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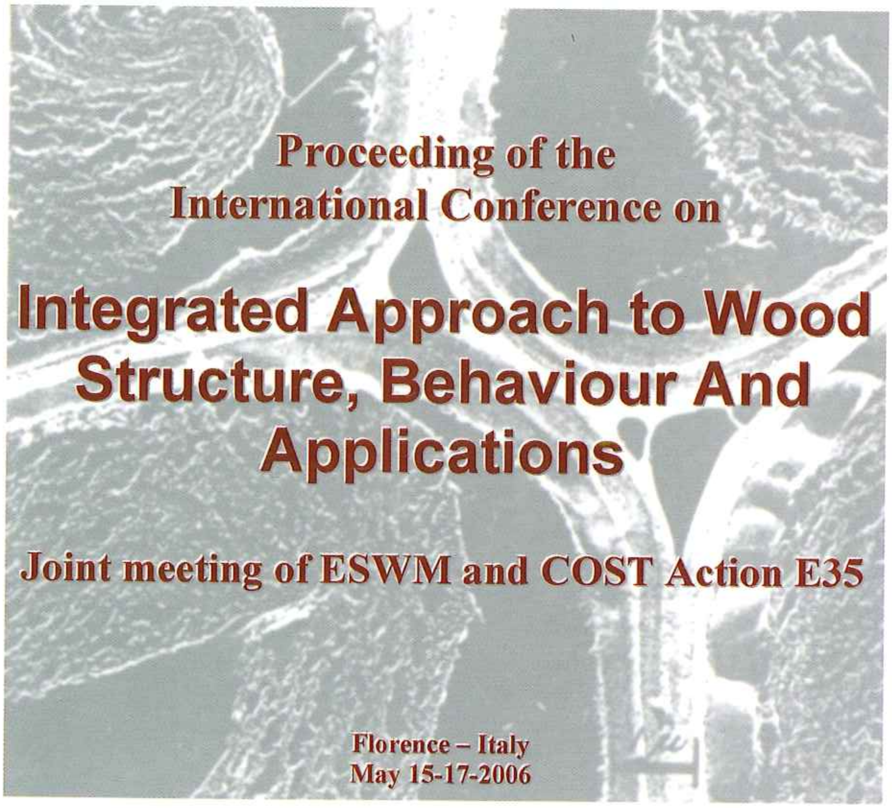

Proceeding of the
International Conference on

Integrated Approach to Wood Structure, Behaviour And Applications

Joint meeting of ESWM and COST Action E35

Florence – Italy
May 15-17-2006

Supported by
COST – European Science Foundation

Edited by
Marco Fioravanti
Nicola Macchioni

Università degli Studi di Firenze
DISTAF - Dipartimento di Scienze e Tecnologie Ambientali Forestali

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CONFERENCE OF THE EUROPEAN SOCIETY FOR WOOD MECHANICS (ESWM)
15^{th}-17^{th} May 2006 – Florence ITALY
Fourth International Conference of European Society for Wood Mechanics

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Preface

This book contains the papers presented at the Fourth International Conference of European Society for Wood Mechanics, held from 15 -17th May 2006, in Florence Italy.
The European Society for Wood Mechanics (ESWM www.eswm.net) has as main aim that of promoting research in the field of wood mechanics among European scientist, by means of regular conferences and publication of the relevant proceedings.
The Florence Conference has represented the conjunction of two different events: the fourth International Conference of the ESWM and the annual meeting of COST Action E 35 (Fracture mechanics and micromechanics of wood and wood composites with regard to wood machining),
The main reasons that have leaded the Board of ESWM and the Management Committee of COST Action E35 to organise a common event, were due to the recognition of the importance of a multidisciplinary approach to research studies on wood and its working technologies, and to the potential benefits for European scientists to met other Non-European researchers that are working on the same fields of interest and that normally attend ESWM Conferences.

The reader of this book will find a collection of 57 papers of high scientific standard presented by scientists from 24 different Countries

The Organisers want to express their sincere gratitude to C.Capretti, P.Mazzanti, N.Sodini for the efforts spent for the organisation and for the staff work done during the conference, and to G.DiGiulio, and L.Rescic for the editorial work of this publication.

Marco Fioravanti (DISTAF – University of Florence)
Nicola Macchioni (IVALSA – CNR)

3. New Materials

   are focussing new products and markets and sometimes better or simpler processes. The development is an ongoing process, currently the light weight panels and WPC products are en vogue. Both of them have already reached a high technological level and in some countries also remarkable market penetration. Nevertheless there are enough open questions and optimization margins left worth while being taken into consideration. Moreover new composites create new challenges for tools and machines.

4. New Tools, tool lifetimes

   are boosted by cost efficiency of the processes, avoiding down times. Besides highly wear resistant materials like new carbide qualities, MCD, PCD, or CVD, coatings have (again) entered the scene. However their effect is not yet proved and the possibilities are far from being fully explored.

5. Cost efficient production technologies

   are often adapted from other branches like plastic technology or electronics, examples:

   - Continuous processes are in general superior to stationary processes in terms of productivity. The new challenges are flexible systems which do not loose more than half of their productivity by the implementation of the flexible components.
   - Mould injection and extrusion of wood based materials (WPC) are adapted from plastic production technologies.
   - Strand production of furniture parts may be a future field against the background of the development of the light weight panels.

6. Part Identification

   is a big issue for productivity, flexibility and process security, for example in high performance optimization chop-saw systems or for lifetime signatures of furniture parts. The state of the art still has a number of short comings, like the lack of legibility on rough sawn parts in the case of printed signatures or still too high cost level in case of transponders for furniture parts.

7. Safety techniques

   have been important issues at all times. Besides the humanistic point of view there are important economic issues like process security and unexpected down times.

8. Defect detection and yield optimization

   has already reached a high standard for example in the 3-D scanning of the log shape in sawmills or the defect identification and optimization in automated chop saws. But there seems still room for further developments like reliability of failure detection or extension of the variety of detectable defects.

The list is of course not exclusive and it should be rounded off by a second list of developments, which have not fulfilled the expectations in the past. For example the integration of CNC routerheads in highly flexible doubl-end-tenoners, which lost their most significant economic strength – the high productivity by this development. This technology is of course still in use, but it is far from dominating the marked, which was the expectation in the first time.

The objective of the paper was to put the needs of the general economic development of the woodworking branch into the centre of our consideration, pointing out that this not a limitation, but further challenge and source of ideas for every researcher.

Chip formation processing wood with different grain orientations using low speed free orthogonal cutting technique

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Abstract

This study examines the wood cutting process at different grain orientations using low speed orthogonal cutting technique to give a contribution to the understanding of the chip formation mechanisms. The chip formation process is still partly undisclosed and slow speed cutting has shown to be very effective in it's understanding, even if presenting some well known limits. The principal and normal forces have been measured cutting with different grain orientation on Douglas Fir, Azobè and Beech. The surface formation have been recorded by the means of sequential photography. For all the selected species we observed a similar behaviour and a few chip formation mechanisms depending mainly on the grain orientation. The results obtained resulted very similar to those appeared in the bibliography, even processing with higher speeds showing how this technique can be useful. Deformation zones have been identified and the behaviour of the cutting forces have been ascribed to the removal angle. Friction coefficient have been computed and some important phenomena have been highlighted, such as the chip thickening processing when processing against the grain or the initial transient at the first cutting stage.

1. INTRODUCTION

The main purpose to study the fundamentals of the wood cutting process can be identified in the improvement of the process itself. The cutting of wood is one of the main industrial processes and the definition of the optimal cutting parameters has always represented one of the main goals for the researchers and for the industry. The fundamentals of the wood cutting process have been defined by the '50s by the pioneering work of Kivimaa [11]. In it's work Kivimaa shows the influence of some factors such as the depth of cut, the grain orientation and the blade geometry on the principal and normal force. Such work has been completed by other fundamental contribution, mainly by Franz [6] and McKenzie [12, 13, 14, 15] which propose some interpretation and models for the surface formation mechanisms. In particular they describe different type of chips cutting along and across the grain. Important contributions have been offered by Woodson and Koch [19] and Stewart [17, 18]. Stewart introduce a first important approach to the effect of the cutting direction with respect to grain orientation on the quality of machined surface, on the tool force components and on the cutting friction coefficient. After such basic works not much seems have been done on the subject and in particular in order to understand the chip formation mechanisms. An analysis of the cutting forces, of the surface roughness and of the acoustic emission processing with different grain orientations has been done by Cyra and Tanaka [2]. Negri and Goli [16] reported a description of the surface quality as a result of the grain orientation when processing with and against the grain in the horizontal plane (from 90/0 to 90/90 cutting conditions) and they also put into evidence the relationship between the surface defects, as described by a visual classification (raised grain, fuzzy grain and torn grain), to be felt as a consequence of the grain orientation. Further investigations has been done by Goli et al. [7, 8, 9 10] and by Costes et al. [1] with two different approaches. In the former case the tests have been carried on in a routing process, in the latter processing with a turning machine; however, the results in the two cases are very similar. In this paper we use the low speed free orthogonal cutting in order to understand what is happening at the surface level during the cut processing with different grain orientations.

2. MATERIAL AND METHOD

Test method

Low speed orthogonal cutting technique has been used as method to study the chip formation and collect useful information to understand the process. Within this framework we are conscious that the cutting mechanics and the cutting forces change with the cutting velocity, but by the other side we believe this method as a fundamental way to understand the chip formation mechanics. A fundamental factor to be taken into account and which makes an important difference in the cutting mechanics at different cutting speeds is the deformation of the material. Experimental results [13] show for metals cutting how the higher the cutting speed the more deformation of the material is localised on a plane called shear plane. Slowing down the cutting speed the deformation becomes an area instead of a plane and is called primary deformation zone (see Figure 1). A secondary and tertiary deformation zones can be identified. The secondary deformation zone is on the chip and corresponds to the zone where the chip is compressed, the tertiary zone is on the back of the tool and depends on the friction due to the spring back of wood after having been cut. As already explain the cutting speed influence all these three deformation zoned and even if this statement is more correct for metals than for wood this is a clear limit of this research. However this approach could lead to the observation of phenomena otherwise not understandable in the surface formation process and in the chip cutting mechanics.

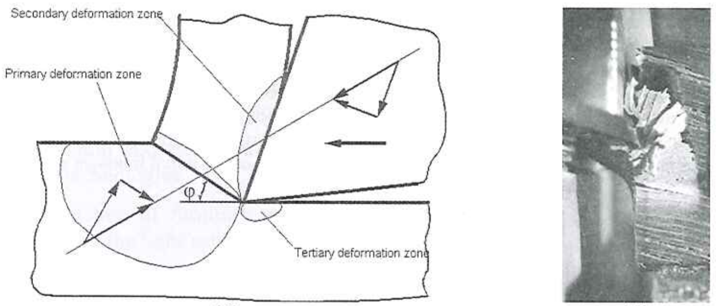


Figure 1: (a) The primary, secondary, tertiary elasto-plastic deformation zones. Sometimes the primary deformation zone extends over the tertiary deformation zone as in (b) where 70° tangential Azobè is cut against the grain.

Test set-up

The specimens used in the experiment were of different species and have been processed with different anatomical orientation as reported in Table 1.

Table 1: Species processed in the experiments

Specie	*MC %*	*P g/cm³*	*Board orientation*
Douglas Fir (*Pseudotsuga Menziesii* Franco)	9,6	0,62	Radial and Tangential
Azobè	9,2	1,11	Radial
Beech	9.22	0.67	Radial

The specimens have been cut by a straight grain board and as close as possible between them in order to minimise the effects of the wood variability. The boards have been chosen without defects and have been conditioned to an homogeneous moisture content. The specimens were 14 mm width , 20 mm long and minimum 35 mm deep in order to offer a base big enough to be firmly fixed on the dynamometric platform. To define the grain orientation towards the cutting edge we used the two angles method given by McKenzie [14] where the first angle (A) is the angle between the blade and the grain and the second angle (Ω) is the angle between the grain and the feed direction. The specimens have been cut in tangential and radial boards and their anatomical orientation is marked with "t" in the case of tangentially oriented specimens and with "r" in the case of radially oriented specimens (see Figure 2a). In the three angles classification proposed by McKenzie in our case A is always 90°, while Ω vary from -90° to 90°. Ω is progressively varied with 10° steps. A value of 0° means processing along the grain, a value going from 10° to 80° means processing with the grain, a value between -10° and -80° means processing against the grain, values of 90° or -90° mean processing across the grain. The values of 0° and -0° and 90° and -90° are just symbolic and mean that

the specimen has been tilted and the values averaged in order to compensate little disalignment of the grain.

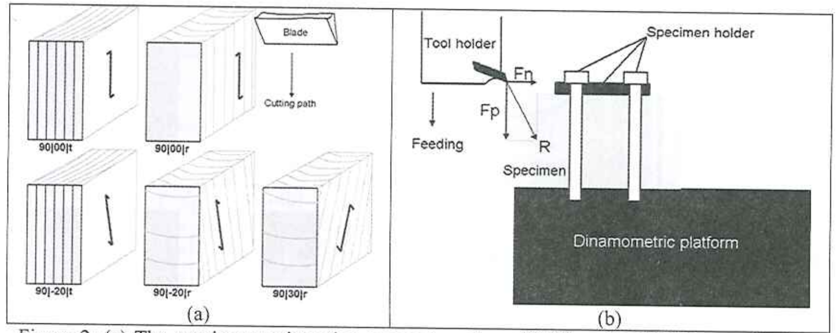


Figure 2: (a) The specimens orientation processing along (90|00), with (90|30) or against the grain (90|-20) for radial (xx|xx|r) or tangential (xx|xx|t) specimens (b) The experiment setup

The experiments have been conducted using a conventional material testing device mounting a stiff arm carrying the blade and driven by linear roller bearing moving on 4 steel columns as guide. The cut has been free and orthogonal, the cutting speed 5 mm/sec, the nominal depth of cut 0,6 mm, the blade material WC and the blade geometry as follows: γ (rake) 20°; β (wedge) 55°; α (clearance) 15°. The specimens have been firmly fixed on the tri-axial dynamometric platform by a compression plate (see Figure 2b). The principal (Fp) and normal force (Fn) has been acquired by the means of a computer acquisition board sampling at 100 samples/sec. The cutting has been photographed in sequence by the means of a digital camera.

3. RESULTS AND DISCUSSION

General chips overview

From the simple observation of the phenomena by the use of the sequential photographs we realised the following main points:

- processing with different grain orientation we can observe the formation of different and yet unclassified chips (see Figure 3);
- the formation mechanics are very different depending on the grain orientation (compression, tension, bending, splitting);
- the real depth of cut appears variable even if set to a nominal value of 0,6 mm (the nominal value can be observed processing at 00 grain orientation in Figure 3e and 3f);
- the deformed chip thickness appears very different , thicker processing against the grain, thinner processing with the grain (Figure 3);
- the friction zone between rake face and chip appears much bigger processing against the grain because of the higher deformation;
- in many cases the chip is cut at the tool tip level even if big deformation arise (Figure 3), in other cases the splitting it is not at the cutting edge level but deep inside the specimen (Figure 1b);
- during the cut important deformations as consequence of the cutting tensions appear in front of the tool (primary deformation zone), on the chip (secondary deformation zone) and on the back of the tool (tertiary deformation zone) as can be seen in Figure 3;
- the primary deformation zone, especially processing against the grain, often extends on the back of the tool on the tertiary deformation zone (Figures 3a, 3b, 3c, 3i, 3l, and 1b)
- we have not observed processes of adhesion of the cut chip on the blade showing that probably this is not a variable to be taken into consideration.

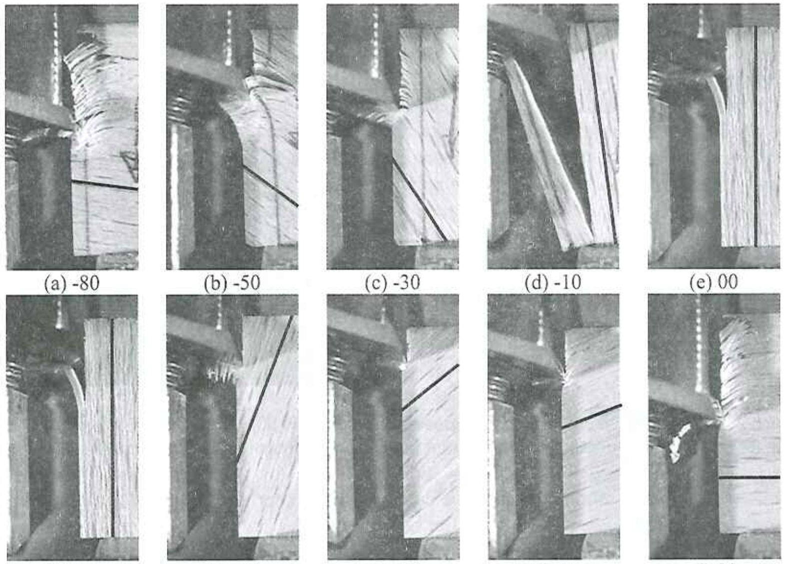


Figure 3: Some examples of chips forming on Beech when processing with different grain orientations with and against the grain. The black line is the grain orientation.

Cutting forces at steady state cutting condition
For every grain orientation, with some exceptions processing against the grain with narrow grain angles where the specimens is destroyed instead of being cut (Figure 3d), the cutting forces have been averaged in steady state cutting condition (Figure 4). The results are very similar to those found by other authors [12, 19, 20, 1 and 8] processing with different and in most cases conventional cutting speeds. It shows how the cutting forces arise from the interaction between the blade and the grain and can be used to explain the surface formation mechanics and to clarify processes not yet focused such as the chip formation, the defects formation and the surface formation mechanics. In some cases the cutting forces during the cut are very regular and can be averaged very easily, in other cases the steady state cutting condition (in particular processing against the grain) is more difficult to locate and it has been necessary to use the sequential images to establish the steady state process.

Processing with the grain: as expected the principal force modulus (Fp) increase with the specific gravity of the species; the higher is found cutting Azobè and in descending order follows Beech and Douglas Fir. The force required for radial and tangential Douglas Fir is very similar, even if the cutting for radial specimens is more discontinuous because of the alternation of high density layers (late-wood) and low density layers (early-wood). Beech and Douglas Fir require similar forces in order to be cut with the grain while Azobè requires values twice the value of the others. Radial and tangential Douglas fir are not very different when cutting at steady state. Observing the plots for all the species a minimum in the cutting principal force can be observed at values between 20° and 30°. For the normal forces a different behaviour for Douglas Fir, Beech and Azobè can be observed. In Douglas fir, for both radial and tangential specimens, a maximum can be observed around 10°/20°, after this value the normal force tends to decrease. The normal force processing Beech and Azobè shows a behaviour much closer to the principal force, growing continuously until 90° is reached.

Processing against the grain: the differences between the species are much bigger than processing with the grain. For narrow cutting angles (0° to -20°/-30°) the specimen is completely broken and a failure propagates from the beginning to the end of the specimen (Figure 3d) making it impossible to measure the cutting forces. For higher grain angles the fracture does not enter as deep into the specimen, after an initial transient the cut comes to steady state and in most cases a chip is formed. Concerning Douglas fir, as can be observed in Figure 4, radial specimens tends to be destroyed much more than tangential because of the bending of late-wood layers not supported under by the early-

wood that collapse. Observing the lines a maximum in the cutting principal force can be observed between -50°/-70°. Is a little bit surprising that Beech and Tangential Douglas Fir show the same values of principal force at -30° and -40°, and Beech and Azobè shows the same value at -50°. An important observation is that the normal force processing against the grain increase very much and even if this behaviour has been observed by Kivimaa [12] has not been observed in other works [1, 8].

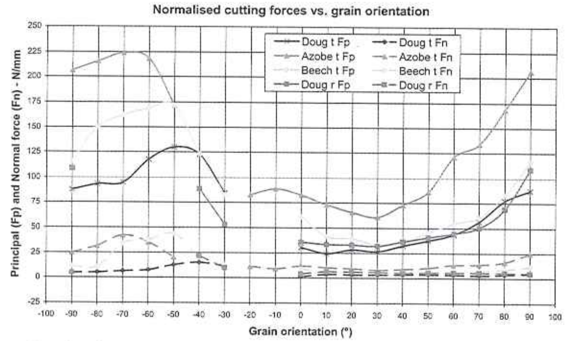
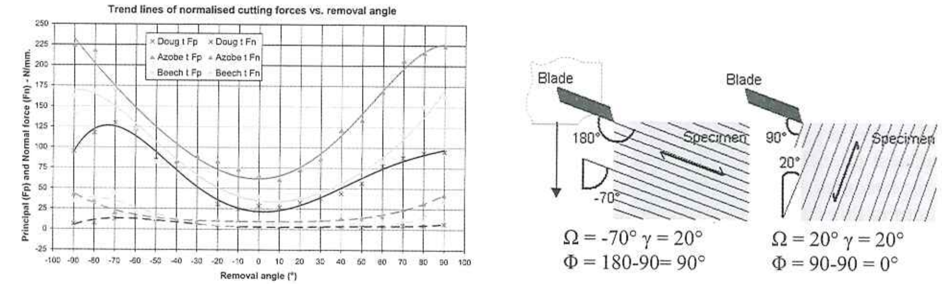


Figure 4: Normalised Principal (Fp) and Normal Forces (Fn) values processing with different grain orientations at steady state cutting condition

The general behaviour can be better highlighted plotting the trend lines (Figure 5a). In this plot it is clearer the role of the grain orientation that combined with the rake angle gives a clear explanation of this behaviour (Figure 5b). In facts the maximum and the minimum observed are well linked to the angle between the rake face and the grain orientation and the cutting forces are very sensitive to the orthotropic behaviour of wood. In particular these two parameters can be summarised in what we call the "removal angle" (Φ) that is the angle between the rake face and the perpendicular to the grain. This angle has positive value when the angle between the rake and the perpendicular to the grain is acute and is negative when this angle is obtuse, see Figure 5b. This angle, defines the orientation of the blade with respect to the orthotropic behaviour of wood. In particular as can be seen in figure 5b, the minimal and maximal force correspond to the fact that the rake face is parallel (Φ=0) or perpendicular (Φ=90) to the grain. This angle is very similar to the "angle de levage" defined by Juan in [12a], however an inversion of the sign have been applied for coherence with our previous definitions.



(a) (b)

Figure 5: Trend lines for normalised cutting forces vs. "removal angle" (Φ) (a) and scheme of the resulting angle between the rake face and the grain while cutting at 20° and -70° (b)

The trend of the principal forces is specie independent, as can be observed in Figure 5a, and mainly linked to the removal angle. For the normal forces, processing against the grain, the results are less clear and the cutting process is much more difficult to be interpreted. In other experiments a rise in the cutting forces, processing against the grain, can be observed. The fibers are tilted in groups, compressed and finally cut, and the cutting forces are very influenced by the bending and the consequent compression.

Cutting friction coefficient at steady state cutting condition
In order to compare our results with other works we computed the cutting friction coefficient. Friction coefficient is defined as the ratio between the tangential tool force (N) and the normal tool force (F). The cutting friction coefficient (μ) can be easily computed ($\tan(\arctan(Fn/Fp)+\gamma)$) and the values are reported in Figure 4. Processing with the grain shows very similar trends for all the species, and the results are similar to those obtained by [20]. Processing against the grain the results are less clear and not always in line with the results of Stewart. Anyway a very similar trend can be observed for Beech and Azobè, while Douglas Fir seem to have a different behaviour.

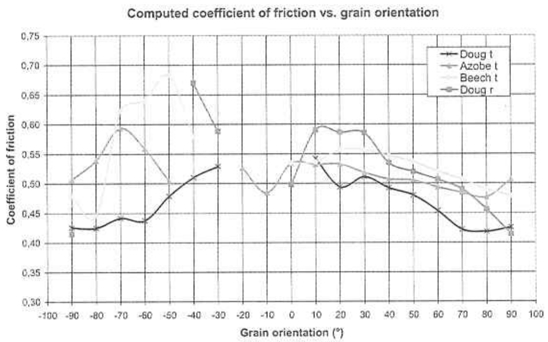


Figure 6: Effect of the grain orientation on the cutting coefficient of friction

Cutting with higher speeds results in a clearer and more continuous chip formation especially processing against the grain and consequently results in different values of the cutting forces. Processing with the grain, the cutting speed probably, does not influence the process very significantly. The discontinuous values of the cutting friction coefficient processing against the grain show how the cutting mechanisms observed processing with low speed cutting can not be transposed to a conventional cutting but possibly help in the comprehension of the phenomena.

Cutting forces at first cutting stage
At the first cutting stage between the blade and the specimen we observed a significant difference in the principal and normal force than when steady state cutting. The behaviour of the principal force is much more simple than for the normal force. Processing against the grain the principal force rise slowly until steady state is reached, processing with the grain the principal force rise much faster and steady state is rapidly reached. For the normal force the behaviour is more complicated and the main differences are in the modulus and in the versus. As can be observed in Figure 7a during the initial transient the normal force is often negative (continuous lines) while at steady state (dashed lines) the force becomes positive. For the value of the initial transient we used the lowest reached by the normal forces in this cutting stage, the steady state values have already been computed and shown previously. Even if this behaviour is not always clear we can observe a trend in both normal force at the first cutting stage and at steady state cutting well bound to the grain orientation. Once again as sensitive points we can locate 20° and -60°/-80°. If verified in a conventional speed cutting this behaviour could play an important role in the up or down milling processes. Up milling the impact is near the surface and at the surface formation time we are processing within the rules of the initial transient. Down milling the impact is far from the surface and at the surface formation time the tool is cutting at steady state condition. This behaviour involves many factors such as the absence of friction on the clearance face at the beginning of the cut (see Figure 7b1) and the absence of the friction force on the rake face. In fact, at the first contact, processing with a removal angle (Φ) going from -90° to 0° the bending goes deep inside the specimen allowing a non contact time between the clearance face and the wood. By the other side the chip has only jus started its deformation but still does not slide on the rake face.

Being the resultant force directed inside the specimen mainly because of these forces the normal force at the impact time is negative. With a removal angle between 0° and 90° we still have a non contact zone at the first stage of cut between the wood and the clearance face and the chip tends to slip along the grain resulting once again in a negative normal force. When the cut pass in steady state condition (see Figure 7b1) the friction force exerted by the sliding chip and the force exerted by the spring back of the wood on the clearance face turns the normal force to positive values.

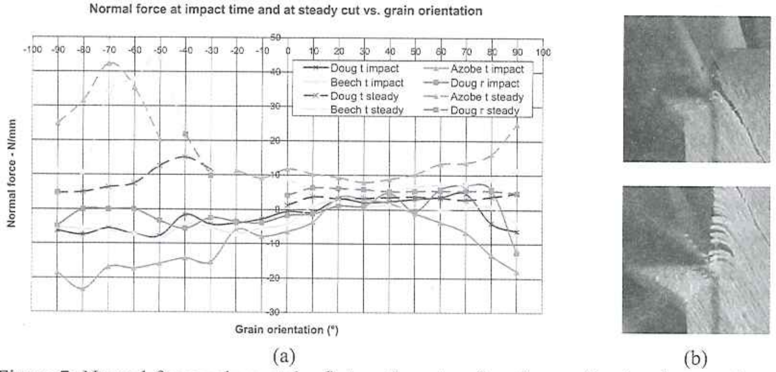


Figure 7: Normal force values at the first cutting stage (continuous lines) and at steady state cutting conditions (a) and particulars of the cutting at the first cutting stage (b1) and at steady state cutting (b2)

Nominal and real depths of cut
By the observation of the principal force during the chip formation processing against the grain we observed that in the first cutting stage the principal force was rising progressively before coming to steady state cutting. By the sequential photographs we highlighted a progressive thickening of the chip due to the bending of the fibers. The observations of the chip formation clearly show how the real depth of cut change according to the grain orientation. In facts processing with or against the grain leads the fibers to be tear out or compressed (see Figure 8) resulting in a thickening of the depth of cut in the former case (Figure 8a) and in a thinning in the latter (Figure 8c).

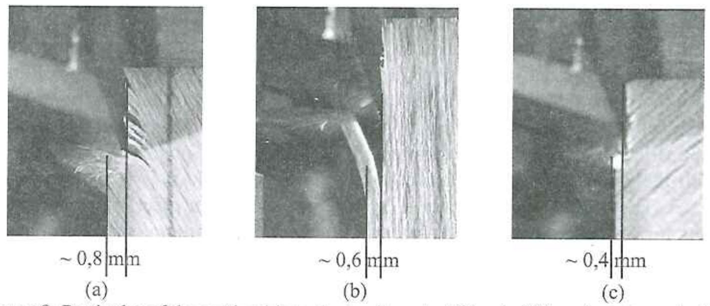


Figure 8: Particular of the cutting blade during the cut of Beech -30° against the grain (a), along the grain (b) and 50° with the grain (c) photographed with the same magnification

To be more precise when processing against the grain the bending of the fibers at the tool tip level results in a tilting of the fibers placed under. The result of this deformation (acting in the secondary deformation zone) is a thickening of the chip. Processing with the grain leads to a transverse compression of the fibers, the wood reacts with an elastic deformation and the real depth of cut decrease (Figure 8c). After the tool has passed the wood springs back and the new surface is above the cutting path. This behaviour can be clearly observed in Figure 8 where processing with grain angles of

-30°, 0° and 50° and with a depth of cut set to 0,6 mm the real depth of cut results in ~ 0,6 mm for 0°, ~ 0,8 mm processing with -30° and ~ 0,4 processing with 50° of grain orientation. For the species and for the cuts resulting in a clear and defined chip we weighted the chips in order to easily highlight the differences. Being the same wood, consequently the same density and as the width and the height of the specimens were well defined, a different weight of the chip can only be attributed to a difference in the depth of cut. The results of the weight tests are reported in Figure 9. As expected processing with the grain the real depth of cut decreased and consequently the chip weight decreased. By the other side processing against the grain a thickening of the chip is observed and consequently an increase of the chip weight.

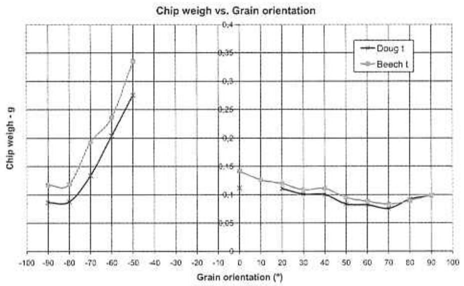


Figure 9: Effect of the grain orientation on the chip weigh for Douglas Fir and Beech

4. CONCLUSIONS

In this paper we analyse the chip and surface formation processing with a conventional blade at different grain orientations using a low speed free orthogonal cutting technique. The measured cutting forces (principal and normal force) confirms trends very close to those reported in the bibliography. The behaviour is similar for all the species and can be easily related to the grain orientation and to the density of the specimens. This evidence even if slightly different from conventional cutting, can be used to highlight some aspects of the wood cutting process. The aspects to be highlighted at our advice are still: chip formation mechanics, fracture propagation, surface formation mechanics, influence of cutting speed and interactions between wedge and grain during the surface formation. Observing the cutting forces two fundamental sensitive values can be noticed for the principal force: 20°/30° and -60°/-70°. By the computation of the removal angle is easy to observe that they correspond to 0° and 90° of Φ. In the former case the grain is parallel to the rake face while in the latter the rake face is perpendicular to the grain. Processing against the grain with low cutting speed the bending of the fibers results in much bigger deformations than processing with the grain. These phenomena probably would be less pronounced processing with conventional cutting speeds, anyway, the observations results very helpful for the understanding of the chip formation. This datum is confirmed by the analysis of the friction coefficient that even if coherent with precedent researches, especially processing with the grain, processing against the grain his behaviour is not clear and change with changing species. These observations, even if in the first stage, can offer some important highlights and suggestions for further investigations. In particular the most important conclusions are: the chips defied by Franz and McKenzie are inadequate to define the types of chips arising in the cutting, an impact transient has been observed having an influence on the versus of the normal force, a thickening and a narrowing of the chip have been observed processing respectively against or with the grain. The comparison of the observed phenomena with those of a conventional speed cutting process could lead to new interpretations of the wood cutting process.

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