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Tool wear effect on cutting forces: In routing process of Aleppo pine wood

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ABSTRACT

This paper uses the cutting forces in a routing process of Aleppo pine wood to estimate the tool wear effect. The aim is to obtain further information about the tool wear effect by monitoring the variation in the cutting forces. A Kistler 9257A 3 axes Dynamometer was positioned under the workpiece to measure the cutting forces at frequencies up to 10,000 Hz. The experiments were carried out on a CNC routing machine RECORD1 of SCM. A carbide tool was used and the cutting parameters were fixed. The cutting speed was approximately 25 m/s. Dasylab software was used to capture the data. The results show a correlation between the tool wear and the computed angle (θ), between the tangential and cutting forces. In fact, the variation of (θ) is unstable in the running period and stable in the linear wear zone, included in the interval [-1.11°; -1.10°]. This study was performed as part of a development program for the Algerian wood industry, hence the selection Aleppo pine wood as the working material.

1. Introduction

Since the first works of F.W. Taylor (1850–1915) a great deal has been learnt about tool wear, as it is a widely studied phenomenon. However, the development of new kinds of tools and new materials has expanded the experimental field. This has resulted in a renewed interest in the study of the phenomena of wear. This renewed interest is highlighted by examples of tool wear investigations in different application fields: Weinert (1993) found, using new advanced materials like metal matrix composites, important differences in tool wear if the hardness of the reinforcement material is higher or lower than the hardness of the cutting material. In the case of dry machining of aerospace aluminium alloys, Nouari et al. (2003) show that the temperature is the major parameter inducing tool wear.

According to Roumesy and Bedrin (1973), the study of wear must be tackled by a gradual and systematic thought process i.e. first, systematically identifying the multiple manifestations of wear and observe their respective development. Then, determine the acceptable limits, according to the quality requirements. The limits will be in the form of quantitative criteria (e.g. crater wear and flank wear), which allow various manifestations of the macroscopic wear.

However, Anselmetti (1996) shows, depending on the various fields of application, that because of the relative nature of wear criteria, it is important to specify which are the most restrictive criteria. It is clear that, in a given field, the wear criteria chosen alone should be used to judge reliably when the tool must be removed from service for renewal of the cutting edge .

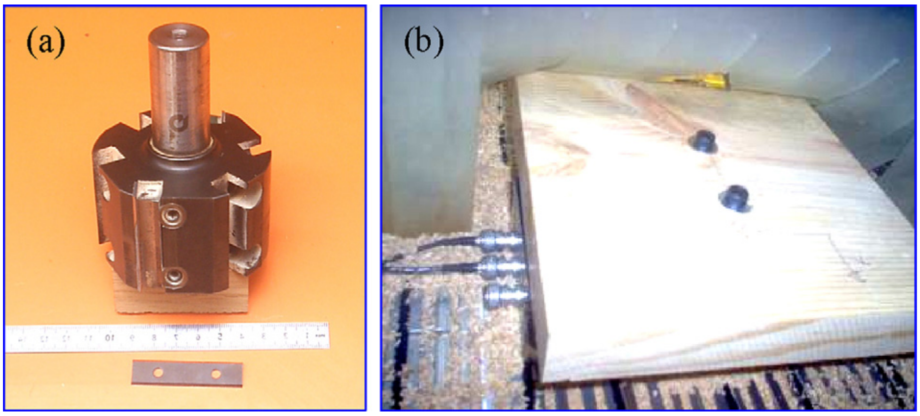

Fig. 1 – (a) Cutting Tool (80 mm diameter); (b) fixture of the sample on the Router table.

The wear can be defined as the loss of material from the cutting edge due to mechanical or chemical factors associated with the cutting process. The cutting edge wear process according to the cutting path in machined material shows three areas that characterize the behaviour of the tool edge recession, which are; running (abrupt wear), linear wear (known as stability period) and catastrophic wear increasing significantly the recession of the tool edge (tool failure).

Itaya and Tsuchiya (2003) concluded that the direct consequence of the cutting edge wear is the gradual loss of its ability to cut the machined material. The result being an increase in the cutting forces and the machine power consumption. These conditions also result in a poor wood surface quality. The wear of the cutting edge therefore has a big impact on the cost of the wood machining process.

Furthermore, it is well known in the machining process that, there is a positive correlation between the cutting edge recessing and the increasing of the cutting forces, highlighted for instance by Kivimaa (1950) in the case of the woodworking, by Stewart (1988) in the case of MDF machining, and by Ravindra et al. (1993) in the case of metal cutting. According to Sheikh-Ahmed and McKenzie (1997), there is a close relationship between the value of the tangential forces divided by the normal forces and the tool lifespan. This gives the opportunity to evaluate the tool wear by measuring cutting forces as shown by Furet and Paturange (1996). Furthermore, we can monitor the tool wear during the machining process and change the tool if necessary. To be aware of the cutting forces, according to Boucher et al. (2007), may also help in the field of tools design i.e. adapting the geometry of the tool, improve the tool holding during machining, and limit tool vibrations which could result in a better final wood surface quality.

The aim of this study is to development an on-line monitoring system dedicated to the routing of the Aleppo pine. By identifying one or more criteria to efficiently quantify and identify rapid tool wear in situ, it can be determined when to change the tool. Furthermore, the Aleppo pine wood is not enough valorised, it contains naturally many defects (knots, resins... etc.), more than other commercial pine wood (Douglas-fir, Norway spruce, Woodland pine...etc.). This makes it necessary to design new specific and strong tools. Our interest for Aleppo pine is that this wood species is widely introduced around Mediterranean Sea, and constitutes the first resource of wood in Algeria.

Table 1 – Cutting parameters

Designation	Values	Designation	Values
Rake angle	10°	Cutting depth	2 mm
Sharpness angle	55°	Rotational speed	6000 rpm
Clearance angle	25°	Cutting speed	25.12 m/s
Tool material	98% WC + 2% Co	Feed speed	5 m/min
Tool diameter	80 mm	Moisture content	12%

2. Materials and methods

2.1. *Sampling*

A CNC routing machine RECORD1 of SCM was utilised, fitted with a carbide tool from LEITZ with just a single cutting edge ($z = 1$) (Fig. 1(a)). The cutting tool was designed to have two cutting edges, so to avoid out of balance effects caused by having only one insert, two inserts were fitted, one was deliberately blunted (so as not to cut) and the second was sharp. All cutting parameters were fixed (cutting geometry; feed rate per teeth...), they are listed in Table 1. The cutting direction related to the part anisotropy axis was 90°–0° (peripheral milling). Wood moisture content (MC) and temperature were controlled and fixed, respectively at 12% and 20 °C. The other parameters were selected in order to obtain prompt treatment and to identify the most appropriate method to analyze the forces. One single sample was prepared to dimensions of 24 mm × 24 mm × 3.5 mm and fixed on the 3 axes Dynamometer for the force acquisitions (Fig. 1(b)). In this way, the influence of wood variability on the cutting force acquisition was reduced. The tool wear was obtained by machining samples taken randomly from 19 Aleppo pine (Pinus halepensis) trees from the Aubagne region in France. These trees were 60 years old and representatives of the resource of this kind of wood around the Mediterranean Sea. Their average diameter was 36 cm (from 32 to 41 cm). The heart wood represent 90% of the wood used for this study, sap wood was removed by sawing in the first transformation. The mean density was: 0.55 g/cm^3 at 12% MC (from 0.53 to 0.58 g/cm^3). The other physical properties are summarized in Table 2.

Table 2 – Physical properties of 19 Aleppo pine trees

Designation	Values	Variations interval
Diameter average	36 cm	From 32 to 41 cm
Density average	0.55 g/cm^3 at 12%	From 0.53 to 0.58 g/cm^3
Average Monnin hardness	2.8	From 2.4 to 3.1
Young's modulus average	11,200 MPa	8300 to 13,500 MPa
Bending fracture stress	82 MPa	From 63 to 98 MPa

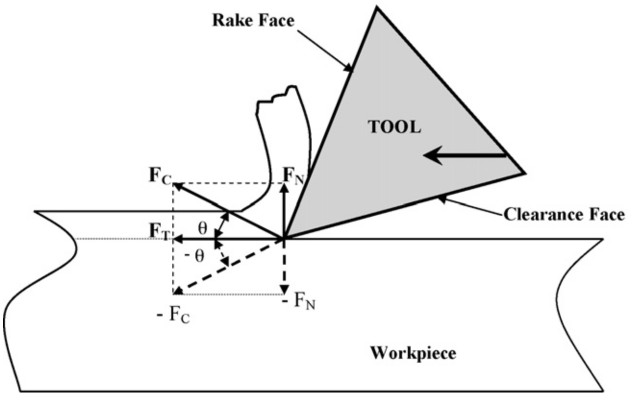

Fig. 2 – Distribution of the cutting forces.

Table 3 – Cutting forces measurement and acquisition parameters

Designation	Values	Designation	Values
Dynamometer frequency	3.5 kHz	Filter frequency	500 Hz
Acquisition frequency	10 kHz	Filter order	4th
Time of a single rotation	0.01 s	Filter kind	Low pass
Tool frequency	100 Hz	Acquisition system	3 axes Dynamometer

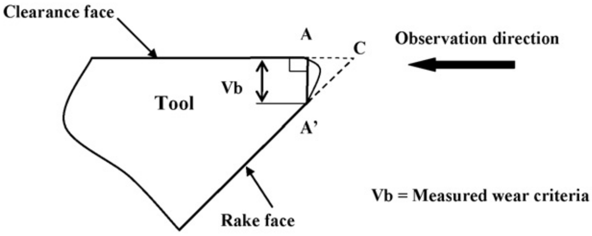

Fig. 3 – Wear measurement principle.

2.2. *Cutting force measurement*

A Kistler 9257A 3 axes Dynamometer was used to measure the cutting forces. The cutting forces were measured according to the two principal directions, tangential and normal, respectively FT and FN (Fig. 2). We define θ as the angle between cutting force F_c and its tangential component FT. To reduce the effect of system vibrations, the data was filtered using a 4th order low pass filter set to 500 Hz. 500 Hz was selected because of the machining frequency being about 462 Hz. Data was computed using Dasylab software. All measured parameters are summarized in Table 3.

2.3. *Wear measurement*

Fig. 3 shows the observation direction and the wear criteria used in this study (wear mark Vb defined by Gottloeber et al. (2001)). The wear was observed using a LEICA MZ12 microscope, which had a suitable field depth (Fig. 4(a)). To minimize positional measurement errors, the observation of the wear was made directly on the cutting tool without removing the insert. A CCD camera, linked to the microscope, was used for the picture acquisition and LEICA software was used for the image computation and to enable on-line measurements. Wear measurements were made along the length of the active cutting edge and each value is an average of 10 measurements, an example of these measurements is shown in Fig. 4(b).

3. Results and discussion

The shape of the curve about the evolution of wear according to the cutting length is similar to the typical wear curve of the tools (Fig. 5). We can consider that the running period is between the beginning of the cutting process and 850 m of cutting length because of the relative fast wear. After 850 m, the tools wear is almost stable and the slope of the curve is less strong than in the first part. The observations are confirmed by the forces variations (Figs. 6 and 7). The high forces variation observed for the 540 m cutting length point is due to the presence of "knots", the knots density is higher than the

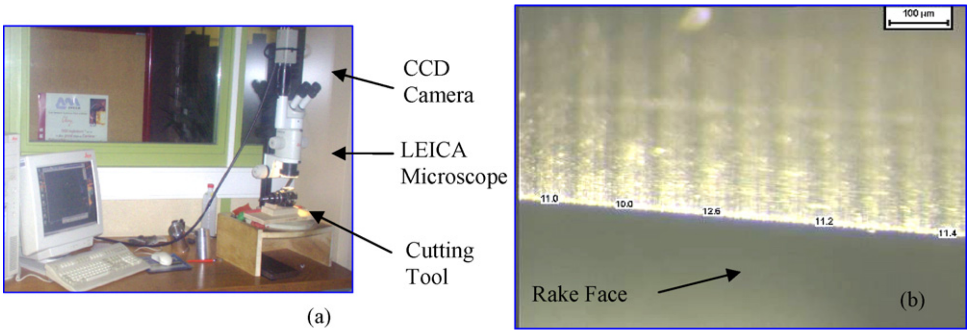

Fig. 4 – (a) The system of observation of wear and (b) a cutting edge measurement example.

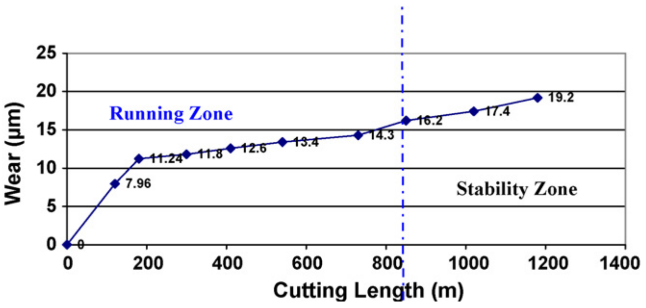

Fig. 5 – Wear evolution according to cutting length.

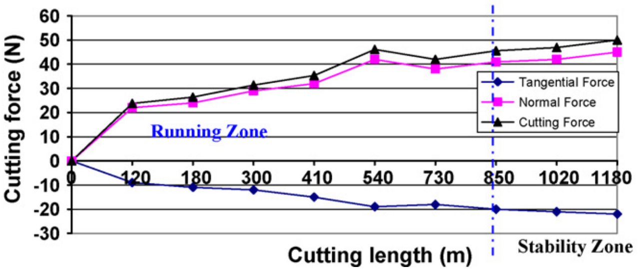

Fig. 6 – Forces variations according to the cutting length.

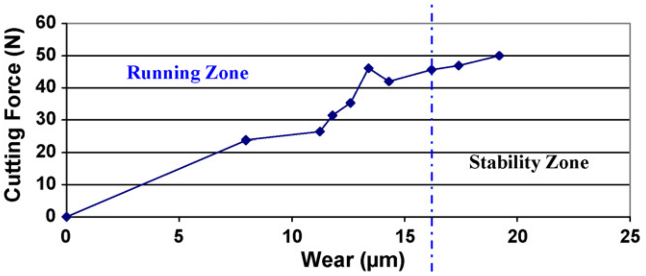

Fig. 7 – Evolution of the cutting force according to the tool wear.

rest of the wood, which explains the increase in force values. This effect has been well reported by Eyma et al. (2004). The knot is one of the natural wood defects; it is a branch that is included in the wood of a tree stem by growth around its base (Kollmann and Côté, 1968). It is interesting to observe that the variation of the computed angle θ (defined earlier as the angle between cutting force F_c and its tangential component FT) has also confirmed that up to 850 m cut length the cutting tool is still in the running period and after 850 m it can be assumed to pass to a stability period (Fig. 8). In fact, in the running zone θ is highly oscillating comparing to the stability zone where the oscillation tends towards zero.

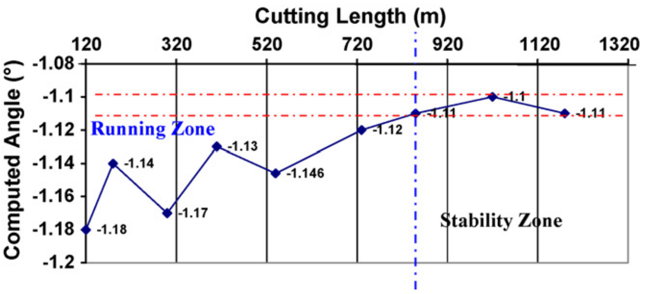

Fig. 8 – Evolution of the θ angle according to the cutting length.

4. Conclusions and prospects

This work provides some interesting results about the tool wear in a machining process of the North African Aleppo pine: the correlation between the tool wear and cutting forces shows that, the running period is about 850 m of cutting length. In this period, θ angle variation is unstable before it is around -1.1° in the stability zone. This confirms the existence of the first two separate areas cited previously, that characterize the behaviour of the tool edge recession, which are running (abrupt wear) and the linear wear (known as stability period). As a consequence we can say that θ angle is a good criterion for tool wear estimation in these practical machining conditions.

We propose to use the same approach with other tools. Another important aspect, particularly in the case of wood, is to estimate the surface quality by measuring its roughness and wettability and to make the link with tool wear i.e. the transformation of wood by removal of matter generates new surfaces which have a precise functionality and will all receive protective films or glues. This highlights the need to characterise wood surface wettability. Depending on the various fields of application, a future aim of this study is to make practical recommendations to wood professionals, summarized in a good practice guide to enhance Aleppo pine solid woods value.

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