The machining process of the european douglas fir: the surface quality

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PREFACE

A little more than three years following the **First International Conference on the Development of Wood Science/Technology and Forestry** at Missenden Abbey, and about eighteen months after the **2nd International Conference on the Development of Wood Science/Technology and Forestry** at Sopron, the third in the series of conferences of the same kind is taking place at Belgrade and Mt. Goč.

The very name of this meeting, **3rd International Conference on the Development of Forestry, Wood Science and Technology**, as has been agreed upon by the joint organizers, with the general theme *Forest and Wood: Challenges and Contributions to the Coming Future* (the conference subtitle), should reflect one of the dominant world preoccupations at the moment. Both the multiple roles of forests (particularly the environmental aspects inclusive of preservation of the world's most precious resources of air, soil and water) and also the utilizations of their products (in particular the noble material of wood) are considered in the sense of the newest scientific achievements. The abundance of the material dictated its distribution between the two equivalent volumes of the Proceedings. It is hoped that within about two hundreds of original scientific papers one can find an adequate survey of challenges to be faced with as well as the contributions that related sciences, engineering and other practices, industries and management can make in order to meet them.

The premises of the Faculty of Forestry of Belgrade University, Belgrade, and its Teaching Base at Mt. Goč (the Conference Tour) should provide the participants with the environments suitable for scientific and personal encounters, getting better insight not only what, but also how and why something is being done under present circumstances, and last but not the least, refreshing the old and acquiring new friendships all around the world. The delegates from about twenty countries from the five continents are taking care of that, the triangular cooperation having been established between the joint organizers also reflecting the diversity of the world today. The Buckinghamshire University College and the University of Sopron, considering the maintenance of international partnership so essential, have started it all, the Faculty of Forestry of Belgrade University as the present host (who would on its part very much like to thank the formers for having made it possible) having a pleasant duty to continue along the lines set and to extend their spectrum.

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THE MACHINING PROCESS OF THE EUROPEAN DOUGLAS FIR: THE SURFACE QUALITY

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INTRODUCTION

The first grown American Douglas fir timber was appreciated in Europe for furniture and joinery. An increase in price and a lack of availability of this timber during the last years, necessitated that a substitute be found.

At present, the Douglas fir is becoming an increasingly important timber resource in Europe. In fact, growing quantities of timber coming from artificial European plantation are available, but it should be pointed out that in these conditions the Douglas fir is a fast grown species. The fast grown timber properties are definitely different from first grown timber.

The fast grown European timber presents large annual rings. Within the ring the latewood density is high (0.9÷1) while the earlywood density is very low (0.3). This huge difference affects quality of the surfaces after a machining process (e.g. planing and spindle shaping machining) and therefore the quality of final products is unsatisfactory. In fact the usual process conditions (such as feeding speed, rake angles of the tools, cutting materials, etc.) are not suitable for machining this type of timber. Hence, apparently the European resource may not be suitable to substitute for the American one for the furniture and joinery industry. Nevertheless the surface quality of the European resource may be improved through a suitable machining process.

The goals of our work are the following: i) to study the defects due to an ordinary machining process; ii) to measure the force of the tools in relationship with the timber density and the surface defects; and then iii) to improve the process parameters in order to achieve an acceptable quality of the surfaces. The results of the first task are summarised in this paper.

THE SURFACE QUALITY

The quality of the timber surface resulting from a machining process can be easily evaluated through a binary judgement like "I do/I do not like it". This empirical method, which is by the way very effective, allows few statistical data process. Nevertheless the human synthesis is able to summarise effectively the influence of different properties such as texture, colour, brightness, roughness, thickness regularity and many others. Some procedures have been proposed to improve the effectiveness of the visual and tactile methods.

By contrast, various machine able to measure the different properties describing the surface quality have been developed. The machine methods are able to measure some physical parameters more or less strictly correlated with the surface quality.

Finally, it should be noted that "surface quality" is a property which depends upon various factors. It change according to the wood species, to the final use, to the epoch, and to other variable parameters.

Visual Method

The machining tests have been standardised by ASTM D-1666-87. The procedures presented in this standard cover such common operation as planing, shaping, turning, boring, mortising and sanding. It includes practical methods for qualitatively evaluating and interpreting the results, through a grading method describing the quality of surfaces.

A similar method for evaluating the planing process was conceived by Petrocchi (1987). It is based on the ASTM standard with some improvements and adaptations.

Machine evaluation

The surface quality can be evaluated by using both direct and indirect methods. The most important direct procedures are the following:

- roughness profile (Talysurf by Rank Taylor Hobson, Perthometer by Mehr Perthen, Surftest 501 by Mitutoyo and others);
- profile visualisation by means of a laser ray (Topovise developed by ENSTIB, [Duchanois et al., 1996]);
- surface visualisation (DICOM system, EDIXIA system based on ultra-violet rays [Gouttebel *et* Sauvignet, 1994]).

The indirect measurements are based on the pressure or friction:

- pressure variation measured upon the changes of the relative vacuum (method introduced by the CTBA for evaluating the veneers [Marchal, 1983]);
- tactile control by means of friction measurements (Toposurf by ENSTIB, [Duchanois et al., 1996]).

MATERIAL AND METHOD

Each test specimen was visually examined carefully for planing defects after each run. The machine used for testing was an ordinary planing machine with the following characteristics:

i) r.p.m. 6500; ii) rake angle, α= 30°; iii) clearance angle, γ=20°; iv) feeding speed 8 m/min (only for the thickness planing) v) stage of machining : 5 mm on the thickness planing machine and 2 mm on the surface plane machine.

The planing characteristics were classified by visual examination on the basis of five grades as follows:

Grade 1, excellent;
Grade 2, good;
Grade 3, fair;
Grade 4, poor;
Grade 5, very poor.

According to *Petrocchi* the Grades 1 and 2 should be always accepted. By contrast from Grade 3 up to 5 the machined timber could be rejected, according to final uses. The machining defects are described by the standard according to various defectc types, as follows:

- the **raised grain** is a roughened condition of the surface of timber in which the hard latewood is raised above the soft earlywood but it not turn loose of it;
- the **fuzzy grain** is due to small particles or groups of fibers which did not sever clearly in machining but which stand up above the general level of the surface;
- the **torn grain** is the part of the wood torning out in dressing;
- the **chip marks** are the shallow dents in the surface caused by shavings that have clung to the knives instead of passing off in the exhaust as intended.

The procedures adopted are completely described in section 11 of ASTM D-1666-87. Some adaptations according to Petrocchi were adopted (different MC, different cutting deep, more data collected). An example of the Sample Data Sheet used in planing tests is given in Table 1.

The timber surfaces were graded into three groups according to the occurence of timber defects able to induce machining defects, as follows:

- the Defect Free Timber (DFT) was the area of the board without timber defects such as knots and grain deviations. It described the machining defects due to the basic properties of the species (such as the anatomy) without the influence of the timber defects;
- the Timber with Defect (TwD) was the wood on which the machining defects were related to the timber defects occurence. We took into account only the timber defects able to induce machining defects, such as the knots and the grain deviation (respectively noted as "Kn" and "GD" in Table 1). This allowed us to relate the machining defects to the timber defects;
- the Whole Board Grading (WBG = Defect Free Timber + Timber with Defect), was the group describing the whole board. The grade was carried out from the DFT and TwD groups by choosing the worst defect found. This allowed us to obtain a global description of the board.

For the Chip Marks no difference due to the timber defects were envisaged, so the grading was directly performed according to the Whole Board Grading. The other machining defects (Raised Grain, Fuzzy Grain and Torn Grain) will be shown in the Results both according to the DFT/TwD groups and according to the WDG group.

N°	Specimen	Machiningd efect-free	Machining defect Raised Grain		Machining defect Fuzzy Grain		Machining defect Torn Grain		Chip Marks	Anatomical Section
			DFT (1)	**TwD**(2)	**DFT**	**TwD**	**DFT**	**TwD**	**WBG** (3)	
1	13A1 SU							*2Kn* (4)		*T*
2	13A2 GIU		*3*				*3*	*3GD* (5)	*3*	*T*
3	.....									

Table 1- Example of Sample Data Sheet used in planing tests

(1) DFT = Defect Free Timber;

(2) TwD = Timber with Defect;

(3) WBG = Whole Board Grading (defect free timber + timber with defect);

(4) Kn = defects related to the occurence of Knots;

(5) GD = defects related to the occurence of Grain Deviation.

A sample of 131 boards of French Douglas fir (*Pseudotsuga Menziesii Franco, var. Menziesii*) 1 m length, 100÷240 mm wide, 40÷45 mm thick sawn from 8 trunks of the same standing has been constituted. The boards were planed up to a thickness of 30 mm.

On each board, one face was machined by a surface planing machine, while the opposite one were machined by a thickness planing machine. Only the faces were taken into account and no observations on the edges were made.

RESULTS

The description of the sample machined parallel to the grain is in **Table 2**.

An amount of 20.6% of the faces was without timber defects and it was graded as DFT (defect-free timber) according to Table1.
Of the 54 faces analysed, 15 (27.8 %) were without machining defects. By contrast only the 2.4% of the faces on which some timber defects occurred were without any machining defect.

	N°	%
N° of boards	*131*	
N° surfaces evaluated	*262*	*100%*
N° of faces without timber defects	54	**20.6%**
N° of faces with timber defects	208	**79.4%**
surface planing	129	49.2%
thickness planing	133	50.8%

Table 2 - *General description of the sample machined parallel to grain*

Boards without timber defect

In **Table 3**, the machining defects and the grades of the 54 faces completely defect-free are reported.

The raised grain did not result a relevant defect (Grades 3, 4, 5: 5.6%), while the fuzzy grain (Grades 3, 4, 5: 16.7%) and the torn grain (Grades 3, 4, 5: 31.5%) affected the surfaces to a greater degree.

Few differences were found between the surface planing and the thickness planing on the whole sample: 32% of faces machined by a surface planer were whithout machining defects; only the 23.1% machined by a thickness planer were completed whithout machining defects.

GRADE	**Raised Grain**		**Fuzzy Grain**		**Torn Grain**	
	N°	%	N°	%	N°	%
1	51	94.4	28	51.9	30	55.6
2	0	0	17	31.5	7	13
3	2	3.7	9	16.7	13	24.1
4	1	1.9	0	0	4	7.4
5	0	0	0	0	0	0
1, 2		94.4		83.3		68.5
3, 4, 5		**5.6**		**16.7**		**31.5**

Table 3 - *Grading of the faces without timber defects*

In **Table 4** the machining defects and the grades of the 54 faces «defect-free timber» according to the type of machining are summarized.

The raised grain did not result a relevant defect for thickness planing (Grades 3, 4, 5: 11.6%), while the same defect did not occur during the surface planing.

For both the processes the fuzzy grain (Grades 3, 4, 5: 14.3÷19.2%) and the torn grain (Grades 3, 4, 5: 28.6÷34.6%) turned out to be more relevant.

GRADE	**Raised g.**	**Fuzzy g.**	**Torn g.**
	%	%	%
	Surface planing		
1, 2	100	85.7	71.4
3, 4, 5	**0**	**14.3**	**28.6**
	Thickness planing		
1, 2	88.5	80.8	65.4
3, 4, 5	**11.5**	**19.2**	**34.6**

Table 4 - *Grading of the faces without timber defects according to the type of planing machine*

Boards with timber defect

On 79.4% of the faces some timber defects occurred. On these boards the faces were graded into both DFT (defect-free timber) and TwD (timber with defects), according to the timber defect occurrence. The global evaluation of the face was expressed under the group WBG (Whole Board Grading = Defect Free Timber + Timber with Defect).

Defect-free timber (DFT) in defective boards

In Table 5, the machining defects and the grades of the 208 faces on which occurred both the area without timber defects and the area with some defects are reported.

The raised grain did not result a relevant defect (Grades 3, 4, 5: 3.3%), while the fuzzy grain (Grades 3, 4, 5: 21.2%) and the torn grain (Grades 3, 4, 5: 36.3%) affected the surfaces significantly.

In Table 6, the machining defects and the grades of the 208 faces with some timber defects according to the type of machining are summarized. The raised grain caused a relevant defect neither for surface nor for thickness planing (Grades 3, 4, 5: 2÷4.7%). For both the processes the fuzzy grain (Grades 3, 4, 5: 15÷26.7%) and the torn grain (Grades 3, 4, 5: 36.4÷36.6%) turned out to be more relevant factors.

On the defect-free timber, the thickness planing gave a better quality surface than the surface planing. Moreover no huge difference was found between the surface quality of the defect-free area in defective boards and the surface of the boards without any timber defect.

Timber with defects (TwD) in defective boards

The timber defects affecting the surface quality are mainly the knots and the grain deviation. As shown in Table 7, the main machining defect was the torn grain which affected 56.1% of the faces.

In Table 8 are reported the results according to the type of planing process. No huge difference was observed between the surface planing (torn grain in 56.6% of faces) and the thickness planing (torn grain in 59.8% of faces). Raised and fuzzy grain did not influence the surface quality.

Whole board grading (WBG)

The global evaluation of the faces was expressed as Whole Board Grading. The grade was carried out on the boards by choosing the worst defect found between the zones with timber defects and without timber defects. It provides a global description of the board.

In Table 9 are reported the machining defects observed on the boards. The raised grain was not a relevant machining defect. It affected only 3.8% of faces. The fuzzy grain affected the quality of surfaces to a greater degree (22.2% of the board faces). The most significant machining defect was definitely the torn grain, which was found on the 69.8% of the board faces.

Finally, in Table 10 are summarized the machining defects and the grades of the 208 faces according to the type of machining. No difference between surface and thickness planing for the raised grain was found. The fuzzy grain proved more relevant for the surface planing; the low grade (3 to 5) faces achieved the 28%. Less fuzzy grain defects (15.9%) were found after the thickness planing. Finally no difference was found between the two planing processes for the torn grain. The chip marks are reported in Table 11. This defect affected the 21.1% of faces. This proved more relevant for the thickness planing (24.4%) than for the surface planing process (17.6%).

The knots influence

The machining defects have been also analysed in relationship with the knot occurrence. The observations were made both in the area within the knot and in the area around the knot. The machining defect due to the knot occurrence was always the torn grain.

The main results are summarised in the Tables 12 (defects within the knot area) and 13 (defects around the knot).

The majority of knots were intergrown (66.8%). Most of them presented some fissures. The occurrence of fissures caused the rupture of small knot particle, graded as torn grain. 23.9% of the knots were dead and some of them presented fissures.

GRADE	Raised g.	Fuzzy g.	Torn g.
	%	%	%
1	95.3	50.5	53.3
2	1.4	28.3	10.4
3	2.8	18.4	29.7
4	0	2.8	6.1
5	0.5	0	0.5
1, 2	96.7	78.8	63.7
3, 4, 5	**3.3**	**21.2**	**36.3**

Table 5 - *Grading of the area defect-free timber (DFT) on the faces with timber defects*

GRADE	Raised g.	Fuzzy g.	Torn g.
	%	%	%
	Surface planing		
1, 2	98	73.3	63.4
3, 4, 5	**2**	**26.7**	**36.6**
	Thickness planing		
1, 2	95.3	85	63.6
3, 4, 5	**4.7**	**15**	**36.4**

Table 6 - *Grading of the area defect-free timber (DFT) according to the type of planing process, carried out on the defective boards*

GRADE	Raised g.	Fuzzy g.	Torn g.
	%	%	%
1	99	97.2	7.6
2	0.5	1.4	36.3
3	0	1.4	34.9
4	0.5	0	19.3
5	0	0	1.9
1, 2	99.5	98.6	43.9
3, 4, 5	**0.5**	**1.4**	**56.1**

Table 7 - *Grading of the area with timber defect-free (TwD)*

GRADE	Raised g.	Fuzzy g.	Torn g.
	%	%	%
	Surface planing		
1, 2	99	99	46.5
3, 4, 5	**1**	**1**	**53.3**
	Thickness planing		
1, 2	100	98.1	40.2
3, 4, 5	**0**	**1.9**	**59.8**

Table 8 - *Grading of the area with timber defect (TwD) according to the type of planing process*

GRADE	**Raised g.**	**Fuzzy g.**	**Torn g.**
	%	**%**	**%**
1	94	50	6.6
2	1.9	27.8	23.6
3	2.8	19.3	46.2
4	0.5	2.8	21.7
5	0.5	0	1.9
1, 2	96.2	77.8	30.2
3, 4, 5	**3.8**	**22.2**	**69.8**

Table 9 - Whole board grading (WBG)

GRADE	**Raised g.**	**Fuzzy g.**	**Torn g.**
	%	**%**	**%**
	Surface planing		
1, 2	97	72	31.1
3, 4, 5	**3**	**28**	**69.3**
	Thickness planing		
1, 2	95.3	84.1	28.7
3, 4, 5	**4.7**	**15.9**	**70.4**

Table 10 - Whole board grading (WBG) of the defective boards according to the type of planing process

The smallest group (9.3%) was represented by the knots with bark. Even if they could be considered as dead knots, they have been observed separately because of a different behaviour in relationship with the effect of machining. No fissures were found in the knots with bark .It was observed that the machining defects were related with the fissures occurrence.

The machining defects within the knot area were mostly in the intergrown knots group (57%, mainly due to the occurrence of the fissures) and in the dead knots group (41.4%). Few knots with bark (10.4%) presented machining defects.

The machining defects around the knot were found in the dead knots group (52%) and in the group of knots with bark (41.3%). The smallest group with machining defects was the intergrown knots (30.3%).

Grade	**1**	**2**	**3**	**4**	**5**	**1, 2**	**3, 4, 5**
both process	60.5	18.4	17.7	3.4	0	**78.9**	**21.1**
surface planing	58	24.4	14.5	3.1	0	**82.4**	**17.6**
thickness planing	63	12.6	20.7	3.7	0	**75.6**	**24.4**

Table 11 - Chip marks grading

GRADE	**Intergrown knots**		**Dead knots**		**Knots with bark**	
	N°	**%**	**N°**	**%**	**N°**	**%**
1	72	**17.2**	53	**35.3**	38	**65.5**
2	108	25.8	35	23.3	14	24.1
3	116	27.7	23	15.3	2	3.4
4	87	20.8	10	6.7	0	0
5	36	8.6	9	6	0	0
1, 2		43		58.6		89.6
3, 4, 5		**57**		**41.4**		**10.4**

Table 12- Machining defects within the knot area. The knots are divided according to three groups: intergrown knots, dead knots and knots with bark

GRADE	Intergrown knots		Dead knots		Knot with bark	
	N°	%	N°	%	N°	%
1	35	8.4	8	5.3	7	12.1
2	257	61.3	64	42.7	27	46.6
3	97	23.2	57	38.0	18	31.0
4	27	6.4	21	14.0	5	8.6
5	3	0.7	0	0.0	1	1.7
1, 2		69.7		48		58.7
3, 4, 5		**30.3**		**52**		**41.3**

Table 13 - Machining defects around the knot

CONCLUSION

The Douglas fir presented some defects due to the machining process. The main machining defects were the fuzzy and torn grain on both the specimens with timber defects and specimens defect-free. The chip marks poorly affected the surface quality. The raised grain was never a relevant defect. The occurrence of a timber defect (mostly knot and grain deviation) was often related to the machining defects. The surface planing provided the best quality surface, particularly for the torn grain defect. The thickness planing, even if it caused more machining defects, generates less fuzzy grain defect.

Therefore the machining of the Douglas fir carried out on an ordinary planing machine was not always satisfactory. In fact the occurrence of timber defect and the density properties on this species often caused various machining defects. Hence, apparently the European resource may not be suitable to substitute for the American Douglas fir for the furniture and joinery industry. Nevertheless the surface quality of the European resource may be improved through a suitable machining process. In order to achieve an acceptable quality of the surfaces, the machining process for this species should be improved by changing some parameters of the process such as feeding speed, rake angles of the tools and new cutting materials.

REFERENCES

1. ASTM D-1666, 1987, *Standard methods for Conducting Machining Tests of Wood and Wood -Base Materials,* Annual Book of ASTM Standards, Volume 04.09 Wood, 257-276
2. Duchanois G., EisenP., Gross P.,Triboulot P., 1996 : *Contrôle Qualité et états de surface bois, TOPOSURF & TOPOVISE, outils complémentaires de mesure des qualités de surface.* 4ème Colloque Sciences et Industrie du bois, Nancy-France, 11-12-13 Septembre 1996, 339-344
3. Gouttebel O., Sauvignet E., 1994 : *Etats de surface du bois massif* Rapport principal de Projet de fin d'études, Ecole Nationale Supérieure d'Arts et Métiers, 73 p.
4. Lundberg A.S., Porankiewicz B., 1995 : *Studies of non-contact methods for roughness measurements on wood surfaces* Holz als Roh- und Werkstoff, 53 (1995), 309-314
5. Marchal R, 1983, *Intérêt de la prise en compte de caractéristiques physiques et anatomiques simples du bois de Chêne pour l'appréciation de la qualité des placages d'ébenisterie.* Diplôme d'études approfondies en Sciences du bois, INPL - Université de Nancy I., 105 p.
6. Mitutoyo Surftest 501 Series 178 *Reference Book,* Manual No.4386, Mitutoyo Co., Japan
7. Petrocchi S., 1987, *Prove di lavorabilità e di abrasione degli utensili su alcune specie legnose.* Tesi di laurea, Università degli studi di Firenze, Facoltà di Agraria, corso di laurea in Scienze Forestali.