Available online www.jocpr.com

Journal of Chemical and Pharmaceutical Research, 2015, 7(4):136-140

Research Article

ISSN : 0975-7384
CODEN(USA) : JCPRC5

Effect of stress distribution on cutting titanium alloy by FEM simulations

Bin Li

Department of Mechanical Engineering, Luoyang Institute of Science and Technology, Luoyang, Henan Province, PR China

---

ABSTRACT

With the development of engineering technology, FEM can be used to simulate metal machining process and gain better understanding of material flow within dies, so as to optimize tooling to eliminate tears, laps and other forging defects. In this paper, the calculated cutting force increases approximately logarithmically, with the simulation of the end milling operation by finite element method, based on the cutting force theory, the cutting forces and tool deflection can be predicted well from the logarithmic rate dependence.

Keywords: Stress distribution; Titanium alloy; Milling.

INTRODUCTION

Among the different alloys of titanium, Ti–6Al–4V is by far the most popular one with its widespread use in the chemical, surgical, ship building and aerospace industry. The primary reason for wide applications of this α–β titanium alloy is its high strength-to-weight ratio that can be maintained at elevated temperatures and excellent corrosion and fracture resistance. However, Ti–6Al–4V is notorious for poor machinability due to its low thermal conductivity that causes high temperature on the tool face and strong chemical affinity with most tool materials, thereby leading to premature tool failure. Furthermore its inhomogeneous deformation by catastrophic shear makes the cutting force fluctuate and aggravates tool-wear and chatter [1-2].

Cutting forces modeling is the basis to understand simulate cutting process and further to control the parameters for obtaining higher precision work pieces. There is no doubt that the magnitude and distributions of the cutting forces are greatly influenced by the cutter run-out effect, which is a very general phenomenon in cutting process. To ensure the accuracy of prediction, enormous research efforts have been made to establish a high-precision and credible cutting force model.

Titanium and its alloys are utilized in aero-engine and airframe manufacture because of their outstanding strength to density ratios relative to other materials. In addition the susceptibility of titanium to work-harden during machining impair their machining ability, hence they are referred to as difficult-to-machine materials. The foremost material used on elements that receive force in an airplane is titanium alloy. Compared with aluminum alloy and steel, it has a higher ratio of strength-to-weight, higher wear-resistance and higher fatigue-resistance. Under the conditions of high temperature where aluminum alloys cannot be used, titanium alloys can work well [3-4].

As for capabilities, especially fatigue resistance, titanium alloy is better than other materials. Using titanium alloys instead of aluminum alloys and steel does not only lighten the weight, but also upraises the service life of an airplane. Unfortunately, the unique physical and chemical properties that make these alloys suitable for many applications also contribute to the difficulty with which they are cut or ground. During grinding using abrasive wheels, which has been one of the most popular processes for titanium alloys and super alloys, short wheel life and severe surface abuse of ground workpiece are the most important among the factors impairing their grind ability [5-6].

Recently, progress has been made by using the finite element method (FEM) to deal with the machining process. With the development of engineering technology, FEM can be used to simulate metal machining process and gain better understanding of material flow within dies, so as to optimize tooling to eliminate tears, laps and other forging defects. The DEFORM software package is a professional FEM software, which serves in the forging and other metal-forming industries for economical process evaluation and optimization [7].

The method is therefore fruitful for a general understanding of the machining process, but it is not suitable for predicting the outcome of a specific machining experiment. The main disadvantage of this method is that no direct comparison with experiments is possible, as there is no real-world material conforming to the parameters used here. In this study, numerical simulation was conducted by using FEM software on the whole cutting process for TC4 alloy mounting parts in an effort to investigate the metal flow behavior. This study not only helps to understand but also to improve and optimize cutting process, which are based on experience combined with a trial-and-error approach.

FINITE ELEMENT MODELING

In the simulation, the entire cutting process is divided into many small time increments. In every small time increment, dynamic and thermal analysis procedures are based on the implementation of an explicit integration rule. The chip formation simulation is performed using explicit method. Dynamic analysis procedure is performed with the following algorithm.

As it is the intent of this paper to gain an understanding of the main effects of the cutting speed on chip formation, a rather simple, generic flow stress law has been used which can be considered as describing a model material. By varying material parameters in the flow stress law, the influence of these parameters on the chip formation process can be studied as well. The flow stress law is based on flow stress measurements of the Titanium alloy Ti6Al4V presented in [8] which were obtained using a split-Hopkinson bar apparatus at strain rates of up to 10^4 s^{-1} at different temperatures. As strain rates in excess of 10^7 s^{-1} are reached in the simulations, an extrapolation over several orders of magnitude is necessary. To do so, logarithmic rate dependence is assumed. The isothermal flow stress σ used in the simulations is given by the following formula: [9]

$$\sigma(\varepsilon,\dot{\varepsilon},T)=K(T)\varepsilon^{n(T)}(1+C\ln(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0})) \tag{1}$$

where ε and $\dot{\varepsilon}$ are strain and strain rate, T the temperature, K and n the temperature-dependent material parameters, and C and $\dot{\varepsilon}_0$ are constants.

The flow stress is determined using a power hardening law model with thermal softening effect, namely:

$$\sigma_f=\sigma_0\Theta(T)(1+\frac{\varepsilon^P}{\varepsilon_0^P})^{1/n} \tag{2}$$

where σ_0 is the initial yield stress at the reference temperature T_0, ε_0^P the reference plastic strain, n the hardening exponent and $\Theta(T)$ the thermal softening factor ranging from 1 at ambient to 0 at melt.

Accelerations are calculated by satisfying the dynamic equilibrium at the beginning of the increment [10]:

$$\ddot{u}_{(i)}=M^{-1}(P_{(i)}-I_{(i)}) \tag{3}$$

where $\ddot{u}_{(i)}$ is the acceleration at the beginning of the increment i; M is the diagonal or lump mass matrix; $P_{(i)}$ is externally applied load and is internal load and $I_{(i)}$ is internal load.

The accelerations are integrated through time using the central differential rule as follow:

$$\dot{u}_{(i+1/2)}=\dot{u}_{(i-1/2)}+\frac{(\Delta t_{(i+1)}+\Delta t_{(i)})}{2}\ddot{u}_{(i)} \tag{4}$$

The velocities are integrated through time:

$$u_{(i+1)}=u_{(i)}+\Delta t_{(i+1)}\dot{u}_{(i+1/2)} \tag{5}$$

The variation of the cutting speed showed a direct transition from continuous to segmented chips. In this section, the cutting forces for continuous chips at high cutting speeds are estimated and compared to those observed for segmented chips. In order to estimate the cutting force for a continuous chip, a lower bound is calculated by assuming that that a homogeneous chip forms with a shear angle of 45°, so that the strain is $2/\sqrt{3}$ and that the process is adiabatic. In this case, the specific cutting force k_s is equal to the integral of the adiabatic stress–strain curve:

$$k_s = \int_0^{2/\sqrt{3}} \sigma_{ad}(\varepsilon, \dot{\varepsilon})\, \mathrm{d}\varepsilon \tag{6}$$

where σ_{ad} is the adiabatic stress as a function of the strain ε and strain rate $\dot{\varepsilon}$. To simplify the calculation, a constant strain rate is assumed.

The energy that is not converted into thermal energy, such as the energy retained in the chips and that associated with the generation of the new surface area is negligibly small. It has been often assumed that the chip is formed instantaneously at the shear plane, so that a uniform plane source and velocity discontinuity may be assumed to exist there.

RESULTS AND DISCUSSION

The model aims to simulate the milling process, calculate to the damage initiation and evolution in the work piece material. So, we can predict the cutting forces, torque, and temperature distribution in the work piece throughout the process. A three-dimensional model is developed using commercial finite element software. The FE model is based on Lagrangian formulation with explicit integration method. Each drilling experiment was carried out with the use of coolant. It is assumed that the cutting induced eat is removed by coolant, thus thermal issues are not accounted in the model. While mass and inertia effects are included in the model. The overall dynamics are not taken into account into consideration in the analysis. The contact and the friction parameters between the tool and work piece are influenced by a number of factor such as cutting speed, feed rate, geometry and the surface properties. The Coulomb friction model is used and a constant friction coefficient of 0.5 is used in the analysis. The overall FE model is shown in Fig. 1.

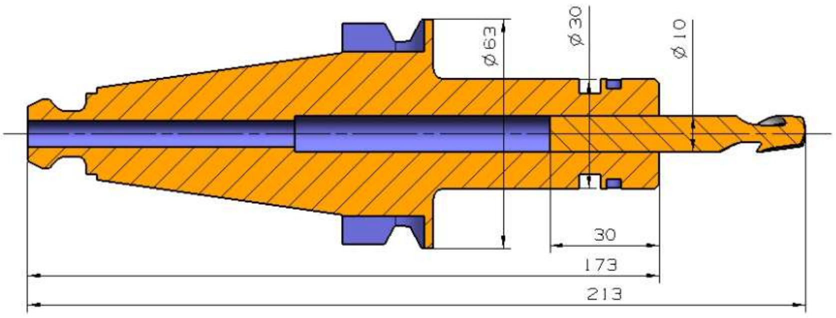

Fig 1. Overall and dimensional FEM model in milling

The calculated cutting force increases approximately logarithmically with the cutting speed, as should be expected from the logarithmic rate dependence. At small cutting speeds, the measured cutting force is larger than the calculated value. This is not surprising as the process is not adiabatic at small cutting speeds and as the shear angle is much smaller than the ideal value. The resulting curve is shown in Fig. 2.

Fig. 3 illustrates effect of axial cutting depth on the maximum deform and effective stress for all the loads of end-milling cutting tool. It can be seen that when the axial cutting depth is 0.2mm, the maximum deform and effective stress are only 0.08mm and 2360MPa. However, when the axial cutting depth is up to 3.0mm, the the maximum deform and effective stress were greatly increased to 1.451mm and 11942MPa, and it is indicated that the maximum deform and effective stress showed an upward trend for machining of end-milling cutting tool.

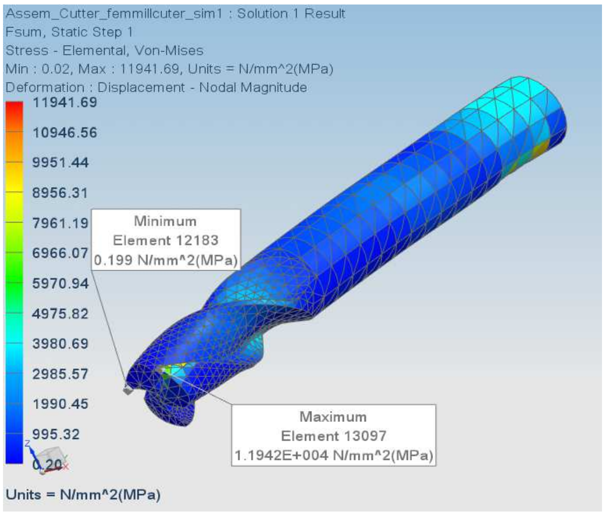

Fig 2. Cutting force change curves in turning TC4 titanium alloy

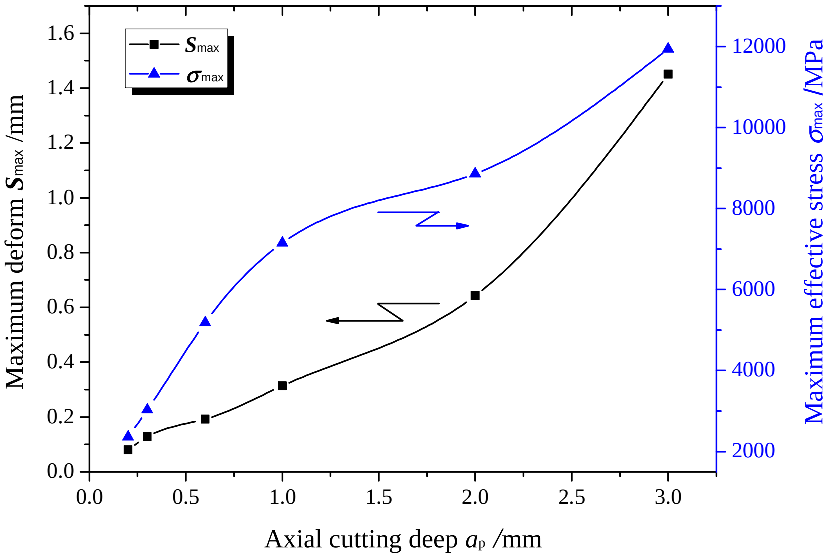

Fig 3. Effect of axial cutting depth on the maximum deform and effective stress for all the loads of end-milling cutting tool

CONCLUSION

Cutting forces modeling is the basis to understand, simulate milling process and further to control milling process parameters for obtaining higher precision work pieces. With the development of engineering technology, FEM can be used to simulate metal machining process and gain better understanding of material flow within dies, so as to optimize tooling to eliminate tears, laps and other forging defects. In this paper, numerical simulation was conducted by using FEM software on the whole cutting process for TC4 alloy mounting parts in an effort to investigate the metal flow behavior. The thermal simulation results obtained were compared with the cutting temperature and discussed in terms of literature data.

Acknowledgements

The work described in this paper is supported by the National Natural Science Foundation of China (No.51475222), the Science and Technology Development Foundation of Henan Province (No.132102210514), the Outstanding Youth Innovation Foundation for Science and Technology of Henan province (No.144100510017), the International Cooperation Projects for Science and Technology of Henan province (No.144300510050), the Young Backbone Teachers Foundation for the Universities of Henan Province (No.2013GGJS-186) and the Development Program for Science and Technology of Luoyang (No.1202016A).

REFERENCES

[1] L Gu; L Li; W Zhao; KP Rajurkar. *Int. J. Mach. Tools Manuf.* **2012**, 53(1), 100-106.
[2] H Ay; WJ Yang. *Int. J. Heat Mass. Tran*. **1998**, 41(3), 613-623.
[3] EO Ezugwu; RD Silva; J Bonney; ÁR Machado. *Int. J. Mach. Tools Manuf.* **2005**, 45(9), 1009-1014.
[4] X Xu; Y Yu; H Huang. *Wear*. **2003**, 255(7–12), 1421-1426.
[5] Y Yuefeng; C Wuyi; G Liansheng. *Chi. J. Aero*. **2010**, 23(3), 386-392.
[6] C LÜ; LW Zhang. *T. Nonferr. Metal Soc.* **2006**, 16(6), 1386-1390.
[7] BC Xie; YK Wang; ZL Wang; WS Zhao. *T. Nonferr. Metal Soc.* **2011**, 21, s2(0), s434-s439.
[8] M Bäker. *J. Mater. Process. Tech*. **2005**, 167(1), 1-13.
[9] H Bil; S KIlIē; AE Tekkaya. *Int. J. Mach. Tools Manuf.* **2004**, 44(9), 933-944.
[10] A Attanasio; E Ceretti; A Fiorentino; C Cappellini; C Giardini. *Wear*. **2010**, 269(5-6), 344-350.