GENERAL INFORMATION ON FLAWS AND DEFECTS

In order to discuss the problems related to surface finishing in detail, we need to provide precise information and neatly divide those reactions we can call as processing defects from those that cannot be defined as such. Every process determines a surface reorganization. The entity of the disorder caused by this 'after-cut' surface reorganization becomes the marking line between absence of defect, minor flaws and processing defects.

INTRODUCTION

This article is the first of a series aimed at showing the main aspects of a current study carried out by DISTAF (department of environmental forest science and technologies) in cooperation with the university of Florence and ENSAM (Ecole Nationale Supérieure d'Arts et Métiers) in Cluny (France).

Together with its innovative technical-scientific contents, that will be explained in this introduction, this study is important for the context in which it is carried out:

- DISTAF organizes many university courses on Wood and related properties, processing, use; these courses continue the scientific and teaching activity founded in Italy

above all by prof. Guglielmo Giordano, applying partly to the students of forest and environmental science and partly to the students of wood technology;
- in ENSAM, an important group of French teachers and researchers integrate their knowledge on wood with important equipment and special laboratories for the study of processes on other materials as well;
- the study is carried out within a Doctorate (to obtain the university title of Research Doctor,
such title can be also achieved through a three-year curriculum after five-year university course); and in particular this Doctorate is co-tutored by the two universities (one Italian and one French), so that, after discussing the thesis, the title of Doc. Giacomo Goli will be valid in Italy as well as in France.
This study examines the creation process and final quality of wood surfaces processed with rotary cutting tools with chip removal; in particular, it analyzes the relationship between the wood-cutting edge contact geometry (basically expressed by the angle between wood fiber and cutting edge trajectory), and the resulting surface quality (expressed on average by type and entity of the so-called 'processing defects').
Any woodworking operator knows well the difference between working 'with straight grain', 'grainwise' and 'countergrain'. Tough extremely important for final results, these concepts have been considered mainly empirically so far, above all by workers. This study aims at establishing a global approach towards the genesis, description and measurement of the surface quality obtained through the processing at different angles to the wood grain.
The issue was scarcely considered by researchers and industry operators so far, who tend to consider it as one of the inevitable consequences of wood 'defects' (more or less inevitable according to employed material and wished results). The increasing diffusion of NC machines usually and inevitably involves wood processing at different angles during the same pass; in order to optimize the results achieved through such excellent machines, we need to know the relation between wood and tool more deeply, together with the related surface creation mechanisms.
The study was carried out through different stages. Before executing systematic tests and measurements, researchers carried out several preliminary tests in order to 'get acquainted' with defects, understand their relations with the grain angle and develop an adequate terminology for their description and classification; at the same time, they developed and verified measurement methods. Later on, practical tests have been carried out on two wood species (oak and douglas-fir) with substantially different anatomic structure and processability features, varying the grain angle in 10° steps, and working with both climb milling and up milling. In this way, they could sample a high number of surfaces obtained through 'grainwise', 'countergrain', 'double-end' and 'straight grain' woodworking.
Every surface obtained was subject to visual analysis, electronic microscope scan analysis, profile analysis and cutting forces analysis. All this helped explain the creation process of defects, expand the number of useful parameters to classify them visually, and explain expected dynamics and quality according to several woodworking operations at different grain angles. Finally, the study is currently analyzing the chips removed by the different processes.
The authors (Dr. Giacomo Goli, Doctorate student; Prof. Luca Uzielli and Rémi Marchai, thesis coordinators and tutors), in agreement with our editorial staff, thought it would be useful to publish these articles, in order to inform all wood industry operators, and in particular those in charge for mechanical processes. In fact, this is an important and innovative contribution, that considers both woodworking technologies and material features at the same time, and that combines technical and anatomic analysis for a new unified interpretation of wood processing technologies seen from the double point of view (biological and mechanical) of wood science and mechanical machining.

by Luca Uzielli

INTRODUCTION TO GENERAL INFORMATION ON FLAWS AND DEFECTS

This study is part of a larger work on the final quality of processed surfaces and their creation process. Such work focuses on finishing processes executed at different grain angles to the worktable, working grainwise and countergrain, with climb and up milling. Processed surfaces were subject to different types of analysis: cutting forces, profile, macroscopic and microscopic, formation process and chip analysis. These characterizing features will be taken in exam individually. The aim of publishing these articles is to provide a specific terminology by identifying adequate definitions for the different conditions of the processed surfaces.

FLAWS

In this chapter, we will focus on the definition and analysis of the flaws found on processed surfaces.

A flaw of a surface is represented by any feature differing from the 'theoretical surface' profile.

In order to explain this definition, we have to clarify the concept of 'theoretical surface' first. The theoretical surface is the surface delimited by the tool cutting edge during the cutting operation. Such surface is not necessarily flat, as it may also have a complex shape, and its flaws can be divided into flaws generated either directly by the material anatomic structure or by the interaction between such structure and the tool cutting edge during the operation. Therefore, flaws are divided into:

- Anatomic flaws
- Process flaws

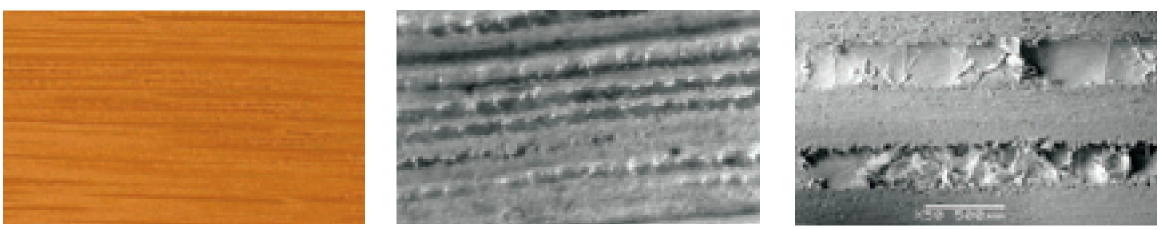
First, the scale to measure the relevance of such flaws must be calibrated. In fact, it is important to refer to quantifiable entities by using a measurement scale. In this case, the main organ for their quantification is the human eye, so the measurement scale must be calibrated basing on the human eye. Actually, any surface will be irregular if observed under magnifying instruments. An essential factor to analyze flaws is therefore the identification of a threshold, above which the detected flaws are significant. Such flaws are classified according to their visibility, as follows:

- clearly visible flaws;
- slightly perceivable flaws
- non perceivable flaws

Among these flaws, we are mainly interested in process-induced flaws, which results into "defects", i.e. the processing flaws that are clearly visible. The other flaws correspond to surface conditions that normally don't arouse significant quality issues.

2.1 Anatomic flaws

These flaws are directly related to the workpiece anatomic structure, and their origin is not found in the machining process. Therefore, they are included in the "aesthetic-anatomic" factors defined under paragraph 4, as peculiar features of a species. So, their size is not critical for the determi-



(a) Oak 0° *(b) Oak 0°* *(c) Oak 0°*

PICTURE 1: Large vessels on an oak sample processed with straight grain (0°); low magnification (a), medium magnification (b) and high magnification (c). [Photo by Goli]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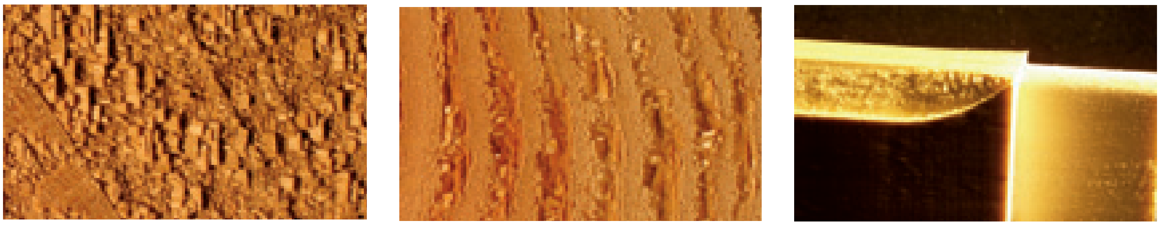


(a) Oak -80° *(b) Douglas-fir -40°* *(c) Poplar*

FIGURE 2 "Clearly visible process flaws", medium magnification on oak and douglas-fir, low magnification on a profiled poplar element. The number indicates the grain angle, and the minus sign indicates a countergrain operation. [Photo by Goli]

nation of surface quality, as they belong to the intrinsic features of the species and are therefore instrumental for the final appearance of the processed surface. "Anatomic flaws" can have different dimensions: just think of the oak vessels (clearly visible to the naked eye) or the douglas-fir fiber-tracheids (only visible under magnifying instruments). The most important and visible flaws are:

- large vessels
- resin ducts

Large vessels often remain clearly visible on the surface after processing, and the same applies for resin ducts. These are clearly visible instances of "pure anatomy" (see Fig. 1). Slightly perceivable and non perceivable flaws include all anatomic elements that are less distinct or only visible under magnification, and considering their poor relevance for final surface quality, they will not be considered in this paper (figure 1).

2.2 Process flaws

Process flaws, instead, are not caused exclusively by the material, as for anatomic flaws, but they are a direct consequence of the interaction between material and tool. Being clearly visible, slightly perceptible or non perceptible, therefore, makes a big difference. "Clearly visible flaws" are "processing defects"; "slightly perceivable flaws" represent the transition from "defect" to "absence of defects"; and "non perceivable flaws" invisible to the human eye indicate the "absence of defects".

2.2.1 Clearly visible process flaws

We are mainly interested in the process flaws that are clearly visible to the human eye, both because they are easily detected, and because they result from a process that is not intended to produce them.

Such flaws make up the category of so-called "processing defects" (see Fig. 2). By virtue of their critical importance for surface quality, they will be discussed in detail (figure 2).

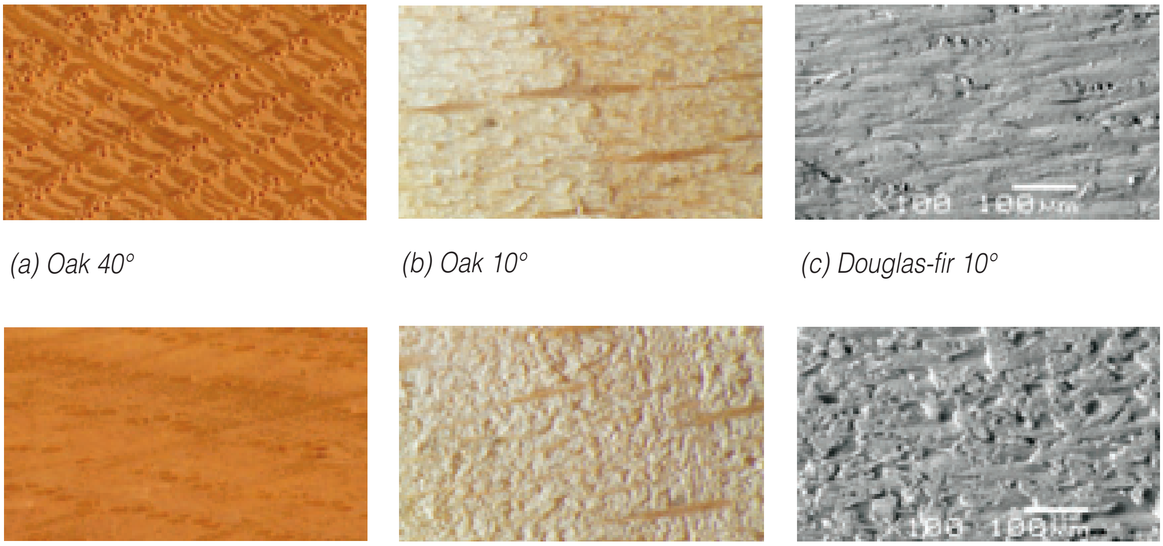
2.2.2 Slightly perceivable process flaws

"Slightly perceivable flaws", though not compliant to the theoretic surface just like "processing defects", differ in that their non-conformity is not clearly visible to the human eye (it is only slightly perceivable), while it can be clearly seen through a magnifying instrument. The basic symptoms of this phenomenon are:

- glossy effect
- dull effect

Glossy and dull effect are the "border line" between defect and non-defect. They are the symptoms of mechanical processes that, should they be intensified, might lead to defects, but due to their low intensity, simply result into alterations that are hardly visible to the human eye.

The glossy effect results from a crosswise compression of grain, typical of grainwise operations, while the dull effect is due to the grain being raised and then compressed on the surface in the opposite direction (figure 3).



(a) Oak 40° (b) Oak 10° (c) Douglas-fir 10°

(d) Oak -20° (e) Oak -10° (f) Douglas-fir -10°

FIGURE 3: Glossy effect (a,b,c) and dull effect (d,e,f) on oak and douglas-fir; low magnification (a, d), medium magnification (b, e) and high magnification (c, f). [Photo by Goli]

2.2.3 Non perceivable process flaws

Minor cutting flaws of single elements, not visible to the naked eye, are nevertheless a consequence of processing. Such flaws, while being caused by processing, are not significant, and as they are not visible, they cannot be classified as processing defects (see Fig. 4).

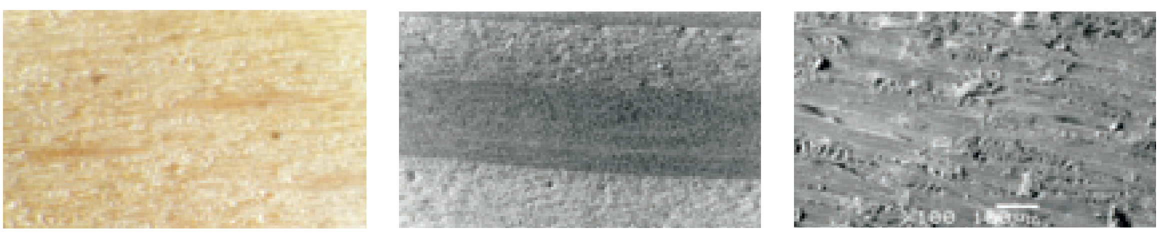
This aspect of processing operations is classified under "absence of defects", which will be analyzed together with the "esthetic-anatomic features" (figure 4).

PROCESSING DEFECTS

For an adequate description of the defects that show up on surface after finishing operations by means of a rotary tool, it is necessary to introduce a definition of defect:

Defect is a fault or lack of completeness, sufficiency or efficiency, something that is lacking, poor or scarce. A concrete element that affects the value of an object.

This definition potentially embraces many features of wood, including some anatomic or esthetic factors, if undesired. But what



(a) Beech 0° (b) Douglas-fir 0° (c) Douglas-fir 0°

FIGURE 4: Non perceivable process flaws detected on beech and douglas-fir; medium magnification (a, b) and high magnification (e). [Photo by Goli]

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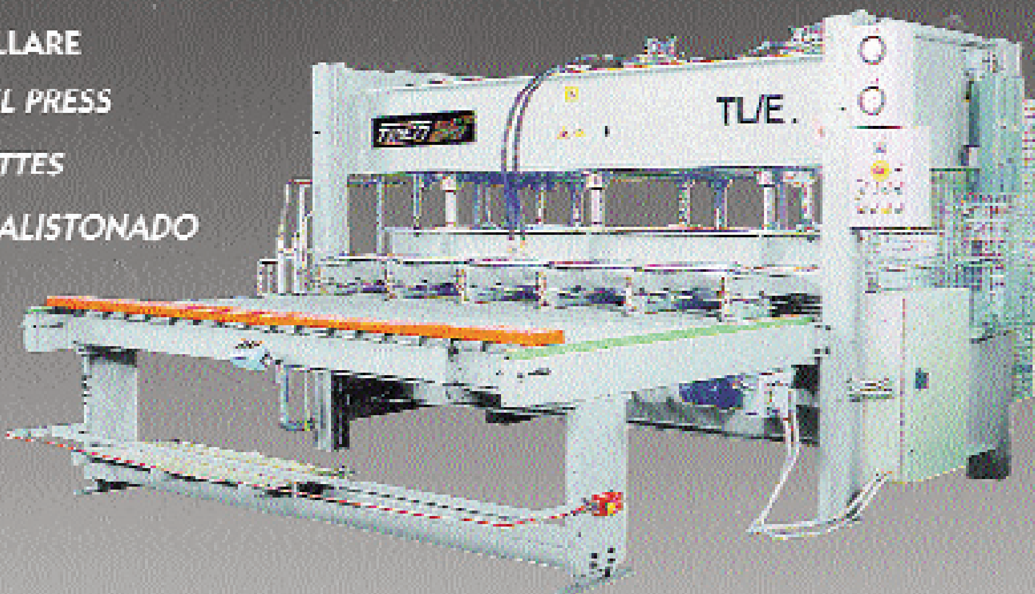

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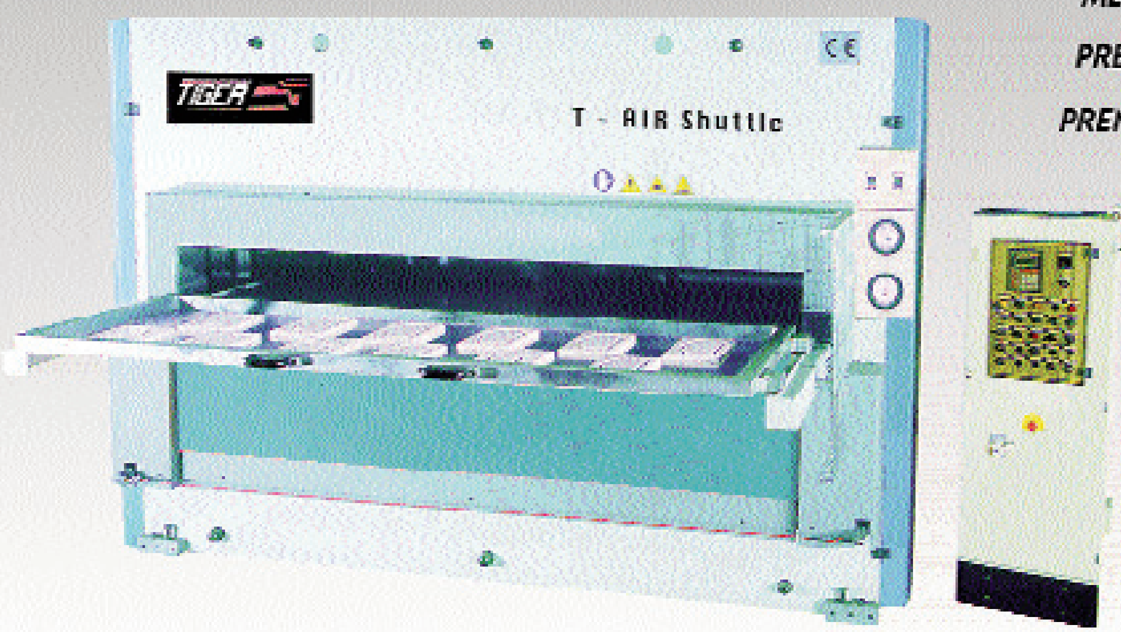

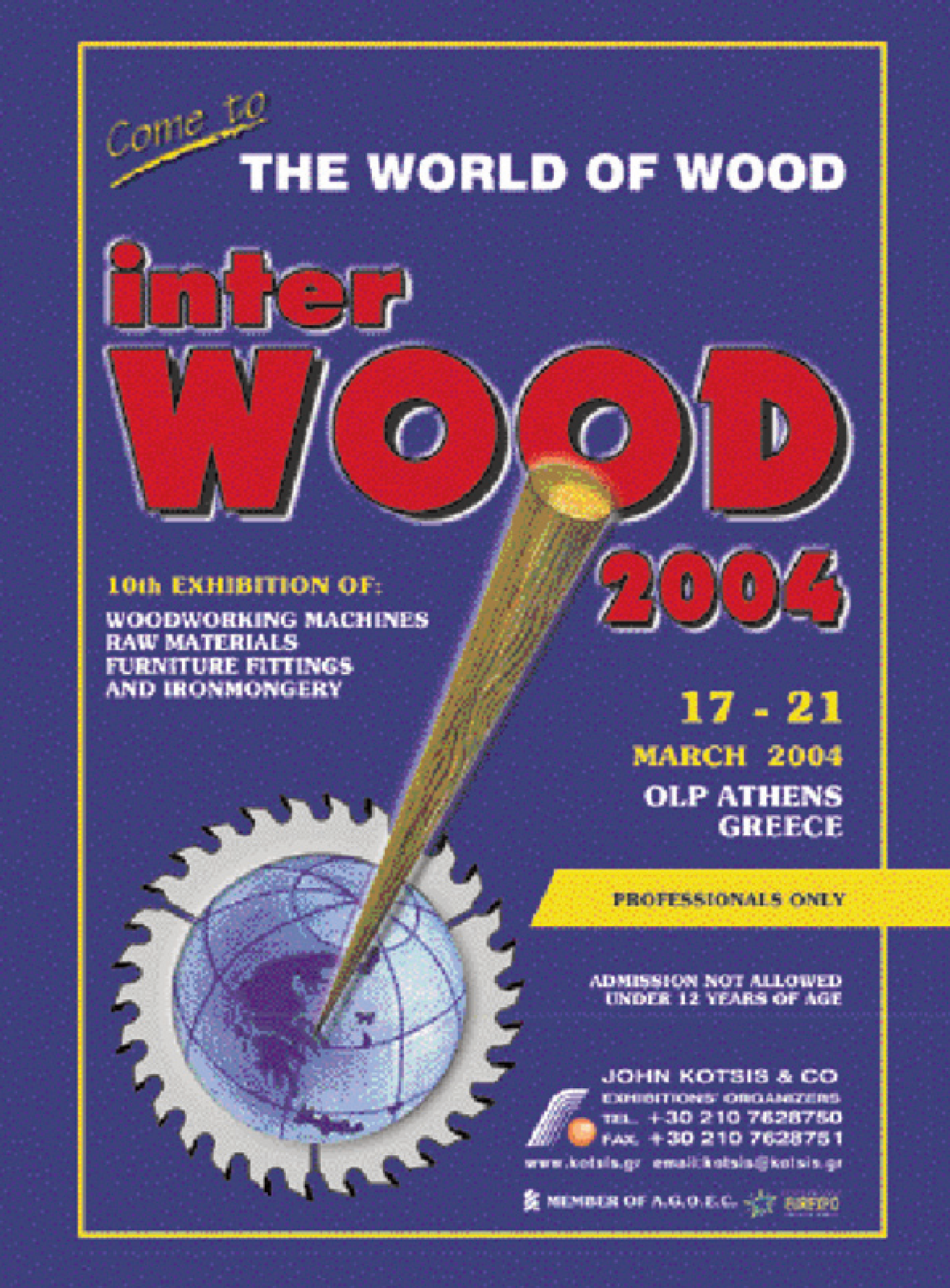
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really matters to us is a part of the big family of wood defects, namely "processing defects".

We call processing defects any deviation from a theoretic surface, directly caused by processing, clearly visible to the human eye, and other than pure anatomic structure.

In other words, using the definitions given in the previous paragraph:

we call processing defects the "process flaws clearly visible to the naked eye". "Processing defects" can be classified according to two interpretations:

- "quality" interpretation
- "mechanical" interpretation

Quality interpretation identifies different defects according to their appearance, and defines different degrees of intensity for each defect, while mechanical interpretation gives a mechanical explanation of the surface conditions, analyzing the interaction between tool and grain.

Defects can also be classified according to general principles and divided into:

- evitable and inevitable
- gradable and non gradable
- diffuse and specific

The purpose of this distinction is not to create an additional classification, but simply to provide more elements for a better description of defects.

Evitable and inevitable defects: it is very difficult to define what is evitable and inevitable in relation to a relative problem. Generally speaking, we can say that a flaw can be considered as inevitable when, after a processing operation carried out according to the state of the art and the intrinsic conditions of the workpiece, the defect still occurs. Evitable defects are normally due to the operator being unable to set the processing parameters or making a mistake (tool RPM, selection of a wrong pitch per tooth, etc.). Inevitable defects are normally related to material properties (for instance, the variation of final quality according to the grain direction, when milling a circle into solid wood).

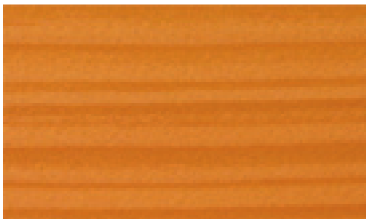
Gradable and non gradable defects: this important distinction is based on the intensity degree of defects. When a single type of defect is found to have different degrees of intensity, then the defect is called "gradable" (standard ASTM D1666-1998 for visual classification defines different defects, and each with 5 degrees of intensity). Defects for which no intensity gradation is possible are called "non gradable". For such defects, then, only their presence or absence on the surface is verified.

Diffuse and specific defects: some defects can be called "diffuse" because they affect several species or several working conditions; others are called "specific" as they only occur with certain species or specific working conditions.

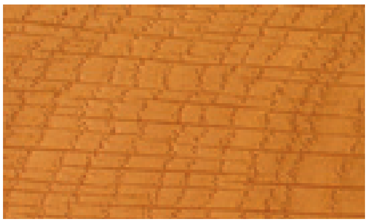
ABSENCE OF DEFECTS AND ESTHETIC-ANATOMIC ASPECTS

It may seem strange or insensible to define the "absence of defects" after defining defects, but this is necessary to determine

(a) Beech 0°



(b) Douglas-fir 0°



(c) Oak 20°

FIGURE 5: "Absence of defects" and "esthetic-anatomic aspects" with low magnification. [Photo by Goli]

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the "non presence" of defects. The absence of defects in surface finishing processes, according to the definition given above, is characterized by the lack of processing flaws that are clearly visible to the naked eye on the machined surface. Such flaws may exist actually, but they are not visible or "slightly perceivable", or they are visible but only due to the anatomic structure (figure 5).
Defect-free surfaces can still have some esthetic diversity due to anatomic factors. So, we call "esthetic-anatomic aspects" those aspects related to anatomic factors that generate esthetic features rather than surface flaws. They are important because they determine the appearance of the surface after the processing operation. Here is a list of the main aspects:
- density variation aspects: the different density of wood in spring and summer causes variations in the appearance of species
- processed section aspects: the processed section affects the final pattern of wood (flamed, striped and more effects)
- parenchyma ray aspects: in the species where they are found, they give a different appearance to surfaces ("snail trails" in oak and "mottles" in maple)
- color variation aspects: just think of the difference between sapwood and hardwood.
Such aspects may potentially become "defects" when they are undesired, but they will never be "processing defects" (see Fig. 5).

by 1 Giacomo Goli,
2 Rémy Marchiai,
3 Luca Uzielli

Giacomo Goli: 3rd-year doctorate student at the Environmental and Forest Science and Technology Department of the University of Florence and at the Ecole Nationale Supérieur d'Arts et Métiers in Cluny (France). e-mail: giacomo.goli@poste.it
Rémy Marchal: University professor at the Ecole Nationale Supérieur d'Arts et Métiers in Cluny (France). e-mail: remy.marchal@cluny.ensam.fr
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