ÉCOLE POLYTECHNIQUE
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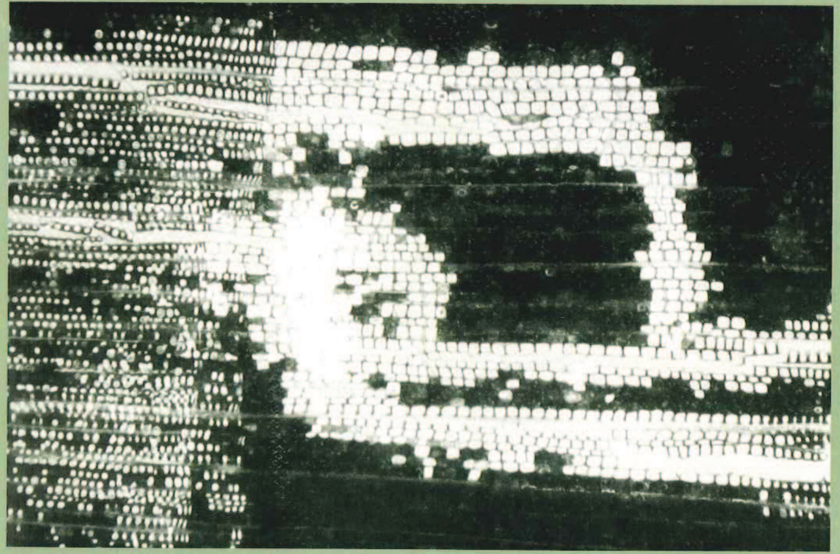
Proceedings of Third International Symposium on Wood Machining

21-23 May, 2007 Lausanne (Switzerland)

Fracture Mechanics and Micromechanics of Wood
and Wood Composites with Regard to Wood Machining



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Première édition 2007
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The amounts of extractives were in the range of the values reported in the literature [2, 3]. The high amount of nonpolar recin acids (Table 2) in the knotwood of pine, compared to stemwood may be the reason for the worse wettability (Fig. 1b) compared to stemwood. Lignan content of spruce knot was at the lower end of the range from that reported in literature [3].

CONCLUSION

Wettability and surface energies are different for knots and surrounding stemwood, the biggest difference is found for the base components. The use of the DVS-scale reduces the base component of the surface energy, compared to the use of the GvOC-scale. A higher polar component of spruce knots on a DVS-scale (Fig. 2b) may explain the better wettability of the knot with water (Fig. 1a). The opposite trend is found for pine knots (Fig. 3b and Fig. 1b), which are wetted worse than stemwood; again the polar component of the better wetted region is increased.

4 ACKNOWLEDGEMENTS

Part of the work was financed by the FFG Austria within the Bridge project number 811008, which is gratefully acknowledged.

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ORTHOGONAL CUTTING OF WOOD AT HIGH SPEED USING A MODIFIED SPLIT HOPKINSON BAR AND A HIGH SPEED CAMERA

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Abstract

The Hopkinson Bars system has been used with a specially designed cutting rig to investigate chip formation at high tool velocities. Samples of Douglas fir with different grain orientation have been prepared from defect-free boards at uniform and constant moisture content. The high-speed cutting process has been filmed by the means of a high speed camera in order to analyse the chip formation. The cutting system is explained and some first cutting results are shown.

1 INTRODUCTION

Chip formation in wood cutting is not still properly understood. The well-known classification by Franz [4] and McKenzie [5, 6] applies only to a limited number of cases. In recent papers [3, 4] we tried to highlight the behaviour of wood during the cutting with different grain orientations and in particular [4] showing that deformation extends below the cut surface as well as within the chip and the consequence are different chip thicknesses instead of those expected and a complicate chip formation not yet explained in terms of fracture mechanics. In particular in cutting with different grain orientations different deformation zones can be identified and the cutting mechanics processing with and against the grain are much more complicate than those defined in [2], [5] and [6]. In a recent paper [4] we tried to explain, better than how they are actually known, the surface formation processes performing tests on Douglas Fir at low cutting speed. In order to analyse the role of the cutting speed and compare the chip formation some tests have been performed with the same cutting condition but at high cutting speed. To achieve high speed cutting a special device was designed and built adapting a Hopkinson Bar system and in order the analyse the chip formation a high speed camera was used.

2 MATERIALS AND METHODS

The special device built for the orthogonal high speed cutting consists of a Hopkinson Bar system with a specially designed cutting rig (see Figure 1). The rig consists of a base which houses a brass ring and a sliding bar where a cutting blade is fixed. The motion is transferred to the sliding bar by the impact of an input bar, propelled at high velocity by a pressure system. The blade mounted in the sliding bar was made of synterised tungsten carbide and the geometry was as follows: γ (rake) 20°; β (wedge) 55°; α (clearance) 15°. The design of the device assured the safety of the process. During the cut the process was filmed by the means of a high speed camera using a resolution of 512X256 px and using a sampling rate of 13.000 fps. Samples of Douglas Fir at a moisture content of 12% have been cut and filmed at -90,-60,-30,0,30,60,90° of grain orientation.

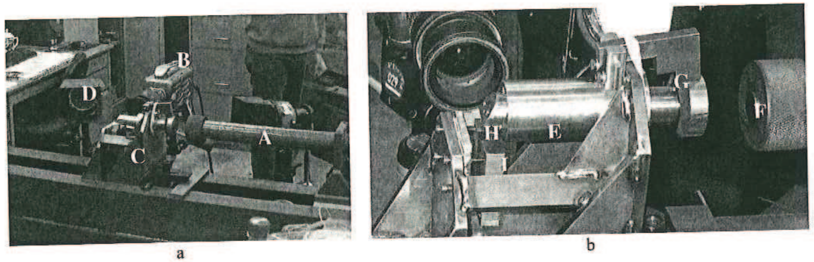

Fig. 1 The setup of the experiment; the acceleration pipe (A), the high speed camera (B), the adaptation rig (C) and the lighting system (D). In b the input bar (F), the sliding bar (G) holding the blade (H) and the brass ring (E). The sample is clamped by a compression plate (I).

Being the first version of the device some problems occurred, such as the movement in the projector during the cut, which did not enable a constant depth of cut to be achieved. The sliding of the projector inside the brass ring in fact is assured by minimal play. This play in highly dynamic conditions resulted in a movement of the bar on the vertical plane. To solve this problem the system was modified and reinforced and finally the movement on the vertical plane was reduced to under 0,05 mm.

3 RESULTS

In the following part some images of the cut are shown and commented in order to give a general idea of the acting phenomenon.

Cutting at **00°** (see Figure 2) grain orientation the cutting begins with the formation of a shear plane with the smallest depth of cut. Because of the higher stiffness of the material, at a very low depth of cut, we observe a transition to fracture. As can be observed in figure 2(b) the fracture propagates in front of the blade at a depth of cut, measured between 0,2-0,3 mm. Processing at low cutting speeds up to a depth of 0,4 mm a shear plane was observed.

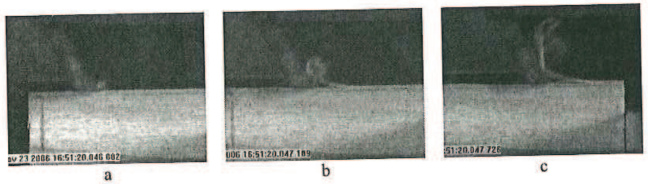

Fig. 2 Cutting with 00° of grain orientation.

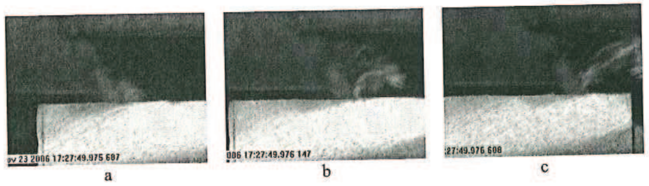

Fig. 3 Cutting with 30° of grain orientation.

Cutting at **30°** of grain orientation (see Figure 3) the process is very similar to that obtained at low cutting speeds. As can be observed, during the cut, the contact area between the chip and the edge is very limited. Groups of fibres are pushed and splits along the grain at high velocity. The final surface quality does not present relevant improvements if compared to the low speed cutting.

Cutting at **-30°** grain orientation (see Figure 4) the result it is not much better then at low cutting speeds. At the first contact the formation of a chip begins (see Figure 4b), but as the depth of cut increase a fractures propagates inside the specimen and across it. The crack begins in the proximity of the blade but its propagation continues after the blade has passed (see Figure 6c). This behaviour is observed even at low cutting speeds.

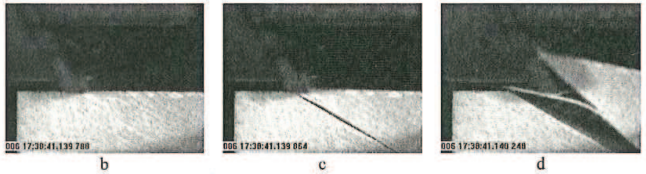

Fig. 4 Cutting with -30° of grain orientation.

Cutting at **60°** grain orientation (see Figure 5) as for the 30° case the chip is broken in shear along the grain but, being the cut more transversal, the segments instead of being projected ahead of the tool slide along the rake face of the blade.

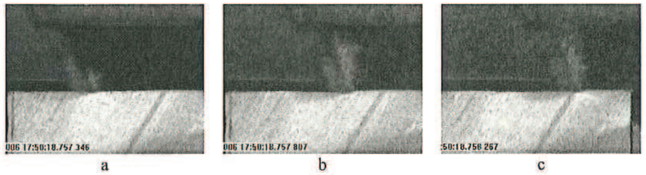

Fig. 5 Cutting with 60° of grain orientation.

Cutting at **-60°** of grain orientation (see Figure 6) a chain of different behaviours can be observed, this is because of the progressive thickening of the chip because the device is moving in the vertical plane. At impact the fibres are pulverised whilst the blade is forming a chip (Figure 6a). With the thickening of the chip, the formation of some fractures can be observed. For higher depths of cut we observe that the wood brakes in bending.

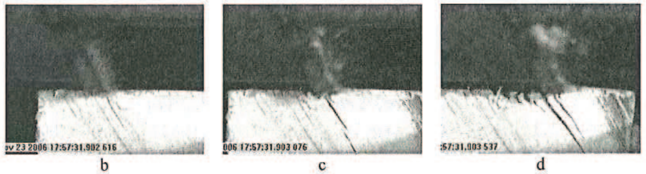

Fig. 6 Cutting with -60° of grain orientation.

At **90°** of grain orientation (see Figure 7) because of the transverse compression during the cut the chip is completely pulverised.

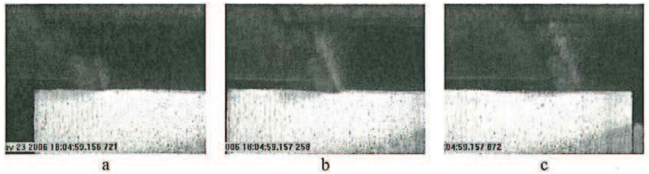

Fig. 7 Cutting with 90° of grain orientation.

4 CONCLUSIONS

A method for orthogonally cutting at high speeds (8 m/s) was developed and different samples have been cut with different grain orientations. At high cutting speed a stiffening of the material can be easily observed, especially when processing along the grain. At higher speeds we observed that the deformation zones around the forming chip at the cutting blade level are less pronounced than at low cutting speed. This is probably due to the dynamic effect. The resultant chips are very pulverised, especially when increasing the grain orientation and the cut becomes progressively transversal instead than longitudinal. Especially processing against the grain the fracture propagation can still be observed even after the blade has passed. The comparison of the final surface quality, of the obtained chips and of the cutting mechanisms processing at low and high cutting speeds will give us the opportunity to better understand the role of the cutting speed when cutting wood.

5 ACKNOWLEDGEMENTS

Acknowledgements to the European Science Foundation, the COST office and the COST E35 action for the financing of two Short Term Scientific Mission that made this work possible.

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DETERMINATION OF THE CUTTING POWER OF THE SAWING PROCESS USING BOTH PRELIMINARY SAWING DATA AND MODERN FRACTURE MECHANICS

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Abstract
The cutting power model obtained during investigation of narrow-kerf sawing process of pine carried out on the modern sash gang saw was a database of a mathematical model formulation of cutting power per one saw. The obtained linear model was formulated for constant values of the kerf (width of cut) S_t *= 2 mm and saw blade thickness s = 0.9 mm. According to modern fracture mechanics it is possible to evaluate the specific work of surface formation (fracture toughness) form the intercept of the model. Furthermore, from the second model coefficient, in the range of larger values of feed per tooth, the other cutting process characteristic data such as: the shear yield stress, the shear strain along the shear plane, the friction correction and the orientation of the plane were calculated. Basing on those determined parameters the theoretical models of the cutting power for narrower saws were worked out. Eventually, they were compared to data obtained directly form the cutting experiments. Obtained relative errors for the narrowest saws* (S_t *= 1.25 mm) have the largest values but they do not exceed of 15.5%. The presented methodology may be suitable for determination of the cutting power for saws which kerf differs from saws used in the preliminary cutting tests.*

1. INTRODUCTION

A new approach to the cutting process shows that cutting forces depend upon the fracture toughness as well as plasticity and friction and reveals a simple way of determining both toughness and flow stress from cutting experiments [1,2]. Furthermore, cutting forces may be employed to determine not only fracture toughness but also shear yield strength for a range of solids, including metals, polymers and wood [1]. Thus, in this paper it is attempted to apply the new cutting model for the sawing process of wood on the sash gang saw (PRW15M, [3,4]), in which three cutting edges of each tooth being in contact with the workpiece take part in sawing, and the process is conducted in a narrow slit (Fig. 1). According to the cutting model [2], the cutting power P_c is given by:

$$P_c = m\left[n\frac{\tau_\gamma S_t \gamma}{Q} v_c f_z + n\frac{RS_t}{Q} v_c\right] = m\left[\frac{H_P}{P}\frac{\tau_\gamma S_t \gamma}{Q} v_c f_z + \frac{H_P}{P}\frac{RS_t}{Q} v_c\right] \tag{1}$$

where: m – number of saws in the gang, n – number of teeth actually cutting, H_P – workpiece height [mm], P – tooth pitch [mm], f_z – feed per tooth (uncut chip thickness, depth of cut) [mm], S_t – kerf (overall set, width of cut) [m], τ_y – the shear yield stress [Pa], γ – the shear strain along the shear plane, given by:

$$\gamma = \cos\gamma_f / \cos(\Phi_c - \gamma_f)\sin\Phi_c \tag{2}$$

where: γ_f – tool side rake angle (Fig. 2), Φ_c – the orientation of the shear plane with respect to cut surface (Fig. 2), which may be calculated for larger values of feed per tooth f_z with the Merchant's equation (because for large uncut chip values Φ_c = const. [2]):

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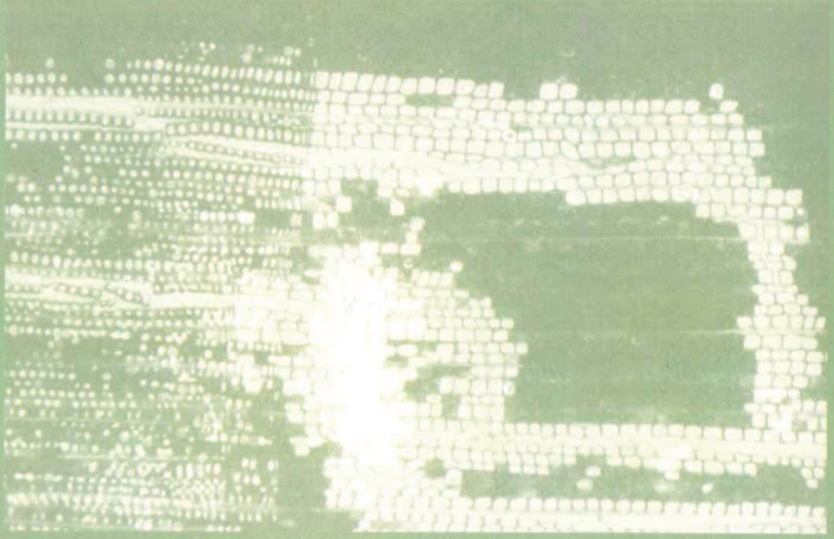

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