Simulation of Inconel 718 alloy machining with respect to the modified material model

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The paper presents simulation researches of the aerospace part machining. A simulation model of Inconel 718 alloy machining based on the Lagrangian formulation contains the Johnson-Cook material model. The dependence of simulation results from the material model formulations (plastic strain, strain rate and temperature) was presented.

KEYWORDS: simulation of machining, Inconel 718, material model

Modern metal constructions, especially in aerospace industry demand a basic understanding of the mechanical behaviour of materials [1÷4]. The modelling of metal cutting has proved to be particularly complex due to the variety of physical phenomena involved, including thermo-mechanical coupling, contact-friction and material failure [5]. Through the use of simulation technologies, the properties of the materials are intensively considered [6]. The complex properties of metal alloys structures present significant challenges during manufacturing processes. For this reason, the proper material model applied in the simulation procedure of machining is an essential tool to analyse the complex behaviour of materials under the high loads, high temperature and quick changes of loads.

This paper presents simulation researches of the aerospace part surface turning. The engine block of cylindrical shape and small wall thickness was applied in the simulation procedure.

Modeling of machining

Numerical simulations of cutting process were performed according to a Lagrangian FE code [7] for a time necessary to achieve the steady-state phase of chip creation. Techniques such as adaptive remeshing and thermal analysis were integrated to model the complex interactions of the tool wedge and workpiece. The workpiece material, Inconel 718 (0.4% Al; 0.04% C; 19% Cr; 18.5% Fe; 3% Mo; 0.9% Ti), was modelled as thermo-elastic-plastic, while the flow stress was considered to be a function of strain, strain-rate and temperature. Two material models were compared in the researches. The first constitutive model was a modified Johnson-Cook model [7]. The equivalent stress is defined in Equation. The table presents the main model parameters.

\[ \sigma(\varepsilon, \dot{\varepsilon}, T) = (A + B\dot{\varepsilon}^n)(1 + c\ln\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right))(1 - \left(\frac{T - T_{room}}{T_{mel}-T_{room}}\right)^m) \]

where: \( A \) is the yield stress, \( B \) is the strain hardening coefficient, \( c \) is the strain rate dependence coefficient, \( n \) is the strain hardening exponent and \( m \) is the temperature dependence coefficient material parameters. \( T_{mel} \) is the melting temperature for the material, \( \dot{\varepsilon}_0 \) is an equivalent plastic strain rate and \( \varepsilon_0 \) is the reference strain rate.

In case of second material model, physical and mechanical properties of Inconel 718 were used in simulation according to the standard data implemented in the software [8], named a standard model in the next part of the paper.

Calculations were performed for the roughing and finishing operations. For roughing operations a sialon insert RNGN120700T01020 was used. Cutting parameters used in roughing were as follows: \( v_c = 200 \text{ m/min}, \) feed \( f = 0.15 \text{ mm/rev} \). For finishing turning cutting data were as follows: \( v_c = 160 \text{ m/min}, f = 0.13 \text{ mm/rev} \). Fig. 1 shows the geometry of semi-finished part and tool paths for turning operations.

Fig. 1. Engine block unit with tool paths for turning operations

The simulation of the engine block unit machining was performed on the CNC machining center. Due to the thin wall nature of the workpiece, as a result of cutting forces influence, geometric deformation can take place which leads to incorrect execution of machined surfaces. During thin-walled parts machining, the value levels of the components of resultant cutting force plays the important role.

In the first stage of research a simulation of chip forming in the decohesion zone was performed. The comparison of example results of numerical calculations of temperature and stress-XX component field distributions for modified (1) and standard (2) material models are presented in Fig. 2÷5.
It can be noticed that chip shape as well as temperature and stress fields distributions are different.

![Fig. 2. Comparison of temperature field distribution for modified (1) and standard (2) material models. Cutting data: \(v_c = 160 \text{ m/min}, f = 0.08 \text{ mm/rev}, a_p = 1 \text{ mm}\)](image)

![Fig. 3. Comparison of temperature field distribution for modified (1) and standard (2) material models. Cutting data: \(v_c = 200 \text{ m/min}, f = 0.2 \text{ mm/rev}, a_p = 1 \text{ mm}\)](image)

![Fig. 4. Comparison of stress-XX component field distribution for modified (1) and standard (2) material models. Cutting data: \(v_c = 160 \text{ m/min}, f = 0.08 \text{ mm/rev}, a_p = 1 \text{ mm}\)](image)

![Fig. 5. Comparison of stress-XX component field distribution for modified (1) and standard (2) material models. Cutting data: \(v_c = 200 \text{ m/min}, f = 0.2 \text{ mm/rev}, a_p = 1 \text{ mm}\)](image)

![Fig. 6. The time course of the tangential cutting force component during turning along the entire tool path for modified (1) and standard (2) material models](image)

![Fig. 7. The time course of the chip thickness during turning along the entire tool path for modified (1) and standard (2) material models](image)

**Conclusions**

Based on the experience in machining and the use of modern software and hardware, it is possible to simulate machining operations precisely in condition that we are able to prepare the correct material model. Otherwise, the calculation results will be inaccurate. The simulation research shown that temperature and cutting force have higher values for the standard material model than for modified one, which translates into further optimization cutting data.

After initial analysis of the force value during machining operations it is possible to change cutting parameters (e.g. feed speed) to increase productivity, tool life or shorten cutting time. It is also necessary to monitor simultaneously the influence of proposed changes on the shape and dimensional accuracy, roughness of machined surfaces and the stability of Machine tool – Tool – Holder – Workpiece (MTHW) configuration.

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**LITERATURE**