QUALITY CLASSIFICATION OF DEFECTS BY VISUAL METHOD

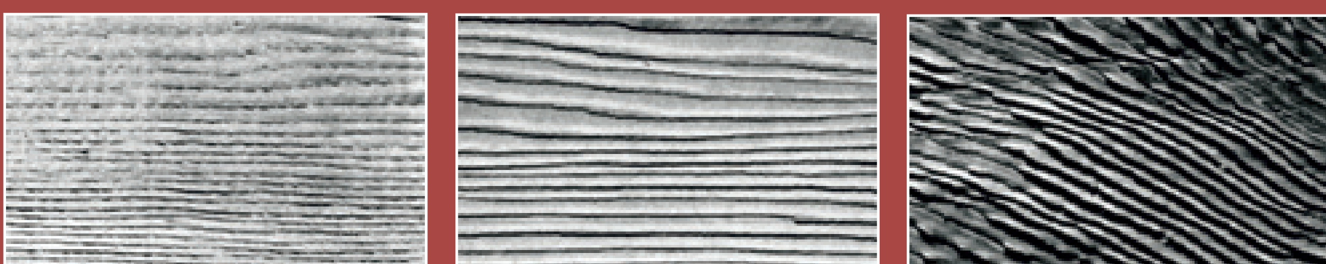
In the previous article about "General Information on Flaws and Defects", the basic definitions were introduced to allow an in-depth discussion of the subject. This presentation exclusively dedicated to "machining defects" is based on the approach of "quality interpretation". In this article, we will describe a "visual" surface analysis method. The most popular standard for this kind of classification is an American ASTM standard, namely D1666-87. This standard will be discussed later on, suggesting additions to the sections where, in our opinion, it proves inadequate.

1 INTRODUCTION

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. Besides introducing a visual classification method, this publication will provide a detailed description of the basic defects that are generated from a finishing operation with rotary tool on solid wood. To analyze the surface, several criteria can be used. There are subjective criteria, often based on human senses, mainly sight (visual method); and objective criteria, which directly measure the surface status (profile analysis) or extrapolate it from physical parameters (pressure or vacuum methods). In this publication, we will carry out a general analysis of defects and then move on to the analysis of the visual method.

2 QUALITY CLASSIFICATION OF DEFECTS

The general purpose of the analysis of "processing defects" is normally to determine



(a) Grade 2 (X0,4) (b) Grade 3 (X0,4) (b) Grade 4 (X0,4)

Figure 1: Classification of raised grain according to standard ASTM D-1666-87 (pictures taken directly from the standard).

the quality of a surface machined with a specific process, in order to identify its "finishing grade". But often, this analysis can be used to determine the machinability of a specific species. These aspects of classification have already been standardized for some time, mainly in standard ASTM D-1666-87 [], that offers an extensive description of the preparation of samples and the operations, as well as a clear and well organized system of reference pictures for visual classification. Hereafter we will briefly introduce the ASTM standard which, for its effectiveness and easy application, is one of the most effective for the quality classification of surfaces. In spite of this, also this standard is incomplete. The purpose of this publication is to analyze the standard in detail and suggest the necessary additions. This classification, which is limited to a visual quality approach, will be integrated by the general mechanisms of surface formation and the interpretation of defects based on such mechanisms, to define a complete approach to surface formation.

3 STANDARD ASTM D-1666-87

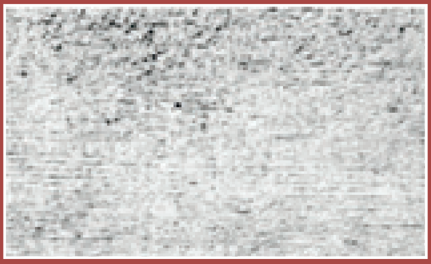
Let's start with an overall description of the principles of standard ASTM D-1666-87. For the main wood operations, this standard defines the features of samples, their minimum quantity for a test, the processing parameters, the classification criteria, the data collection forms and the statistical analysis methods. The standard covers many different operations (planing, sanding, drilling, milling, mortising, turning), both for solid wood and for wood-based products. The standard provides a common reference for defect description. As we will see, its classification has proved inadequate for some aspects, and so we have defined new defects whenever it was not possible to refer to standard defects. The four basic defects identified by the standard, and described in quality and quantity, are the following :

- Raised grain
- Fuzzy grain
- Torn grain
- Chip marks

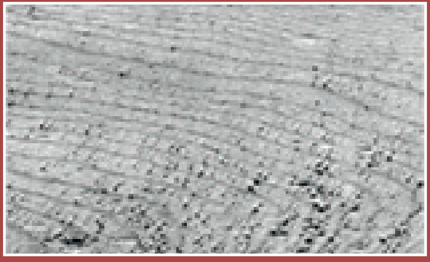
For each defect, the standard defines five different intensity grades:

- grade 1, excellent
- grade 2, good
- grade 3, fair
- grade 4, poor
- grade 5, very poor

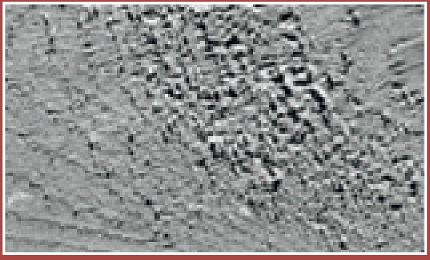
"Grade 1" corresponds to no defect, i.e. the achievement of a surface that can be defined as excellent. "Grade 2", "Grade 3" and "Grade 4" are defined by reference pictures, representing different degrees of increasing intensity of the defect. "Grade 5" includes all defects that can be classified as worse than "Grade 4", so it needs no reference picture. The individual defects will be examined in detail later on, together with the suggested additions to the standard.



(a) Grade 2 (X0,4)

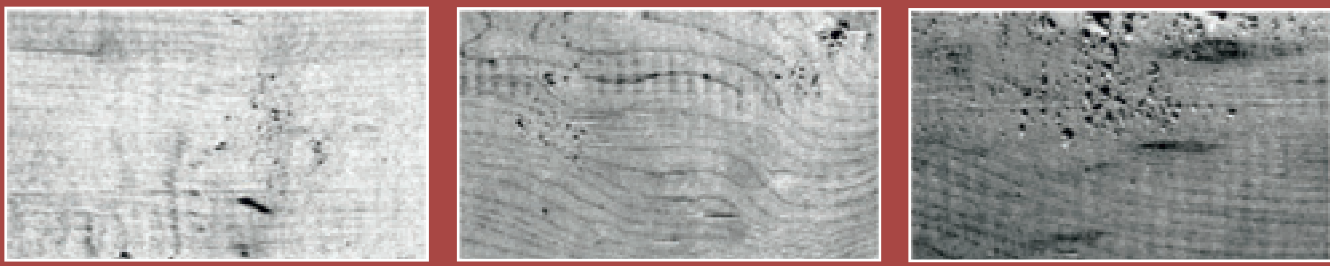


(b) Grade 3 (X0,4)



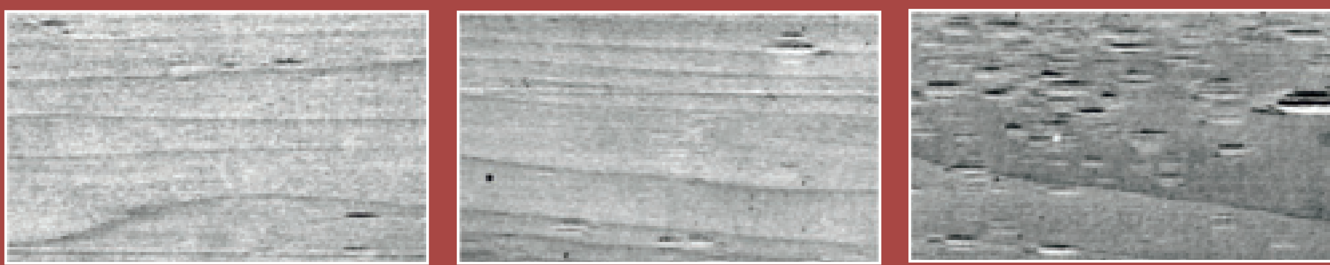
(c) Grade 4 (X0,4)

Figure 2: Classification of fuzzy grain according to standard ASTM D-1666-87 (pictures taken directly from the standard).



(a) Grade 2 (X0,4) (b) Grade 3 (X0,4) (c) Grade 4 (X0,4)

Figure 3: Classification of torn grain according to standard ASTM D-1666-87 (pictures taken directly from the standard).



(a) Grade 2 (X0,4) (b) Grade 3 (X0,4) (c) Grade 4 (X0,4)

Figure 4: Classification of chip marks according to standard ASTM D-1666-87 (pictures taken directly from the standard).

4 ADDITIONS AND REVISIONS TO THE STANDARD

During the execution of operations, defects have often been detected that did not match the reference pictures of standard ASTM D-1666-87. So, an integration and revision of the standard was necessary. As these defects had different features, it was also necessary to differentiate them.

• Principal defects: they are classified as "diffused" and above all "gradable" . These include classical defects with the addition of "pressed grain" and "tilted grain". Therefore, the principal defects are:

- Raised grain
- Fuzzy grain
- Torn grain
- Chip marks
- Pressed grain
- Tilted grain

• Minor defects: these defects are less frequent than the previous ones, and to be defined as such, they must be "specific" and "non gradable". They include:

- protruding early wood
- Hook-shaped vessels
- Sunk rays

During operations, defects of secondary importance were often met, which were not classified and hardly gradable. This classification was studied to include also these defects within this general discussion, although nothing prevents to neglect them when the processing tests are carried out.

4.1 Principal defects

The principal defects are those defects that can be classified as "diffused" and "gradable". They include the four main types of defects identified and classified by the ASTM D-1666-87 [] standard with the addition of "pressed grain" and "tilted grain".

• Raised grain
This is an irregular condition of the processed surface, where the summer wood, compact and tough, is pushed over the early wood, which is inconsistent and spongy, and therefore is pressed under (Fig. 1).

• Fuzzy grain
These are groups of elements, partially torn and raised by the tool during operation, where one end is anchored to the processed surface, while the other is free to move above the working surface (Fig. 2).

• Torn grain
These are groups of elements that are torn below the 'theoretic surface', instead of being cut during operation, thus creating a cavity in the surface (Fig. 3).

• Chip marks
These are 'footprints' on the processed surface impressed by wood particles that stick to the knife after the cut instead of being removed, or that cross the trajectory of the knife owing to poor suction and get caught between tool and surface, preventing proper processing (Fig. 4).

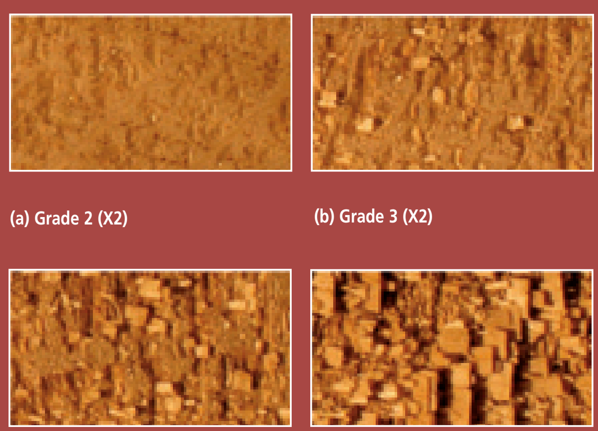
Table 1: Multilingual summary table of standard ASTM D1666-87 for visual classification and its extension as relates to "principal" defects (Principal defects - Défauts principaux)

Difetto	***Defect***	***Défaut***
Fibra rialzata	*Raised grain*	*Fibres soulevées*
Fibra lanuginosa	*Fuzzy grain*	*Surfaces pelucheuses*
Fibra strappata	*Torn grain*	*Fibres arrachées*
Segni di trucioli	*Chip marks*	*Marques de copeaux*
Fibra schiacciata	*Pressed grain*	*Fibres comprimées*
Fibra embriciata	*Tilted grain*	*Fibres retournées*

• Pressed grain
Besides the defects defined by standard ASTM, the authors of other publications had already added another defect called "Pressed grain" [,]. This defect is caused by the raising of cellular elements in counter-grain processing. After being raised, the elements are rotated and plastically pressed against the surface by the knife. This implies the formation of very irregular surfaces, unpleasant to touch, as the elements are rigidly pressed against the surface. This defect, being due to a plastic compression of grain, is called 'pressed

(a) Grade 2 (X2) (b) Grade 3 (X2)
(c) Grade 4 (X2) (d) Grade 5 (X2)

Figure 5: Classification of pressed grain in three grades according to standard ASTM D-1666-87; for a complete description, also an example of Grade 5 is provided. [Photo by Goli]



(a) Grade 2 (X2) (b) Grade 3 (X2)
(c) Grade 4 (X2) (d) Grade 5 (X2)

Figure 6: Classification of tilted grain in three grades according to standard ASTM D-1666-87; for a complete description, also an example of Grade 5 is provided. [Photo by Goli]

Table 2: Multilingual summary table of grades according to standard ASTM D1666-87

	Grado	Grade	Degrée
1	*ottimo*	*excellent*	*excellent*
2	*buono*	*good*	*bon*
3	*medio*	*fair*	*moyen*
4	*mediocre*	*poor*	*médiocre*
5	*basso*	*very poor*	*mauvais*

grain'. The picture shows this defect in grades 2, 3 and 4, in order to be able to apply classification where necessary. As an example, we also provide a picture of what might be considered as Grade 5.

• Tilted grain

The execution of tests has also led to the identification of another defect, probably previously overlooked because it could only be obtained by working with climb milling. The climb milling operation technology plays a secondary role in solid wood machining, owing to the equipment it requires (safe and automatic machinery), and because for this machining operation with solid wood, normally lower quality is obtained than with up milling. Maybe for this reason, it had been overlooked at the time of drafting the standard. This new defect was called "tilted grain[,]". The name comes from the fact that all raised "laminations" are rotated and the overlap partially at a certain angle, i.e. tilting. The pictures shows a comprehensive illustration of this defect. In low intensity defects, the laminations are torn off, but the scaled distribution of tears still indicates the existence of this defect. As a general rule, it can be stated that, if you are working with climb milling, the problem of torn grain is replaced by tilted grain.

As already mentioned, this classification has the purpose to allow an evaluation of the final quality after a determined machining process, or to evaluate the processability of a species independently of the reasons why these defects arise. Standard ASTM D1666-87 is still very useful for the classification of processed surfaces; simple, clear, easy to apply and based on rather objective criteria. We suggest using this standard in the cases mentioned above, with the addition of "pressed grain" for all kinds of operations and "tilted grain" for the surfaces processed with climb milling. Table 1 shows a complete list of the principal defects and their translations in Italian, English and French.

4.2 Minor defects

these defects are less frequent than the previous ones, and to be defined as such, they must be "specific" and "non gradable" (see par. 4). This classification meets the need to describe defects that arise under peculiar conditions and, moreover, have no intensity variation; simply, their existence or non-existence on a processed surface is detected. Three defects are included:

- protruding early wood
- hook-shaped vessels
- sunk rays

The following is a detailed description of these defects, with a complete picture gallery (see Fig. 7).

Protruding early wood: the different density between spring and summer wood causes a different reaction of the two wood types during processing. In detail, the different

Table 3: Multilingual summary table of "minor" defects (Minor defects - Défauts secondaires)

Difetto	Defect	Défauts
Legno primaverile sporgente	*Leaning early-wood*	*Bois de printemps proéminent*
Vasi uncinati	*Hooked-vessels*	*Vaisseaux "rappeurs"*
Raggi infossati	*Hollow rays*	*Rayons enfoncés*

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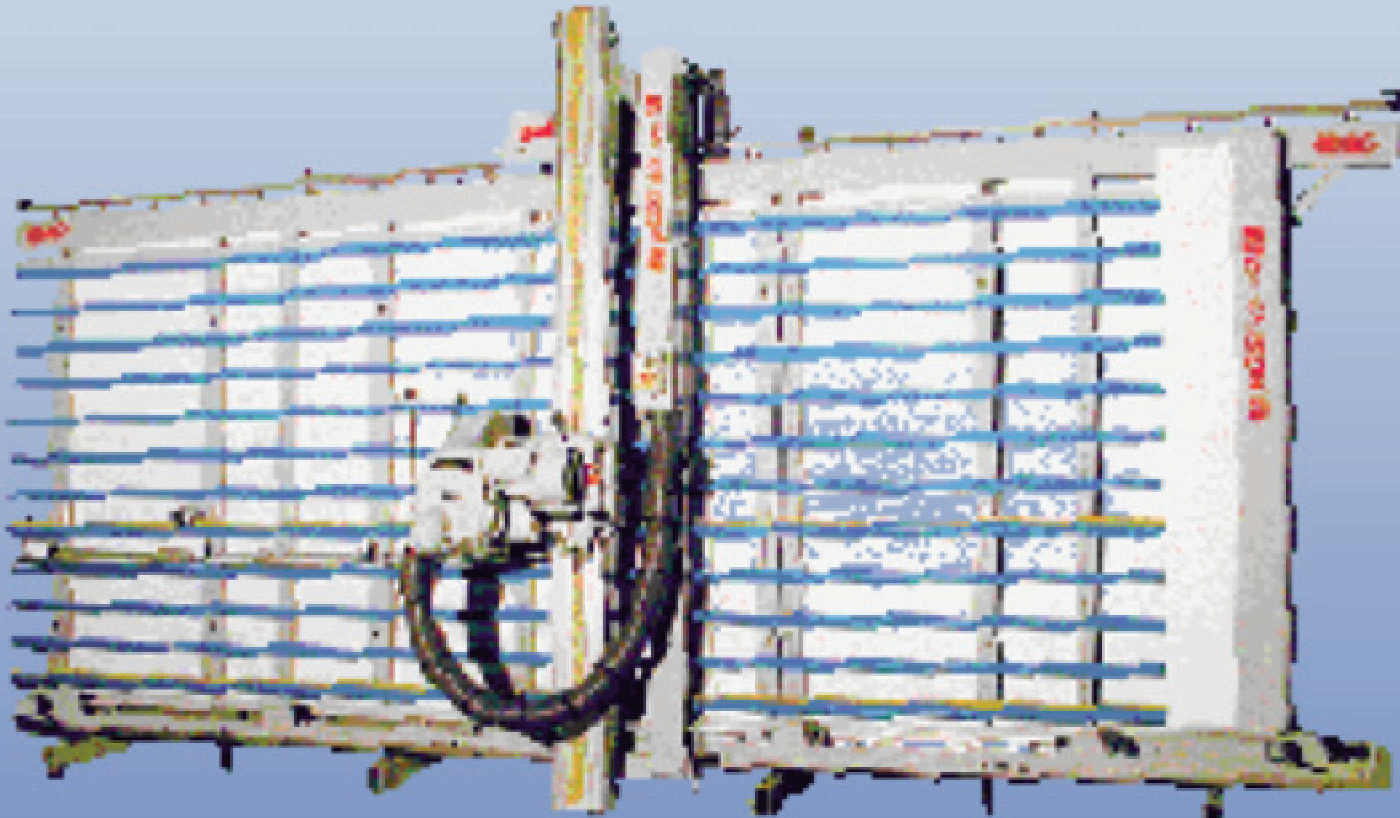

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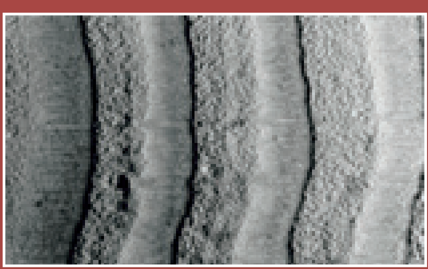
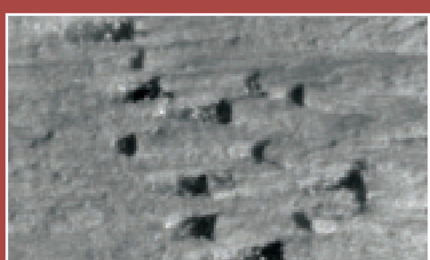
shock absorbing capacity of the two wood types translates into different springback. In terms of quality, the surface is not perceived as low quality. It is simply observed that early wood and summer wood lie on two different levels, thus matching the definition of "processing defect" .
This behavior is the more apparent, the higher the wood's capacity to react elastically. However, this defect never exceeds certain limits and, therefore, cannot be considered as 'gradable'. Also, it only affects species characterized by a big difference between early and summer wood, hence being limited to 'specific' processing instances.
Hook-shaped vessels: this is a typical problem of hardwood with large vessels, which occurs when you work grainwise, with low grain angles, both with up milling and with climb milling. In this situation, during the cut, as the knife exerts pressure onto the elements which tend to withstand the cutting action, the vessel edge is pushed into its own lumen, and protrudes again after the knife has passed. This protruding part, lying higher than the working surface, is a major element of tactile interference, although visual disturbance is limited.
Sunk rays: this is a typical problem of species with rays, which should not be mixed up with parenchyma ray aspects that belong to the "esthetic-anatomic aspects" and, therefore, cannot be classified as defects. The problem with 'sunk rays' is the different orientation of fibers, which react differently from other cellular elements, creating two different levels after the operation. This behavior, hardly visible to the naked eye, can be highlighted through grazing lighting.

by Giacomo Goli , Rémy Marchal , Luca Uzielli



(a) Protruding early wood (X2,5)



(b) Hook-shaped vessels (X10)

(c) Sunk rays (X10)

Figure 7: Classification of minor defects, with medium (protruding early wood) and high magnification (sunk rays, hook-shaped vessels). Being 'non gradable', these defects cannot be classified by levels of intensity. [Photo by Goli]