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Friction model for tool/work material contact applied to surface integrity prediction in orthogonal cutting simulation

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Abstract

Tribological behavior at both tool/chip and tool/work material interfaces should be highly considered while simulating the machining process. In fact, it is no longer accurate to suppose one independent constant friction coefficient at the tool/chip interface, since in reality it depends on the applied contact conditions, including the sliding velocity and pressure. The contact conditions at both above mentioned interfaces may affect the thermal and mechanical phenomena and consequently the surface integrity predictions.
In this article, the influence of contact conditions (sliding velocity) on the tribological behavior of uncoated tungsten carbide tool against OFHC copper work material was investigated. Series of tribology tests combined with numerical simulations of the contact process were performed under different sliding speeds and contact pressures, in order to identify the friction coefficient and the heat partition between OFHC copper and tungsten carbide. The friction coefficient in function of the sliding velocity was then integrated into a FE model of the orthogonal cutting of OFHC copper and applied to surface integrity prediction.

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Keywords: friction modeling; tribology tests; cutting simulation; carbide tool; OFHC copper.

1. Introduction

Productivity improvement of machining operations requires the optimization of tool geometry and cutting conditions. In parallel, a special attention should be paid to the surface integrity of machined parts, since the cutting conditions have an influence on the functional performance and life of such parts [1]. Modelling and simulation of metal cutting is a way to enable this optimization and to ensure the quality of machined surfaces. Among the key input data necessary for metal cutting models, a friction model between the work material and the cutting tool is required. However, obtaining realistic friction data for metal cutting simulation of Oxygen Free High Conductivity (*OFHC*) copper remains an issue for several reasons. First, its mechanical [2] and tribological behaviors depend on the heat treatment applied to this material. Second, the cutting under dry, near dry or with incorrect lubricant can generate work material adhesion to the tool, affecting dramatically the friction coefficient [3].

Most of the literature dealing with metal cutting modelling considers a constant Coulomb friction coefficient [5, 6, 7], which does not corresponds to the reality. The values of the friction coefficient reported in the literature for *OFHC* copper vary between 0.1 [5] and 0.7 [10] depending on several factors, including: tool material, tool surface roughness, lubrication conditions, sliding speed and contact pressure. Finally, Astakhov has shown that the presence of a cutting fluid can reduce dramatically the friction coefficient during machining, and its effect depends on the nature of the fluid [3].

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The conditions used to determine the friction coefficient are rarely reported in the literature, which makes it difficult to be used it in further investigations.

The current study proposes a friction model for the contact between the *OFHC* copper and the uncoated cemented tungsten carbide cutting tool, under forced cooled air conditions. This friction model considers the friction coefficient as a function of the sliding velocity only.

2. Determination of the fiction coefficient

After characterizing the tribology ruling the tool/material contact while the cutting operation, a contact law is here proposed. To identify the coefficients relative to this law, friction tests are performed.

2.1. Mechanical and thermo-physical properties of the tool and work materials

The cutting tool is made of uncoated cemented tungsten carbide (grade ISO M10, ANSI C7). The work material is Oxygen Free High Conductivity (*OFHC*) copper annealed at 450°C for 2 hours. The thermo-mechanical properties of the interacting tool/work material are given in Table 1 [11, 13].

Table 1. The tool and work material properties.

Properties	Unit	Value for carbide	Value for copper
Density	kg/m^3	14450	8960
Young modulus E	GPa	630	127
Poisson coefficient υ		0.3	0.33
Conductivity κ	W/mK	44.6	401
Specific heat C_p	J/kgK	226	380
Expansion α	°K^{-1}	-----	1.4E-5

2.2. Tribological tests: theory

The test aims to measure the apparent macroscopic friction coefficient, μ_{app}, corresponding to the ratio F_t/F_n, where F_n is the normal force and F_t is the tangential force, which were applied on the pin. The apparent friction coefficient may be decomposed into an elasto-plastic deformation coefficient, μ_{def}, and an interfacial friction coefficient, μ_{adh}, also called adhesive friction coefficient as follows:

$$\mu_{app} = \frac{F_t}{F_n} = \mu_{adh} + \mu_{def} \quad (1)$$

The friction test results are treated to separate the adhesive friction coefficient from the apparent one. This treatment is performed after analyzing the work material deposits on the pin head. Analysis is done by applying Eq. 2 to Eq. 9. The geometrical parameters used in those equations are represented in Fig. 1.

$$\vec{F}_n = (BP - D\tau)\cdot\vec{Z} \quad (2)$$

$$\vec{F}_t = (AP + C\tau)\cdot\vec{X} \quad (3)$$

$$A = D = \left|\int_{Sc}\left(dS\vec{n}\cdot\vec{X}\right)\right| = \left|\int_{Sc}\left(dS\vec{t}\cdot\vec{Z}\right)\right| \quad (4)$$

$$B = C = \left|\int_{Sc}\left(dS\vec{n}\cdot\vec{Z}\right)\right| = \left|\int_{Sc}\left(dS\vec{t}\cdot\vec{X}\right)\right| \quad (5)$$

$$S_t = \left(R^2 - a^2\sin^2\omega\right)\sin^{-1}\left(a\cos\omega / r\right) - a\cos\omega\sqrt{R^2 - a^2} \quad (6)$$

$$r = \sqrt{R^2 - a^2\sin^2\omega} \quad (7)$$

$$\mu_{app} = \frac{\left\|\vec{F}_t\right\|}{\left\|\vec{F}_n\right\|} = \frac{AP + C\tau}{BP - D\tau} = \frac{AP + C\mu_{adh}}{BP - D\mu_{adh}} \quad (8)$$

$$\mu_{adh} = \frac{B\mu_{app} - A}{C + D\mu_{app}} \quad (9)$$

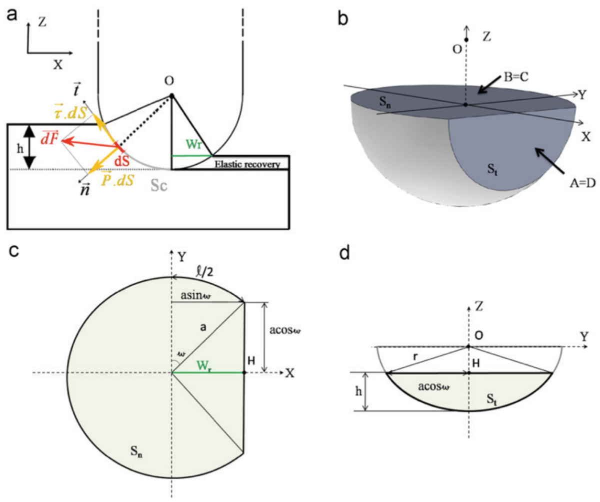

Fig. 1. Geometry of the surface/pin contact in a friction test: (a) friction of the pin on the surface; (b) perspective view of the portion of the pin head engaged in the work material; (c) geometry of the rubbed material print on the pin head in an XY plan and (d) in a ZY plan [4].

2.3. Tribological tests: experimental setup

Tribological tests aim to identify a friction model able to describe the interaction between the carbide tool and the *OFHC* copper in the presence of forced cooled air supplied by a Vortex system (-5 ± 2 °C, 6 bar).

The experimental setup (Fig. 2) is composed by a cylindrical bar of ∅85 mm diameter in *OFHC* copper mounted on a CNC lathe machine, animated with a rotation speed, and a pin of uncoated tungsten carbide with a spherical head diameter of ∅34 mm is rubbing over the cylindrical surface of the bar. The pin is moving along the bar axis direction with a constant feed of 0.18 mm/rev. Simultaneously, normal force (F_n) to the bar surface is applied by the pin through a hydraulic actuator. A piezoelectric dynamometer is used to measure this force, as well as the tangential force, and a thermocouple is placed on the pin to