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Short communication

Flow stress of AISI H13 die steel in hard machining

Hong Yan [a,*], J. Hua [b], R. Shivpuri [b]

[a] *School of Mechanical–Electrical Engineering, Nanchang University, 339 Beijing Dong Road, Nanchang 330029, China*
[b] *Industrial, Welding & Systems Engineering, The Ohio State University, Columbus, OH 43210, USA*

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Abstract

In general, the flow stress models used for theoretic analysis and computer simulation in machining processes are a function of strain, strain rate and temperature during the cutting process. However, these models do not adequately describe the material behaviour in hard machining, where the workpiece material is machined in its hardened condition. This hardness modifies the strength and work hardening characteristics of the material being cut. An approach is presented to characterize the stress response of workpiece in hard machining, accounted for the effect of the initial workpiece hardness in addition to temperature, strain and strain rate on flow stress in this paper. AISI H13 die steel was chosen to verify this methodology. The proposed flow stress model demonstrates a good agreement with data collected from published experiments. Therefore, the proposed model can be used to predict the corresponding flow stress–strain response of AISI H13 die steel with variation of the initial workpiece hardness in hard machining.

Keywords: Flow stress; Hard machining; Finite element modeling; AISI H13 die steel

1. Introduction

The manufacturing process of dies/molds is one of the most demanding tasks in manufacturing engineering. Complex workpiece geometries, high material hardness as well as short lead time are among the main obstacles. At the same time, quality requirements become more and more important due to intensified competition and quality awareness.

Traditionally, the production of molds/dies generally involves conventional machining in the annealed (soft) state, followed by heat treatment, electrode manufacture, electro-discharge machining (EDM) and manual polish/finish grinding [1]. A significant portion of the lead-time is spent for finish machining including electrode manufacture, EDM and manual polish/finish grinding, taking approximately two third of total manufacturing costs. As a result of the advances in machine tools and cutting tool technology, high speed hard machining (milling) becomes a cost-effective manufacturing process to produce parts with precision and surface quality. Especially now it has been applied to the manufacture of moulds and dies in which some processes can be eliminated by substituting a single process for two or more such as replacing the slow EDM and manual polish/finish grinding processes in many applications, giving considerable savings in both time and cost. High flexibility and the ability to manufacture complex workpiece geometry in one set-up represent the main advantages of hard cutting in comparison to grinding [2]. In addition, improved quality/workpiece surface integrity (SI) leading to longer component life is also reported [1–3].

AISI H13 die steel possesses good resistance to thermal softening and heat checking, high hardenability, high strength and high toughness. So, this steel has been applied widely to produce many kinds of hot work dies, such as forging dies, extrusion dies, die-casting dies and so on.

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[*] Corresponding author. Tel: +86 791 8304570; fax: +86 791 8305064.
E-mail address: hyan@ncu.edu.cn (H. Yan).

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The hardness of AISI H13 die steel varies with its application for the different type of dies. AISI H13 hardness recommended is at 43-52 HRC for extrusion dies, at 44-50 HRC for die-casting dies, at 40-55 for forging dies and so on [4]. However, the effect of variation of the initial hardness on flow stress cannot be taken into account in current material flow stress model. In order to implement FE simulation and theoretical analysis of hard machining of AISI H13 die steel, flow stress data are needed with variation of the initial workpiece hardness. Therefore, the flow stress model with variation of the initial workpiece hardness is first required to be developed.

2. Flow stress of AISI H13 die steel at its different hardness

The parameters in the existed flow stress models [5–10] were determined by tests for the specific initial hardness of material. If the initial workpiece hardness is changed, these parameters need to be redetermined by tests. Therefore, it is not convenient to use these models for characterizing the corresponding stress response with variation of the initial workpiece hardness in hard machining. A reasonable material model should meet two basic requirements: high accuracy and mathematical simplicity. A new approach is presented in this study to characterize the stress response of workpiece in hard machining for taking into account the effect of the initial workpiece hardness on flow stress.

2.1. Procedure for establishing flow stress model in hard machining

The construction of material model accounted for the influence of the initial workpiece hardness is considered as follows. First, the reference flow stress curve at the certain workpiece hardness is chosen. Then, an additional component of stress is included for taking into account the effect of the initial workpiece hardness on flow stress. The overall material stress response is presented by coupling these two parts as follows.

$$\bar{\sigma}(\bar{\varepsilon},\dot{\bar{\varepsilon}},T,\mathrm{HRC}=\mathrm{const})=f(\bar{\sigma}_{\mathrm{Re}f}(\bar{\varepsilon},\dot{\bar{\varepsilon}},T),\\ \Delta\sigma(\mathrm{HRC}=\mathrm{const})), \qquad (1)$$

where $\bar{\sigma}_{\mathrm{Re}f}(\bar{\varepsilon},\dot{\bar{\varepsilon}},T)$ presents the reference flow stress curve at the certain workpiece hardness. $\Delta\ \sigma(\mathrm{HRC})$ denotes an additional component of stress, reflecting the influence of the initial workpiece hardness.

2.2. Determination of the reference flow stress curve

The reference flow stress curve is chosen to be described with Johnson–Cook's model [6] due to its incorporation of strain, strain rate and thermal softening effects, which is suitable for characterize the stress response of AISI H13 die steel in hard machining [11].

$$\bar{\sigma}_{\mathrm{Re}f}(\bar{\varepsilon},\dot{\bar{\varepsilon}},T)=(A+B\bar{\varepsilon}^{n})(1+E\ln\dot{\bar{\varepsilon}}^{*})(1-(T^{*})^{m}), \qquad (2)$$

where $\dot{\bar{\varepsilon}}^{*}=\dot{\bar{\varepsilon}}/\dot{\bar{\varepsilon}}_0$ is the dimensionless strain rate for $\dot{\bar{\varepsilon}}_0=1.0\ \mathrm{s}^{-1}$ and A, B, E, n and m are considered to be material constants, T^* the homologous temperature $T^*=(T-T_0)/(T_{\mathrm{melting}}-T_0)$, T the workpiece temperature, and T_{melting} and T_0 are, respectively, the material melting temperature and the reference ambient temperature. Strain hardening, strain-rate hardening, and thermal softening are taken into account. The hardness for the reference flow stress curve is chosen as the certain workpiece hardness of HRC46. Based on the experimental data [11], the parameters in the reference flow stress curve can be determined by the regression analysis procedure, the five parameters can be estimated to be $A=908.54$ MPa, $B=321.39$ MPa, $n=0.278$, $E=0.028$ and $m=1.18$.

2.3. Determination of an additional component of stress

For a given material, the hardness behaviour varies with different heat treatment. This increases in strength due to hardness is not due to mechanical work but due to thermal treatment. Consequently, it can be resumed that hardness is independent of mechanical work and does not change with the short time in the high temperature cutting zone (shear zone). Therefore, in this study the initial hardness of the workpiece is incorporated in the flow stress using the following procedure: (1) Take yield stress and tensile strength as the start and the end points for a specific flow stress curve. If the hardness is higher, then both the yield stress and tensile strength are increasing. The points within this range are obtained by assuming a logarithm behaviour which will be add to the reference work – hardening value. (2) For the given material assume the Young's modulus to be independent of hardness. This is often the case for most materials.

In order to take into account the influence of the initial workpiece hardness, an additional component of stress $\Delta\sigma$ is proposed as expressed in the following equation, which is the function of incremental flow stress between the reference flow stress and those having a different hardness with variation of strain.

$$\Delta\sigma(\mathrm{HRC}=\mathrm{const})=C\ln(\varepsilon_0+\varepsilon)+D, \qquad (3)$$

where ε_0 presents the reference strain and is taken to be 10^{-3}. The C and D are the function of the initial workpiece hardness accounted for the influence of hardness. Fig. 1 shows the relationships of both yield stress and tensile strength with variation of workiece hardness [4]. Following this figure, Table 1 lists the differences of the yield stress and tensile strength between their