Design of a device for testing and analyzing the friction coefficient during metal cutting

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Abstract. This paper seeks to illustrate the development of a device for tribotesting and analysing of friction and normal forces in orthogonal cutting. In order to investigate the friction and normal forces, the objective of the device will be focused on the analyzing of the behavior of the tool-chip (rake surface) or tool-workpiece interface (flank surface) under dry metal cutting conditions. The device will simulate an orthogonal cutting process conditions that can be afterward modified for another cutting process basically with different geometries. The testing setup allows the friction coefficient to be estimated using the well-known Coulomb's friction law. Experimental procedures were conducted to validate the new device. The experiments were carried out using a tungsten carbide P20 as insert and C45 as the workpiece material, and the results showed that the coefficient of friction is dependent on the area of contact between the tool and workpiece.

1. Introduction

The friction due to the contact between the cutting tool and workpiece has been the subject to many research activities and studies in the past due to its high importance regarding the exit parameters of the process (tool life, chip formation, surface quality etc., overall sustainability).

With the increased development of new materials and tools, and the present work being insufficient to accurately describe the friction phenomena, it becomes mandatory that further study on this subject must be applied. The determination of friction coefficient using analytical relationships is complicated and often gives very approximate results due to the fact that the utilized formulas doesn't include all the influences or the interdependence of different factors. Such being the case, very often, for the determination of the exact values of the friction coefficients, scientists have resorted to empirical methods which utilises for those determinations the so-called "tribometers". This paper seeks to illustrate the development of a new device capable of simulating and modifying tool geometries in order to contribute to the studies on friction at the tool-chip-workpiece interface.

2. Background

The authors of paper [1] published a state of the art paper regarding the development of empirical models for friction in metal. According to his research, three different models can be used to investigate the friction during metal cutting: cutting force measurements, conventional tribometers and specially designed tribometers.

The first method consists in measuring the normal and tangential forces during orthogonal cutting with piezoelectric or strain-gauge dynamometers and estimating the macroscopic equivalent friction coefficients by comparing the values obtained for these output parameters. The second method consists in measuring the normal and tangential forces of a specially designed tribometer that adopt one of the classical arrangements pin-on-disc, ball-on-plate, pin-on-plate and pin on plane (horizontal) (fig.1). The results obtained with this kind of tribometers are usually unsatisfactory given the fact that the surface of the specimen is not refreshed and corresponds to the closed tribosystems. One example for this kind of method is presented in [2]. Another good example is presented in [3] where the authors measured the sliding coefficient of friction between flank wear and workpiece using the arrangement block-on-disk, the block being a CBN insert and the disk made of 60WCrV7 steel bar hardened to 55+2 HRc.

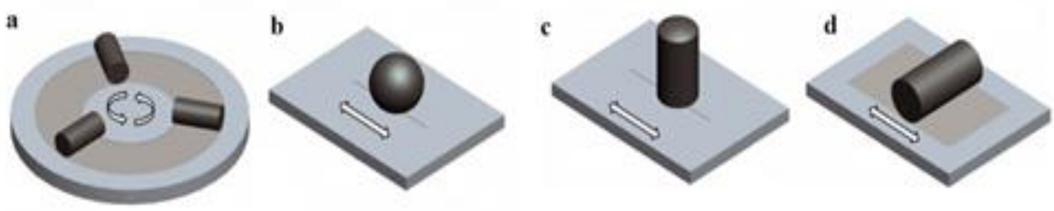


Figure 1. Most widely used tribo-testing geometric configurations: a. pin-on-disk, b. ball-on-plate, c. pin-on-plate, d. pin on plane (horizontal) [4]

The third method consists in specially designed tribometers that corresponds to the open tribosystems (newly refreshed surface) using a pin placed right after the cutting zone during machining. These kind of tribometers are used by many authors like [5] where he studied the friction between stainless steel and cemented carbide pin, [6] (fig. 2.b) where the authors developed a tribometer designed for frictional analysis at the tool/chip/workpiece interfaces based on a plane-sphere contact configuration between 27MnCr5 annealed steel and a carbide cutting tool under dry cutting conditions. There are many more authors like [7] (fig 2.c),[8] (fig. 2.e), that used specially designed open tribometers.

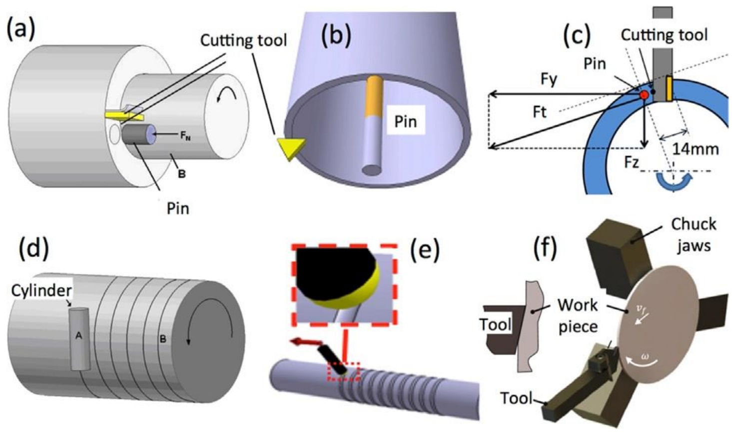
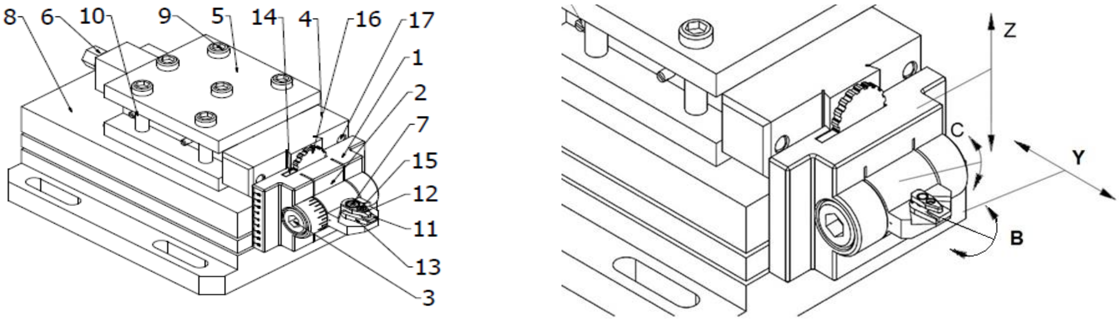


Figure 2. Tribometers for determining friction in cutting [1]

Other studies represent modified pin-on-ring systems, where the pin is in contact with the cylinder during a helical movement [9] (fig. 2.d). In the paper [10]. (fig. 2.f), the authors used a adapted type of tribosystem that simulates a large negative rake angle. The friction coefficient was determined for the couple of materials C45E+N (AISI1045) and uncoated cemented carbide insert.

3. Concept and theory of a new friction device

A new friction testing tribometer was designed to determine and analyze the friction coefficient simulating the normal cutting conditions. The tribometer and its components are shown in figure 3.a.



a) Device for friction coefficient determination **b)** degrees of freedom of the device

Figure 3. The tribometer and its components

1. Rack body; 2. Insert head; 3. Lock bolt; 4. Tool body; 5. Dynamometer support; 6. Pinion cylinder; 7. Fixing screw; 8. Dynamometer; 9. Dynamometer support fixing screw; 10. Tool body locking screw; 11. Insert; 12. Bridle; 13. Intermediate support; 14. Rack; 15. Locking screw; 16. Pinion; 17. Locking screw.

The tribometer can simulate the rake and flank face and varying the cutting edge, rake and clearance angles. To measure the friction between the rake or clearance surface with the designed device, the device is fastened with the dynamometer support 5 on the Kistler dynamometer, who also is mounted on the SN 320x750 transverse slide

Figure 3.b. represents all the possible movements of the devices elements.

To adjust the device for a certain position (tool geometry), proceed as follows:

o Vertical position (OZ) – Moving the rack body 1 by rotating the pinion cylinder 6 which contacts the pinion 16 and the rack 14, the rotation being made through the end of the pinion cylinder by means of a standard wrench with the opening S = 12. Locking into the desired position is accomplished by tightening the locking screws 17 mounted in the standardized pockets of the tool body 4.

o Position in the OXY plane –Rotation over OX axis – axis B – The movement of the insert 11 on the axis of rotation B is done by means of the intermediate support 13. The insert is fixed to the support by means of the bridle 12, which in turn is blocked by the locking screw 15 on the intermediate support 13.

o Translation along the OY axis – The translation on OY axis didn’t offer any possibility of movement because the length of the dynamometer. However, there is the possibility of moving on the OY axis of the whole assembly – dynamometer + device, by moving the transverse slide.

4. Experimental setup

In order to validate the device, a series of tests were carried out. Figure 4 represents the experimental chain as follows: 1. The device described at section 3; 2. Piezoelectric dynamometer Kistler, 9257B for turning operations ; 3. Kistler Amplifier 5070.; 4. Lathe SN320x750 .

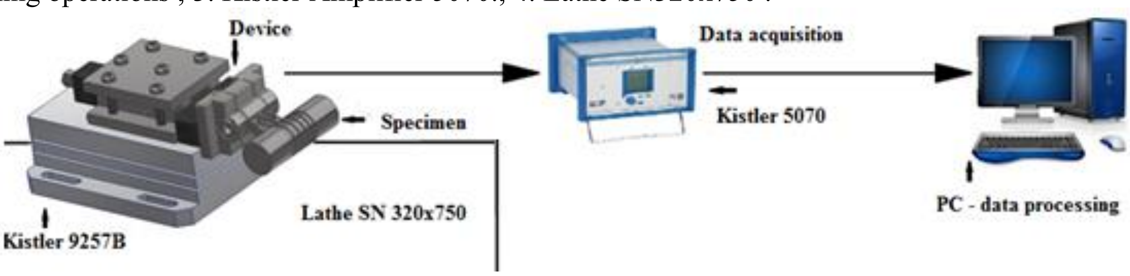
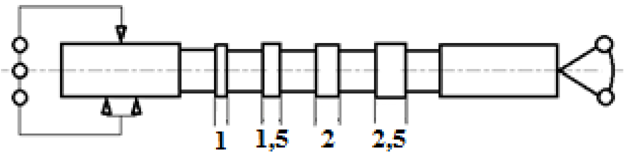
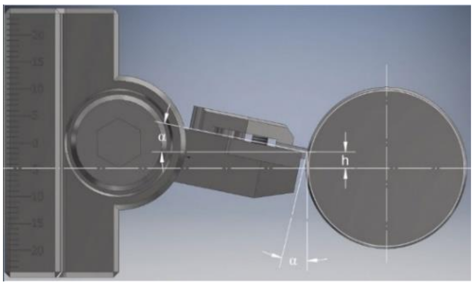


Figure 4. Measuring chain of the experimental setup

The device is mount on the Kistler dynamometer in order to determine the friction and normal forces during the process. The testing material is made of C45E and it has four rings with different widths as showed in figure 5.a.



a) Specimen made for friction tests



b) elevation of the contact zone to simulate clearance angle

Figure 5 The testing material

The tool insert used in the machining tests that were carried out was a P20 grade carbon steel. The device is set to have the clearance angle of 10° and the rake, inclination and attack angle 0°. In order to simulate orthogonal machining and the clearance angle, the contact of the insert with the workpiece is set at a given distance (fig. 5.b.) from the axes as presented in equation (1).

$$h = R \cdot tg(\alpha) \tag{1}$$

where R = radius of the workpiece and α = clearance angle

The depth of cut (pressure) was kept constant during all determinations. In this setup, the tool nose radius is absent or neglected. For all the determinations the sliding velocity is v_c = 20 m/min.

The friction coefficient is obtained using the well known Coulomb's friction law, equation (2).

$$\mu = \frac{F}{N} \tag{2}$$

where F is friction force and N is normal force.

5. Experimental results

The experiments were carried out on four different surface widths that simulates the depths of cut during normal machining. Figure 6 illustrates the experimental data obtain during the tests.

In the beginning, when the first contact is made, the plastic deformation of the material can be seen.

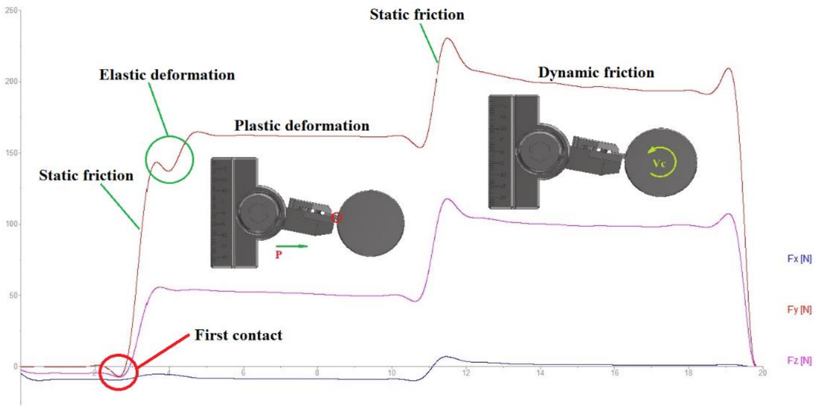


Figure 6. Graphic analysis of the simulation process

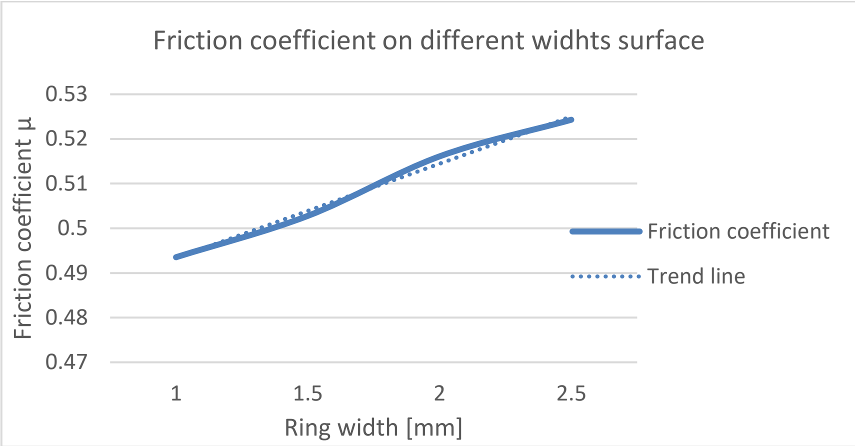


Figure 7. Variation of friction coefficient with contact length

After the contact, when the actual machining simulation occurs and the workpiece starts to rotate, we can measure the static and kinematic friction. Also, during the machining simulation, because the surface is not refreshed, the effect of peening appears where the workpiece surface smoothens. Even though the peening effect occurs, after several measurements in different parts of the graph, the friction coefficient seems to remain constant. Also, in figure 7, the obtained results show us the variation of friction coefficient with contact length. As seen in the graph, the friction coefficient increases with the increased width of the surfaces which states a true affirmation that the coefficient of friction increases with the increasing depth of cut in normal machining.

6. Conclusions and future work

A new friction device was developed that can measure the friction coefficient in the contact zone of the workpiece with the flank surface. The device is designed to be able to continue future works with different kinds of geometries, even with the implementation of cutting edge angle. The experimental results obtained after the tests validates that the device can be used for future studies.

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