High Speed Machining of AISI 1050 Steel: Modelling and Experimental

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High Speed Machining of AISI 1050 Steel: Modelling and Experimental

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ABSTRACT: An analytical approach is used to model orthogonal cutting process. The material characteristics such as strain rate sensitivity, strain hardening and thermal softening are considered. The chip formation is supposed to occur mainly by shearing within a thin band called primary shear zone. The analysis is limited to stationary flow and the material flow within the primary shear zone is modelled by using a one-dimensional approach. Thermomechanical coupling and inertia effects are accounted for. At the tool-chip interface, a temperature dependent friction law is introduced to take account of the extreme conditions of pressure, velocities and temperature encountered during machining. Comparisons between model predictions and experimental results are performed for different cutting conditions.

Key words: High speed machining, modelling, friction

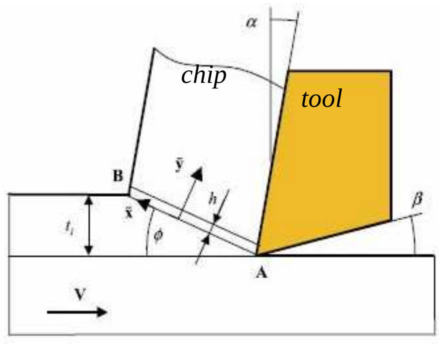
1 ANALYTICAL MODELLING OF ORTHOGONAL CUTTING

During the thermomechanical process of chip formation the strain rates, the shear strain and the temperature are large. Thus, the thermomechanical behaviour of the workpiece material has to be identified at conditions close to those of machining. In this work, the work material is an isotropic, viscoplastic rigid material, whose behaviour is described by a Johnson-Cook law:

$$\tau = \frac{1}{\sqrt{3}}\left[A + B\left(\frac{\gamma}{\sqrt{3}}\right)^n\right]\left[1 + m\ln\left(\frac{\dot{\gamma}}{\dot{\gamma}_0}\right)\right]\left[1-\left(\frac{T-T_r}{T_f-T_r}\right)^\nu\right] \quad (1)$$

The material characteristics are defined by the strain hardening exponent n, the strain rate sensitivity m, the thermal softening coefficient ν, the constants A, B, $\dot{\gamma}_0$, the temperatures T_r (reference temperature) and T_f (melting temperature).

In the proposed approach, the primary shear zone is considered as a thin band of constant thickness h, Molinari et Dudzinski [1992], Moufki et al. [1998]. The primary shear zone is characterised by the shear angle ϕ, see FIG. 1. The plastic deformation in the chip is supposed to be limited to this band. The complex material flow near the tool edge and the secondary shear zone, due to the friction at the tool-chip interface, are neglected. The analysis is limited to stationary flow (no time dependence). The material flow within the primary shear zone can be modelled by using a one dimensional approach where all the variables in the band depend solely on the coordinate y along the normal to the band. These variables are determined in terms of the thermomechanical behavior of the work material, the cutting conditions, the thickness h, the shear angle ϕ and the mean friction coefficient $\bar{\mu}$ at the rake face.



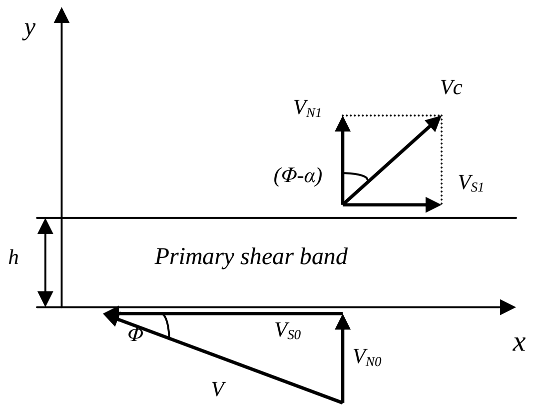


Fig. 1. Analytical modelling of orthogonal cutting, Molinari *et al.* [1992].

At the tool-chip interface, an important heating is produced by the large values of the pressure and the sliding velocity. It is clear that the friction conditions at the tool rake face are affected by this heating. In Moufki et al. [1998], a Coulomb friction law has been introduced with a mean friction coefficient $\overline{\mu} = tan\lambda$ depending upon the mean temperature $\overline{T}_{int}$ at the interface:

$$\overline{\mu} = \overline{\mu}(\overline{T}_{\text{int}}) = \mu_0 \left(1 - \left(\frac{\overline{T}_{\text{int}}}{T_{ref}} \right)^q \right) \qquad (2)$$

T_f is the melting temperature of the workpiece material. The coefficients $\overline{\mu}_0$ and q can be identified from experimental data obtained in orthogonal cutting.

The temperature distribution within the chip beyond the primary shear zone is determined by using the approach of Moufki *et al*. [1998]. The chip heating is due to the viscoplastic deformation in the primary shear band and the friction at the tool-chip interface. To simplify the problem, the following hypothesis are introduced: (i) the cutting edge is supposed to be sharp, (ii) the flank contact is neglected, (iii) the heat flow through the tool surface is neglected and (vi) the heat transfer in the flow direction due to conduction is neglected with respect to the heat convection due to the material flow. The secondary shear zone is not considered; this assumption is acceptable for large cutting speeds. The analysis is limited to the stationary case. Thus the analysis of transient phenomena, such as segmentation, is excluded. The problem is supposed as two-dimensional, the temperature distribution depends solely on the coordinates measured respectively along the direction normal to the rake face and the flow direction. Since the width of the zone thermally affected by friction is small, one can suppose that for a distance large enough the temperature at the tool-chip interface is weakly dependent on the inclination $(\phi - \alpha)$ of the primary shear band with respect to direction normal to the rake face. Therefore to determine the temperature distribution in the chip, this inclination is neglected and the shear band is taken perpendicular to the tool-chip interface.

2 VALIDATION OF MODELLING

Orthogonal cutting tests have been conducted with an AISI 1050 steel coupled with a TiAlN coated carbide tool. Different velocities, feeds and cutting angle are considered.

The behaviour of AISI 1050 steel is given by Eq.1. The Johnson-Cook parameters have been determined by Jaspers and Dautzenberg [2001], (Table 1).

Table1. Johnson-Cook parameters, Jaspers and Dautzenberg, 2001

A (Mpa)	B (Mpa)	n	m	ν	Tf (K)
553,1	600,8	0,234	0,0134	1	1733

The friction law is described by the Eq.2 for each couple tool-workpiece. The parameters μ_0 , q and T_{ref} are identified by a least square method (*μ_0 = 0.71, q = 6.5,* and *T_{ref} = 1500).* Note that in the Eq.2, $\overline{T}_{int}$ is calculated by the analytical model.

The effects of the cutting velocity on the forces are now investigated. The cutting velocity is varied in a range of [75 ; 600] m/min. The cutting angle is α=5° (see Fig. 1), and the width is 2 mm. Two values of feeds are considered, t1 = 0.12, 0.16 mm/rev. In Fig .2, it is observed from experimental data, that an increase of the cutting velocity leads to a decrease of the cutting and thrust forces. This trend is clearly reproduced by the modelling (straight line). This can be explained in the following way: as the cutting velocity is enhanced, the average temperature at the interface $\overline{T}_{int}$ is increased. The average friction coefficient $\overline{\mu}$ is then reduced, see Eq.2. Figure 2 also captures the effect of feed on the forces for a fed feed varying from 0.12 to 0.16 mm/rev. For example, when the cutting velocity is 300 m/min the experimental cutting force passes from 456 to 596N. This observation is depicted by the modelling. Moreover for the different cutting conditions considered, experimental data are accurately reproduced by the modelling.

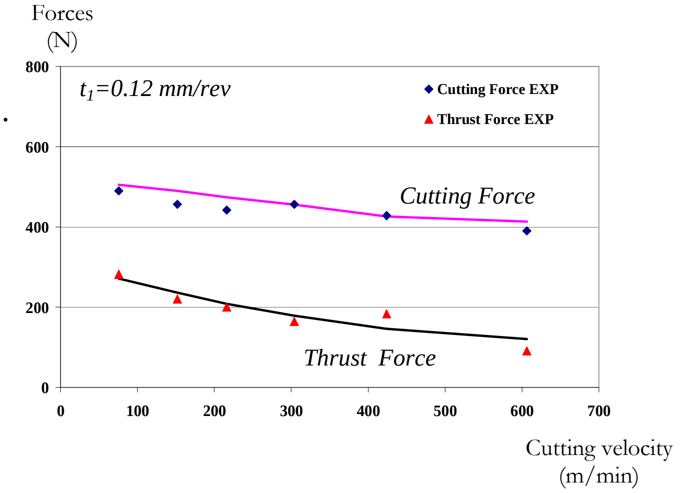


Fig. 2. Comparison between predicted (lines) and experimental data for the values of undeformed chip thickness. The cutting conditions are: the cutting angle α = 5°, w = 2mm, feed = 0.12 mm/rev

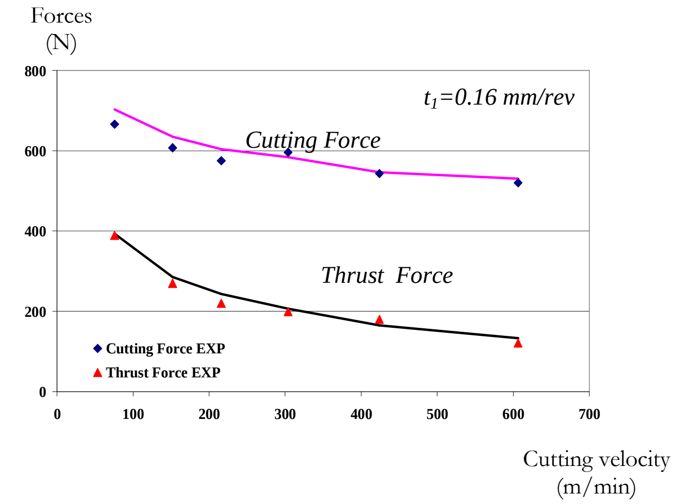


Fig. 3. Comparison between predicted (lines) and experimental data for the values of undeformed chip thickness. The cutting conditions are: the cutting angle α = 5°, w = 2mm, feed = 0.16 mm/rev

3 CONCLUSIONS

In this present work, a comparison is made between cutting and thrust forces obtained from analytical approach (Molinari *et al.* [1992], Moufki and Molinari [1998]) and experimental data for an AISI 1050 steel (coupled with a TiAlN coated carbide tool). From experiments it is noticed that a decrease of the cutting velocity or an increase of the feed leads to an increase of the forces. In the modelling, the temperature dependence of friction law allows us to reproduce these trends. Moreover, experimental data are predicted with a good agreement by the modelling for different cutting conditions.

Notice that the proposed approach provides also the temperature distribution on the tool rake face (not presented here).

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