Classification of wood surface defects according to their mechanical formation during machining

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Classification of Wood Surface Defects According to their Mechanical Formation during Machining

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Abstract
In the framework of a research dealing with surface quality, some specimens of douglas fir, oak and beech have been processed, at various grain angles, up- and down-milling, along and against the grain, with a 3-axis routing machine [6]. Surfaces have been examined macroscopically and microscopically, in order to understand their mechanical formation. Surface formation has been explained, and a new classification of defects mechanical origin has been developed. The defects have been classified according to their main mechanical origin, sub-mechanical behaviour and breaking behaviour.

1 Introduction

In wood machining it is well known that the final quality depends on many factors. One of the main factors is the grain direction. In facts processing at different grain directions as regards the processing plane provides really different cutting conditions. This difference is mainly connected to the differences in the cutting mechanics dues to the anisotropy of the material, consequently to the different properties of wood in the different directions [8,9,10]. The authors have already described how the processing defects, the cutting forces and the surface quality change according to the grain angle giving some interpretations of the phenomena involved [4,5,6]. The evolution of the surface can be explained by a mechanical and micro-mechanical point of view, studying the stresses that cause the defects formation. This study begins by the examining the basic stresses applied to the material, then analyses their evolution to give a general interpretation and classification of the wood cutting mechanics. This work should be considered as a "work in progress" and a first approach to the problem, the proposed classification could be modified according to suggestions and to the developments of the study.

2 Materials and methods

This study is the outcome of a long ensemble of tests carried out to study the surface defects and better understand the surface formation mechanisms. The study has been divided in several phases: establishment of the processing settings, selection of different species to be processed, processing at various grain angles to achieve the formation of the defects, macroscopic, microscopic, SEM and profile analysis of the surfaces processed, visual analysis of the surfaces, analysis of the cutting mechanisms, classification of the cutting mechanisms, analysis of the cutting forces evolution when processing at different grain angles. The results presented in this paper have been obtained by processing different species (douglas fir, oak, beech, lime, poplar) at various grain angles up- and down-milling with and against the grain. The tests at different grain angles have been carried out increasing by steps of 10° the grain angle after each test and conserving the processed surface in order to execute further analyses. For each species all the tests have been carried out in the same piece of wood, chosen with a regular grain. Each test started by processing at straight grain (0°) and ended by processing on the end-grain (90°). The intermediate angles were processed with the grain and against the grain (in the latter case, a "-"sign is placed before the angle). With this type of test it is possible to observe the formation of all possible defects that could arise from processing a piece of wood with given settings, making easy a complete description of the defects. In this paper no distinctions are made between different processing settings, but the target is to give a general idea of the mechanics acting during the cut and a classification of the mechanics acting in the defects formation. The test principles are summarised in Figure 1.

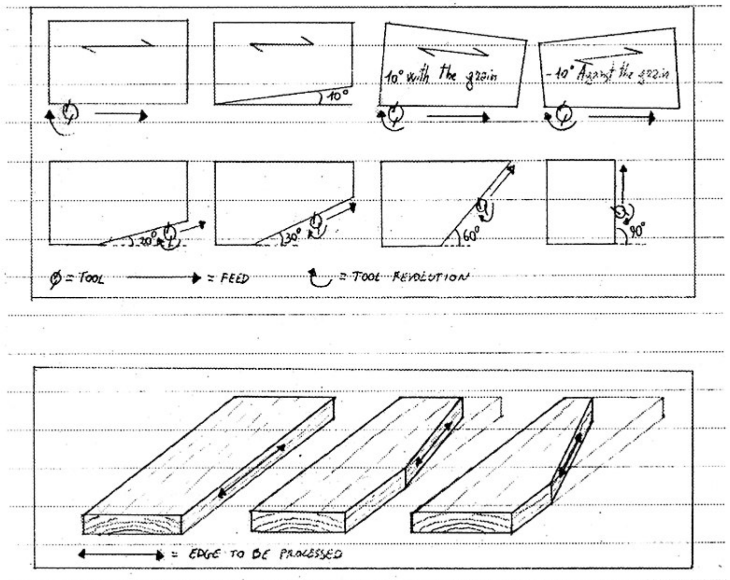


Figure 1: *The general test principles used to process at different grain angles up-milling. The same tests, with the same specimen, have been performed down-milling by changing the feed direction.*

3 Results and discussion

3.1 The main forces involved in the cutting process

The surface defects originate from the cutting edge being unable to correctly perform the cut. To analyse the effect of a bad cut we should firstly define the operation of cutting wood by the means of a tool:

> The cutting is the splitting of the material along the path described by the cutting edge, and the deflection of the split material [2].

In many cases the inefficiency of the cut is not connected with the tool itself, but mainly to the way the wood reacts to the applied forces. Wood machining often results in surface defects even if the machining is performed according to the present state of the art; we feel that this limitation can be mainly attributed to the tool, but the tendency to result in surface

defects also depends from the wood properties and the processing parameters Wood is an anisotropic material whose mechanical features change according to the anatomical directions, since wood cells are connected by bonds of various types and various strength: covalent bonds in longitudinal direction, hydrogen bonds in transverse directions. The cutting edge being not perfectly sharp applies a stress on the wood; cells walls react with a "reaction against splitting" that changes, as the grain angle changes.

> *Reaction against splitting* is the reaction opposed by the wood elements to the splitting at the cutting edge level.

This reaction comes from the orientation of the wood elements, being one of the main factors determining the evolution of the processed surface. The way the surface evolutes during the cut determines the type of splitting, which depends from the interaction between the reaction against splitting and the strength of the material in the direction of the applied force. The reaction against splitting concerns a few cellular elements being in contact with the cutting edge, while the split type derives from the reaction of the material and concerns groups of elements and their mechanical behaviour. The force resulting by the interaction tool-material has been decomposed by Ernst and Merchant in the following components: N: force normal to the rake face, T: friction chip-tool R: resultant, Fs: shear force, Fn: force normal to the shear plane, Fz: principal force, Fx: feeding force. The reaction against splitting is mainly the horizontal component –Fz.

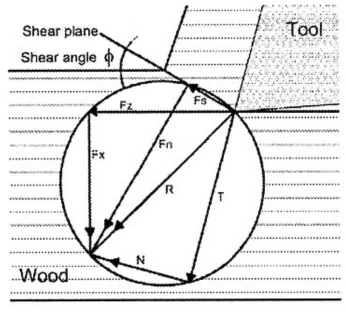


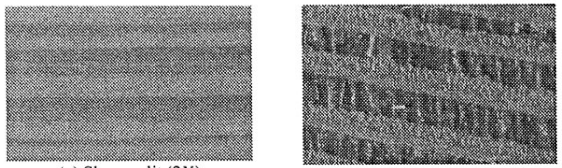
Figure 2: *Forces circle according to Ernst and Merchant [as reported by 3].*

3.2 Splitting type

The group of cells interested by the cutting action opposes a reaction to the forces called *reaction against splitting*, which depends on the behaviour of individual elements directly concerned and on the reaction of the cellular elements lying behind. The evolution of the surface and in particular the splitting type will depend as a chain on the behaviour of the material to the reaction against splitting. This behaviour is tightly connected with the strength of the material, which depend on the orientation of the specimen. The surface can react to the stresses exerted by the cutting edge with a clear cut or with failures. According to this reaction the split can be divided in (See Figure 3):

- shear split
- failure split.

They will be both analysed in the following chapters.



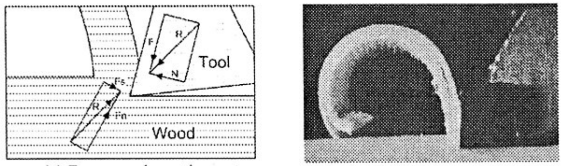
(a) Shear split (2X) (b) Failure split (2X)

Figure 3: *'Shear split' and 'failure split' on douglas fir with 11% moisture content.*

3.2.1 Shear split and nominal surface

The splitting by shear allows the formation of a shear plane and the sharp cutting of the wood elements. This behaviour prevents the formation of structural failures in the wood. The fact that the reaction against splitting is smaller than the strength of the wood in the direction of the applied force allows a clear cut, and this behaviour is called "shear split".

> *Shear split* occurs when the "reaction against splitting" is smaller than the strength of the material in the direction the force is acting, so that the split is clear and sharp along the path described by the cutting edge.



(a) Forces and reactions (b) Chip "Type II"

Figure 4: *"Shear split", producing a chip type II. (a) Scheme of the stresses and of the reactions acting dung the cut. (b) Machining operation producing a chip "Type II" as described by Franz [1], involving a "shear split" [7].*

With this type of behaviour the split occurs mainly by shear, but the shear stress is not the only one acting on the wood elements. Usually we observe the formation of a "Type II" chip (see Figure 4) among the three types described by Franz [2]. To satisfy this condition it is not necessary a particular orientation of the grain, but it is sure that being the wood stronger in the longitudinal plane and being the weakness plan oriented axially, for the species with low and medium density it is easier to attain this condition when processing with straight grain or with narrow grain angles, while with high density and homogeneous species their mechanical properties involve a "shear split" even at high grain angles or processing across the grain (90°). The surface obtained in this way is very close to the "nominal surface".

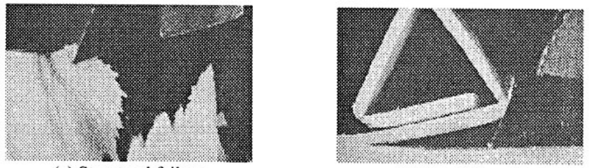
> *Nominal surface* is the surface described by the combination of the tool motion with the feeding motion of the piece during the machining.

This surface is the target to use for the comparison with the surfaces obtained in processing, in order to determine their final quality.

3.2.2 Failure split

This type of split is characterised by structural failures, connected with the properties of the material. The "reaction against splitting" is higher than the strength of the material (see Figure 5). This high strength and a low support from the elements laying behind lead to structural failures instead of a clear cut.

> *Failure split* is the cut where the "reaction against splitting" is higher than the strength of the material in the direction of the acting force, implying structural failures instead of a clear cut along the cutting path.



(a) Structural failure (b) Chip "Type I"

Figure 5: **(a)** *'Failure split', following transverse compression [7], and* **(b)** *transverse tension, with the formation of a chip "Type I" according to Franz [1 - 7].*

Failure split occurs mainly when the wood elements are sloped as to the cutting plane, and is due to the poor strength of wood in transverse section and at a high "shear strength" in this direction. The cut in the sub-axial, sub-transversal or transversal direction is more difficult as to the cut in axial direction. These mechanisms cause structural failures that are the origin of the formation of the "machining defects"
This type of split can arise from two types of reactions:

- transverse tension
- transverse compression

they can be related to processing mechanics that involve a compression of the material being processed or a lift-up. These reactions concern the machining "with the grain" (with compression) and "against the grain" (with tension). In this case tension and compression must be intended as "prevalent", because they do not exclude other forces.

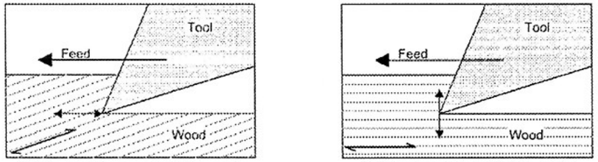
3.2.2.1 Transverse tension

This reaction occurs when the sollicitations applyed by the knife to the cellular elements during the cut tends to lift up the elements. This happens because of the slope of the elements, when the knife moves forward the elements resist to the cut and tend to turn around the fulcrum polaced under the surface or on the surface plane (as the chips "Type I"). The tendency to be lift-up of the cellular elements induce a transverse tension with the underlayng elements (see Figure 6). This reaction can be generally ascribed to the processing against the grain direction:

> *Processing against the grain* is the machining process where the grain forms an angle between 0° and 90° with the trajectory of the cutting edge, such angle being measured ahead of the contact zone between tool and wood

and in some cases in processing parallel to the grain:

Processing parallel to the grain is the machining process where the grain direction forms an angle of 0° with the trajectory of the cutting edge.



(a) Processing against the grain (b) Processing with the grain

Figure 6: **(a)** *Scheme of the mechanisms with transverse tension, processing against the grain and* **(b)** *at straight grain.*

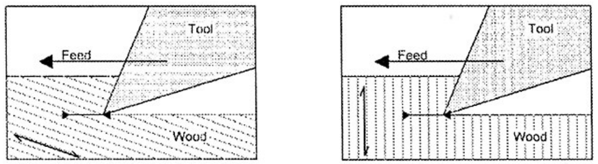
3.2.2.2 Transverse compression

This reaction happens when the sollicitations applyed by the knife during the cut tends to compress the cellular elements involved in the cut. This happens because of the slope of the elements, when the knife moves forward the elements resists to the cut, the lumen collapse and the element is compressed against the underlayer (see Figure 7). This reaction can be generally ascribed to the processing with the grain:

Processing with the grain is the machining process where the grain forms an angle between 90° and 180° with the trajectory of the cutting edge, such angle being measured ahead of the contact zone between tool and wood

and across the grain:

Processing across the grain is the machining process where the grain direction forms an angle of 90° with the trajectory of the cutting edge.



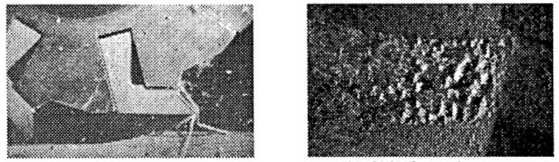
(a) Processing with the grain (b) Processing on the top

Figure 7: *Scheme of the mechanisms with transverse compression* **(a)** *processing with the grain and* **(b)** *across the grain.*

3.3 "Functional zone" and "Mechanisms chain"

Important factors like the zone where the surface originates and the dynamic interaction between the cellular elements and the tool have an explanation in the two basic concepts of "functional zone" and "mechanisms chain".

Is being defined *functional zone* the region where the acting processes have a mechanical or aesthetic influence on the processed surface.



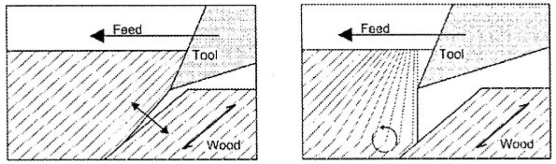
(a) Failures (b) Chip formation zone

Figure 8: **(a)** *The failures in the high part do not influence the final quality of the surface [7]. In* **(b)** *see a chip formation zone where the machining have been stopped, see how the defects in the high part do not appear on the surface.*

The stresses acting in this zone are basic for the surface formation mechanism, and evolve in time. For this reason the formation of a surface must be considered as a chain of actions that can be named "mechanisms chain".

Mechanisms chain is the succession of all the actions affecting the functional zone, and resulting in the final surface condition.

Therefore the complex of actions on a given zone, evolving in time, determines the surface formation in wood shaping. This sequence of mechanisms is the "mechanisms chain", and the zone where these mechanisms act is the "functional zone". The mechanisms chain identifies unequivocally the surface formation mechanisms, and is the base for their classification.



(a) Tension (b) Bending

Figure 9: *Scheme of a "mechanisms chain". The defect origins with transverse tension, and the failure occurs by bending.*

Stresses applied outside the "functional zone" do not affect the "mechanisms chain", but take part to this chain the geometrical and mechanical differences between the up- or down-milling techniques. As known the up- and down-milling techniques are very different from a mechanical point of view. Processing up-milling the cut starts in the point of tangency with the final surface and with the minimum chip thickness proceeding with climbing motion. Processing down-milling the cut starts with the maximal chip thickness proceeding with sinking motion to the minimal chip thickness. This is a very important mechanical difference between the two processes. An important factor for the interpretation of these phenomena is the "functional zone" Where the "functional zone" is very close to point of tangency with the final surface the "mechanisms chain" will result very similar processing up- and down-milling, while with a large "functional zone" the differences in the two processes will be much more important. Where the "functional zone" results so little to not influence the "mechanisms chain" and the surface quality we didn't apply mechanical distinctions. Where the "functional zone" is a crucial factor we distinguished the two processes in two variants or different "mechanics".

3.4 Formation mechanics and their classification

According to the definitions until now introduced the surface formation mechanisms can be divided in two main groups:

- Prevalent shear mechanism
- Hybrid mechanism

The "prevalent shear mechanism" originates by "shear split" and they do no present failures, while the "hybrid mechanism" involve reactions different by the shear and originate a "failure split".

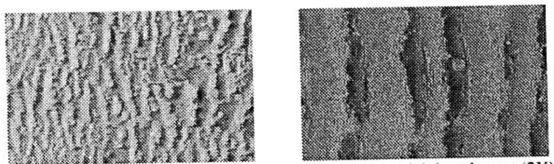
3.4.1 Shear mechanism

For this kind of mechanism the "functional zone" is small and very near to the tangency point between the surface and the tool trajectory. The shear of the material occurs for "prevalent shear mechanism" and the material is strong enough to allow a clear cut without failures.

3.4.2 Hybrid mechanics

This group includes all the mechanisms acting without shear. The classification principle is the general behaviour and re-organisation. Re-organisation is the movement or the detachment of material from the nominal surface (see Figure 10). According to this principle these mechanisms can be divided in two ***formation classes***:

- with "*material shifting*", when the material forming the surface is almost the same as the nominal surface but is differently organised
- with "*material detachment*", when during the cutting some fibers or groups of fibers are torn away from a layer under the nominal surface



(a) With material shifting (1X) (b) With material detachment (2X)

Figure 10: *The two main formation classes:* **(a)** *with material shifting for poplar (Populus alba); if the shifted material could be placed again in the gaps, the resulting surface would be very close to the nominal surface* **(b)** *"with material detachment" where some groups of fibers have been completely torn away from the surface.*

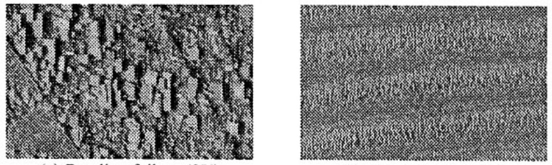
These formation classes are divided in different ***principal mechanisms*** on the base of the "mechanical reaction". There are two types if mechanical reactions:

- *with prevalent transverse tension*, when processing "against the grain" and "parallel to the grain"
- *with prevalent transverse compression*, when processing "with the grain" or "across the grain".

A further element of distinction is the braking behaviour, which defines the ***secondary mechanism***. A distinction is here made between failure and reaction, because in some cases we have a real failure, while in other cases we have particular reactions of the material (see Figure 11). Several types of secondary mechanisms have been described:

- *bending failure*
- *longitudinal tension failure*
- *incomplete failure*
- *plastic failure*
- *elastic reaction*

Every different mechanism until now described is represented in the classification by a capital letter.



(a) Bending failure (2X) (b) Plastic failure (2X)

Figure 11: *Examples of secondary mechanisms: (a) bending failure in oak, and (b) plastic failure in douglas fir.*

Finally, some secondary mechanisms have been divided in sub-mechanics and variants. The **sub-mechanics** are described by a progressive number, coupled with the capital letter describing the mechanisms until now described. Similar mechanisms are described by the same letter and differentiated by a number. The ***variants*** describe differences in the "mechanisms chain", which are related with the up- or down-milling technologies.

3.4.3 Classification of mechanisms

The complete list of the mechanisms originating the surfaces is summarised in Table 1.

Table 1: *Classification of the surface formation mechanisms*

Formation class	Principal mechanism	Secondary mechanism	Type
Material shifting	Transv. Tens.	partial failure	A1 (var. 1, 2)
		plastic failure	B1
	Transv. Comp.	elastic reaction	C1, C2, C3
		plastic failure	D1
Material detachment	Transv. Tens.	bending failure	E1 (var. 1, 2), E2
	Transv. Comp.	longitudinal tension failure	F1, F2 (var. 1,2)

This classification represents a partial view of the surface formation processes. To have a complete idea of the processes going on while cutting, the cutting mechanics should be connected with the consequent defect graded with visual grading.

4 Conclusions

The mechanisms of surface formation which occur when processing with a straight blade, up- and down-milling at different grain angles, have been studied, described and classified. The theoretical forces involved in the cutting process have been reconsidered in order to be applied to the wood. The first point achieved is that he surface defects originate from the cutting edge being unable to correctly perform the cut, and in particular to split the material.

The material splitting can occur in two main ways: by "shear split" or by "failure split". The former allows a clear cut and a clean surface, whereas the latter results in failures of groups of wood fibres, which are broken instead of being cut. We have shown how the failure split can occur with two main reactions: "with transverse tension" and "with transverse compression", depending on the angle between the grain and the processing plane. Concerning the quality of the final surface, the abovementioned behaviours are mainly significant in a particular zone called "functional zone". The stresses acting in this zone evolve in the time and are basic for the surface formation that must be considered as a chain of events that can be named "mechanisms chain". On this chain is built up the classification of the surface mechanisms formation defining: the "formation mechanic", that can be: for shear (resulting in a clean surface) or hybrid (resulting in a failure split). The hybrid mechanisms can be divided in formation classes, principal mechanics, secondary mechanics, sub-mechanics and variants. This classification offers a clear image of the mechanisms which occur during the machining, considering together the processing technologies and the properties of the material offering a new bio-mechanical approach to the wood processing.

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Determination of Horizontal Side-Pressure in Storage (and transportation) of Wood Grains

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Abstract

By the storage and automated material transportation of wood grains and wood wastes, physical and mechanical properties of the material are critical.

The factor of the horizontal pressure seems to play a very significant role, in the course of regulation of the parameters of the warehouses, where wood material is to be stored.

The experiments were designed to define the typical creeping curve of the samples of wood grains and wood wastes and after that side-pressure coefficients, deriving from different grain compositions, different tree species, and different moisture content, were determined as a function of the Poisson-number(μ=0,3~0,4) - characteristic to the sets, written above - in the 0 – 15 kP domain.

The following findings have been identified from the experiments: the side-pressure coefficient is influenced especially and significantly by the vertical pressure and the moisture content. The influence of tree species and grain composition is not that spectacular.

1 Introduction

The side-pressure coefficients were determined with help of equipment designed for that purpose [1].

The equipment has 4 major units:

- Storage pan for dust-chip (200x200x250 mm)
- Push-brace (with a clamp plate on it) and counterbalance
- Measuring element
- Frame

The storage pan for dust-chip was located on the frame. On the side of the storage pan - 74 mm away vertically from the motherboard - a circle shaped bench plate can be found, which is able to move horizontally. A deformation gauge block is connected to the bench plate, which has a diameter of 80 mm. I measured its deformation - caused by the displacement of the bench plate - with help of a micrometer. The displacement of the bench plate is caused by side-pressure and its value is in connection with the emergent side-pressure.

The different vertical pressures were ensured with weights, positioned on the balanced-arm.