, vol. 47, pp. 401-411, 2007

[11] Keng Soon Woon, Mustafizur Rahman, The effect of tool edge radius on the chip formation behavior of tool-based micromachining**.** October 2010. International Journal of Advanced Manufacturing Technology 50(9):961-977

[12] Ng, E.-G., Tahany I. E.W., Dumitrescu, M., and Elbastawi, M.A., 2002, Physics-based simulation of high speed machining. Machining science and technology, 6/3,301-329

[13] Guo,Y.B and Yen, D.W., 2004, A FEM study on mechanisms of discontinuous chip formation in hard turning. J. Materials Processing Technology, 155-156, 1350-1356