Identification of advanced frictional laws in severe contact conditions

M. Watremez\textsuperscript{1,2a}, K. Le Mercier\textsuperscript{1,2}, D. Meresse\textsuperscript{1,2} and L. Dubar\textsuperscript{1,2}

\textsuperscript{1}UVHC, LAMIH UMR CNRS 8201, F-59313 Valenciennes, France
\textsuperscript{2}Institut Carnots Arts, F-75013 Paris, France
\textsuperscript{a}michel.watremez@univ-valenciennes.fr

Abstract. This paper proposes a new approach to characterize friction behaviour at the contact interface of severe industrial processes. This work is illustrated for high speed machining and intends to formulate an empirical friction law depending on local interfacial variables like contact pressure, interfacial temperature and sliding velocity. Two specific devices are designed to carry out several tests and simulate the friction behaviour at the tool-chip interface.

Introduction

Numerical approaches to simulate accurately many industrial processes are necessary since in situ optimisation is long and costly. Very intense plastic strains and high strain rates are characteristics of some industrial processes such as for example cold and hot forming, hot cutting or again high speed machining. For all these processes, existing numerical approaches with current friction models don’t lead to good correlations with processes variables. Rheological behaviour of both antagonists and representative friction model at the contact interface have to be studied. This work is focussed on frictional behaviour and is illustrated here for high speed machining. For this application, linear friction models and nonlinear relations [1-2] are commonly used to describe the contact at tool-chip interface. The existing numerical approaches using these classical friction models do not generate good correlations of the process variables, such as the cutting forces or tool-chip contact length. Recent studies [3-6] show the influence of friction model on numerical predictions of process variables.

The originality of this work is to discern in the tool-chip interface two specific zones and to characterise the friction behaviour with two specific friction devices. As shown by Fig. 1, a low sliding velocity combined with a contact pressure value higher than 1 GPa are characteristic at the beginning of cutting. The second zone is subjected to lower contact pressures levels but a sliding velocity up to the speed of the chip. This study is led with AISI 1045 steel and an uncoated carbide tool.

Methodology and experiments

Many steps are necessary for friction analysis. Thermo-mechanical parameters of machining process are firstly considered as characteristics contact conditions to be reproduced on testing stands. The contact pressure, the interfacial temperature and the sliding velocity of chip are assessed with a finite element modelling of high speed machining. In order to perform tests in concordance with the previous contact conditions, the input parameters of test benches such as the contactor penetration and the specimen temperature have to be determined. Several tests are then performed to provide experimental friction data. The ratio between the tangential and the normal force is defined as a friction index. Numerical model of tests are needed to get the friction coefficient. An iterative method is used to determine a Coulomb's coefficient by minimizing differences between the experimental and the numerical forces. Local contact variables like temperature gradient field, contact pressure distribution, and relative sliding velocity are then extracted from numerical modelling for each configuration. From a set of configurations, tribological data are thus used to define the friction coefficient versus to the contact pressure, the sliding velocity and the interfacial temperature.

An upsetting sliding test (Fig. 2a) is used to simulate the specific contact conditions of the interface zone near the cutting edge. This specific device composed of a moving and a fixed part is set on a standard tensile machine. The moving set-up is supported by the load cell linked to the crosshead whereas the other part is fixed on the tensile machine table. The moving part enables to carry away the contactor with a relative penetration p into the specimen. Specimen and contactor temperatures are regulated.
During the test, the contactor penetrates the specimen and slides along its surface with a constant sliding velocity to generate a residual friction track. Both normal and tangential forces are recorded. When test is ended, 3D optical surface profile measurements are carried out on the specimen to determine the actual penetration which will be used for the numerical model of the upsetting sliding test. As shown by Fig. 3 for one configuration (penetration = 84 $\mu$m, sliding velocity = 400 mm.s$^{-1}$, specimen temperature = 752 K), an optimal friction coefficient ($\mu$=0.24) is obtained from measured experimental forces and numerical ones for each configuration of tests. Finally, numerical modelling achieved with an optimal frictional coefficient of 0.24 provides for this configuration a contact pressure of 1 GPa, an interface temperature of 880 K and a sliding speed of 340 mm.s$^{-1}$.

Fig. 3: Experimental and numerical results for each configuration of tests.

To study the second zone, a specific high speed tribometer (Fig. 2b) has been designed and set on a high speed machining machine to study frictional phenomena with velocities up to 1000 m.min$^{-1}$. Normal and tangential forces are measured using a 3D sensor. Thermocouples and a monochromatic pyrometer are used for temperatures measurements. Tests are performed with only a single round of the specimen. The methodology remains the same but enables to get friction data for higher velocities.

Conclusions

From all friction data, Coulomb's friction coefficient can be formulated according to contact pressure, interfacial temperature and sliding velocity by this frictional law:

$$\mu = c_1 \cdot \sigma_n^{c_2} \cdot \nu_g^{c_3} \cdot T_{int}^{c_4}$$

where $c_1$, $c_2$, $c_3$, $c_4$ are constants determined. (1)

For high speed machining application, the friction coefficient decreases all the more so the pressure and the sliding velocity are higher. On the contrary, the friction coefficient takes an higher value when the interfacial temperature increases. A friction law is thus identified for steel AISI 1045 combined with uncoated carbide. Finally, the interfacial law can be implemented in a finite element model of machining.

References