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Prediction of Cutting forces in heat assisted turning of super alloy

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Abstract:

Heat assisted machining is a possible way for improving machinability of hard to cut materials. Due to preheating it reduces the shear strength of the material which indeed makes ease of machining. In the present paper, heat assisted turning of Inconel 718 alloy has been studied for cutting forces at different speed, feed and depth of cut. Finite element based analysis is carried out using a commercial software ABAQUS/Explicit to predict the cutting forces. Johnson cook material model which is popularly used in FE simulations to represent the actual behaviour of material. The simulation results were compared with the experimental values and found that the trend in the results is in good agreement. The cutting forces obtained at preheating condition got reduced compared to conventional machining.

***Keywords*:** Inconel 718, Heat assisted machining, Cutting force, FEM

1. Introduction

The demand for Inconel 718 is ever increasing as it has prominent role in high temperature applications particularly in chemical and aerospace industries. However the outstanding properties of Inconel 718 make the material hard to cut. Due to this the rise of cutting forces, increase of tool wear and poor surface characteristics will be resulted. Increase in nose radius reduces the chip thickness and chip tool length in preheated condition [1]. It is observed that during pre-heating temperature the deformation is due to plastic strain and at room temperature the deformation is due to both fracture and plastic strain [2]. The temperature in machined surface decreases with increase of cutting speed for large feed values since more time is needed to spread heat across the uncut chip in the succeeding cut. It is observed that at low feed rate the machining temperature has increased which may leads to micro structural changes in the work piece [3]. Pre heating of the work piece causes to high temperatures at the shear zone, which leads to reduction in the shear flow stress. Hence, heat generation in the shear region during LAM is minimised compared with conventional machining [4]. In thermally enhanced machining of difficult to cut metals like High-chrome white cast iron (HCWCI) alloy, selection of appropriate cutting tools and machining parameters is very crucial. Improper selection causes increase of production cost and poor machining quality. Also, the selection of appropriate heating technique, work piece pre heating temperature, and suitable positioning of heat source will improve the quality [5, 6, and 7]. It is observed that at high cutting speeds and surface pre heating temperature range between 350 and 400 °C obtained good surface finish. Further rise of the surface temperature softens the work piece due to which the hardened carbide particles might have emitted up from the base metal as a chip rather than getting sheared, causing waviness on the surface. Also, there might be possibility of built up edge formation on the tool face which might be another reason for poor surface finish [8, 9]. In hard turning process, instead of opting costly tooling materials for softening of the work piece, gas preheating could be an attractive alternative. This technique reduces the chances of work hardening and minimizes the resistance to cutting. Localized heating softens only the chip/cut material, leaving the work piece relatively cool and metallurgically undamaged [10]. In the present work, heated assisted machining of super alloy has been carried out to compare experimental and simulation results and to study the influence of preheating temperature.

2. Experimental Details

In this work, heat assisted turning is carried out on Inconel 718 alloy with 30mm diameter and 200mm length. A liquefied petroleum gas (LPG) heating setup was provided to heat the work piece shown in Fig. 1. Flame torch is provided in place of coolant nozzle to have movement of heat source along the length while turning. LPG heating is the better choice for hot machining since it economical, although the gross heat available and the energy transfer density will be low. Metallurgical changes to the work piece will be low. During all the experiments, constant distance of 25 mm between the torch and work piece is maintained. The turning experiments on Inconel 718 alloy were conducted on TURNMASTER-350 Lathe machine. The chemical composition of Inconel 718 is shown in Table 1. Carbide insert with CNMG 120408 NC6210 specification is used as a cutting tool. The input parameters range was selected on basis of machine capacity and preliminary experiments. The range of input parameters is shown in Table 2.

Fig.1: Experimental setup

Table 1 Chemical composition of Inconel 718

Element	C	Ti	Cr	Fe	Ni	Nb	Mo
Wt %	8.24	0.59	14.81	15.46	54.39	4.10	2.41

Table 2 Input parameters

surface temp(°C)	Room temp, 150, 300
Speed (m/min)	17,42.5,67
feed (mm/rev)	0.05, 0.1, 0.16
Depth of cut (mm)	0.1

Cutting force, feed force and radial force were obtained by using Piezo-electric dynamometer. The results obtained were compared at different surface heating temperatures to observe the influence of pre heating.

2.1. Finite Element Modelling

In this work, finite element model was created using ABAQUS software for evaluating the performance of pre heating in machining. The work piece of size 20mm x 4mm x 2mm and tungsten carbide (WC) cutting tool with 15^0 rake angle and 7^0 clearance angles were chosen for this simulation studies based on work piece material properties. The properties of Inconel 718 alloy and WC are listed in Table 3. Johnson-Cook (JC) model is used to represent the behaviour of work piece and cutting tool. The parameters for the model are listed in Table 4. The JC model of the material is represented by the Eq.1 and failure model is represented in Eq.2.The contact between the work piece and cutting tool is very crucial in order to achieve good results. The general contact type interaction is chosen and friction between the contacts is applied as 0.3.

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

Where A is yield stress, B is strain hardening parameter, n is strain hardening exponent, C is strain rate sensitivity parameter, m is temperature exponent, ε_p is plastic strain, $\dot{\varepsilon}^* = (\varepsilon_p{}^* / \varepsilon_0)$ is dimensionless strain rate and $T^{*m} = (T-T_0) / (T_m - T_0)$; T, T0 and T_m being the working temperature, room temperature and melting temperature respectively.

$$\varepsilon_f = [D_1 + D_2 \exp(D_3\sigma^*)][1 + D_4 \ln(\dot{\varepsilon}_p{}^*)][1 + D_5 T^*] \qquad (2)$$

Where ε_f is fracture strain, D_1 to D_5 are coefficients of Johnson-Cook material shear failure initiation criterion and the stress σ^*= mean stress (σ_m)/ equivalent stress (σ_{eq}).

C3D8RT element type which is an 8-node thermally coupled brick, trilinear displacement and temperature, reduced integration, hourglass control is selected which provides the means to get both mechanical and thermal data. The work piece is meshed and it contains 4400 elements and cutting tool contains 512 elements.

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

Table 4 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

3. Results and Discussion

The cutting forces at different cutting conditions both experimental and simulated values are shown in Table 5. It is observed that the cutting forces reduced at pre heating temperature (150^{0}C) compared to room temperature during constant speed and feed values. The cutting force even got reduced at speed 100 m/min, feed 0.05 mm/rev and pre heating temperature 300^{0}C.

Table 5 Cutting Forces at different machining conditions

Exp. No	Pre-heating temp.(^{0}C)	Speed (m/min)	Feed (mm/rev)	Cutting Force					
				Fx		Fy		Fz	
				Simulated	Experimental	Simulated	Experimental	Simulated	Experimental
1	30	26	0.05	67.1	117.72	30.4	58.86	84.7	88.29
2	30	65	0.1	58.5	68.67	100	29.43	78	58.86
3	150	26	0.05	135.8	147.15	65.1	98.1	160.8	137.34

4	150	65	0.1	120	78.48	125.7	58.86	145.5	98.1
5	300	100	0.05	49.5	39.24	35	19.62	64	49.05

The simulation plots of cutting force at different conditions are shown in Fig. 2 to Fig.4.

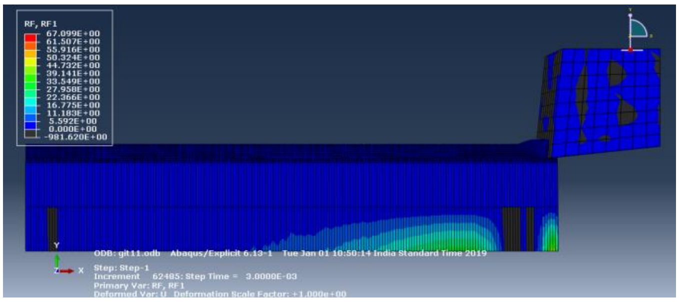

Fig.2: V= 26m/min, f=0.05mm/rev, T= 30^0C

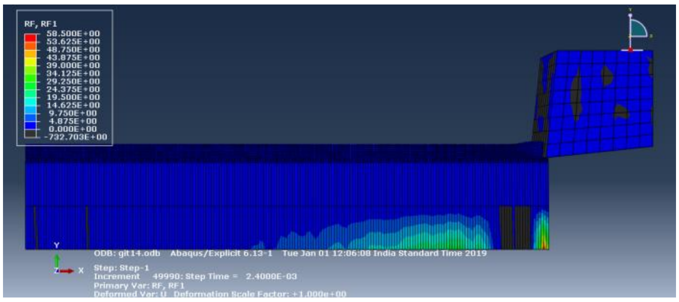

Fig.3: V= 26m/min, f=0.05mm/rev, T= 150^0C

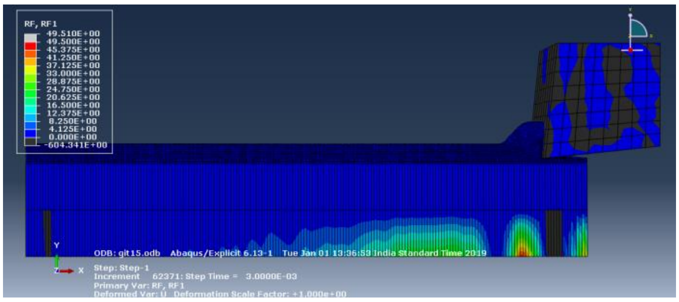

Fig.4: V= 100m/min, f=0.05mm/rev, T= 300^0C

Figures 5a to 5c shows the comparison between experimental and simulated results of cutting forc-

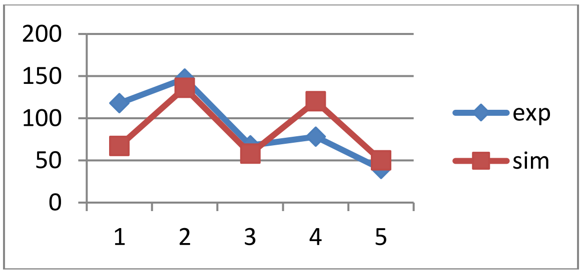

Fig.5a: cutting force(F_x) Exp. vs Simulation

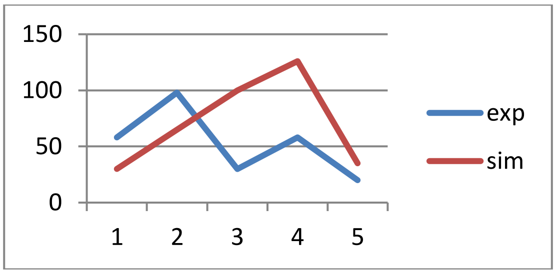

Fig.5b: cuttingforce(Fy) Exp.vs Simulation

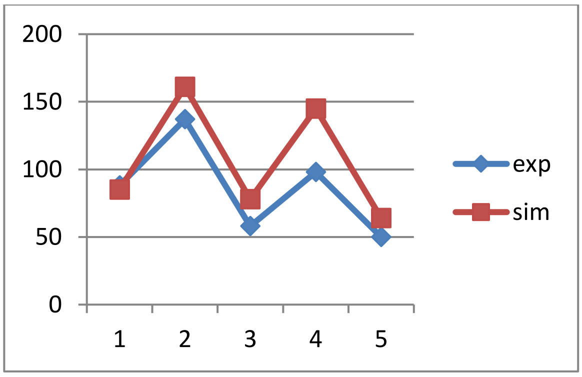

Fig. 5c: cutting force(Fz) Exp. vs Simulation

es, in which the cutting forces both in experimantal and simulation conditions shows almost similar trend. The trend clearly shows that the cutting forces at preheating temperature is lower than the corresponding room temperature machining.

4. Conclusion

- The cutting forces with heat assisted machining are less compared to room temperature machining.
- The cutting forces in experiments and simulations got similar trend in the plots which means the results are in good agreement.
- Hence the developed FEA model is very much suitable for predicting cutting forces in heat assisted machining.
- The cost of experimentation and effort can be minimised using FEA simulations.

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