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EXPERIMENTAL RESEARCH ON SAWING FROZEN WOOD

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Abstract: *The main objective of the present research is to establish the differences in the behavior during sawing of frozen and unfrozen wood. Two species, a resinous one (spruce, Picea abies L.) and a broad-leaved one (oak, Quercus robur L.) were selected for this study. The tested wood specimens originated from the same log (one spruce log and one oak log). Half of the specimens were frozen down to –30ºC, with a freezing rate of -15ºC/h and then maintained for 1 week in frozen state; half remained unfrozen, as controls. Both the frozen and the unfrozen specimens were cut by means of a circular saw blade under absolutely identical conditions (same machine, same tool, same devices and same cutting conditions), in order to determine comparatively the power consumption and the resistance specific to cutting involved in the two cases. The results revealed that freezing determines – in the given conditions – a visible decrease of the necessary cutting power and the specific resistance to cutting (by up to 46.1% for spruce and up to 47.2% for oak).*

Key words: *frozen wood, spruce, oak, cutting power, specific resistance to cutting.*

1. Introduction

In cold climate zones, during winter, when outside temperatures drop frequently below 0ºC, logs stored in an open yard freeze. In this state, they have to be converted into timber boards and then further sawn by edging, ripping, sectioning at the same sub-zero temperature. Considering this situation, the present paper presents the comparative behaviour of frozen and unfrozen spruce (Picea abies L.) and oak (Quercus robur L.) wood during sawing by means of circular saw blades, aiming at establishing the extent to which the frozen state affects (or not) the necessary power for cutting and the specific resistance to cutting.

The following statements concerning the freezing effect can be considered as confirmed:

• only free water freezes in wood if the temperature does not drop below –30ºC [2];

• the transformation of liquid water into ice inside the cell lumena develops a certain pressure upon the cell walls; it can be assumed that the generated mechanical energy is capable of breaking some bonds between the bound water molecules and the wooden substance, "sqeezing" out a certain amount of water from the cell walls and re-locating it into the cell lumena; due to this compressive stress exerted by the expansion of liquid water into the lumen, certain micro-fissures occur within the cell

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wall structure, diminishing the mechanical properties of wood [4], [15];

• the freezing rate has a decisive importance upon the gravity of micro-fissures that occur: the slower the freezing, the more damage it causes [14], due to the bigger size of the ice crystal formed;

• at sub-zero temperatures, the mechanical properties tend to increase [1], [3], [18]. Experimental studies on frozen and unfrozen Swedish pine (*Pinus silvestris*) wood revealed a higher MOE value (14.2 GPa) at -20 ºC then at +20°C (11.6 GPa) [8]. This may, at least partially, be explained by the dependency between the strength properties and the temperature of ice: according to Michel (1978), cited by Merkel [11], the compressive strength of ice grows exponentially with increasing sub-zero temperature.

As far as the behaviour of frozen wood during sawing is concerned many authors [7 - 9], [12], [13], [16], [17] indicate that the cutting forces and energy consumptions increase during freezing. This behaviour is attributed to the free water transformation into ice crystals. Other sources ([10], [20]) discuss the difficulty in evacuating the sawdust resulted during cutting. This sawdust tends to accumulate into the kerf, between the sawing blade and the piece of wood. Thus, it increases friction and may even cause the saw blade blocking.

Unlike other researches on wood sawing (most of them being performed with logs), the present study was performed on wood parts with small thickness and by using a circular saw (instead of frame saw or band saw).

2. Method and Materials

The material used within the present research consisted of sixteen 40mm thick and 0.4m long timber boards for each wood species, cut from the same log (one spruce log and one oak log), according to the scheme presented in Fig. 1, after removing the pith area. Both trees were harvested from forest areals nearby Brasov-Romania.

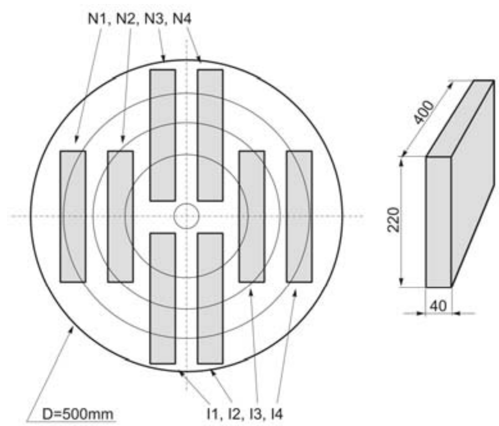


Fig. 1. *Cutting scheme for obtaining the wood specimens.*

The average initial moisture content of the specimens, determined by the oven-dry method (EN 13183-1:2003) was 57% for spruce and 60% for oak.

Hereinafter, all wood samples necessary for the sawing tests were cut at 300x200x25mm.

Half of the parts (obtained from I1…I4 timber parts) were first frozen at –30ºC in a FEUTRON climate chamber type 3423/16, at a freezing speed of -15°C/h. A temperature sensor inside wood confirmed that after 2 hours of artificial freezing the wood temperature (in the middle of the sample) had reached –30ºC. The other half of the samples (obtained from N1…N4 timber parts) remained unfrozen.

The working schemes are presented in Fig. 2. The experiments were conducted not on a circular saw, but on a vertical moulder type MNF10 equipped with a circular blade. The reason for choosing this arrangement was dictated by the necessity of clamping the wood samples by means of a mechanical feed device capable of being fixed on the machine table. This was necessary in order to ensure an exact adjustment of the feed speed [5], [6]. Fig. 3 shows the working set-up.

The power measurements were carried out by means of a data acquisition system (DAQ), comprising: a three-phase transducer for active power type Sineax P530, a Velleman Instruments DAQ board and a PC. The main technical characteristics of the Sineax P530 transducer are:

- nominal input voltage: 220/380 V;
- nominal input current: 5 A;
- input frequencies: 45 ... 55 Hz;
- output voltage: 0 ... 10 V;
- output current: 0 ... 20 mA;
- precision: 1%.

The DAQ software was Velleman Pc-Lab 2000. The DAQ was made with a frequency of 100Hz.

The parameters of the working schedules applied within the experimental research are presented below:

- tool diameter: ***Ds*** = 200 mm;
- number of cutting teeth: ***z*** = 34;
- rotation speed of working shaft: ***n*** = 5043, 6831 rpm;
- cutting speed: ***v*** = 52.78, 71.49 m/s;
- cutting thickness: ***h*** = 25 mm;
- feed speed: ***u*** = 6, 12, 20, 30 m/min.

The geometrical parameters of the circular blade teeth are presented in Fig. 4. Due to the geometry of the teeth, the succession of cuts looks like in Fig. 5. As can be seen, the calculated tooth bite (u_{zc}):

$$u_{zc} = \frac{1000 \cdot u}{n \cdot z}, \quad [\text{mm}] \qquad (1)$$

is half of the real one (u_{zR}). The values of the latter are given in Table 1.

Table 1

The real values of the tooth bite u_{zR} as resulted from the teeth geometry and the cutting parameters used within the experiments

u [m/min]	***n*** = 5043 rpm	***n*** = 6831 rpm
6	0.070	0.052
12	0.140	0.103
20	0.233	0.172
30	0.350	0.258

The final data processing was performed by means of the MICROSOFT EXCEL 2002 under WINDOWS XP Professional.

The processing of the experimental results included the calculation of the specific resistance to cutting k, as function of the measured power values:

$$k = \frac{6000 \cdot P_a}{b \cdot h \cdot u}, \quad [\text{daN/mm}^2] \qquad (2)$$

where: P_a is the active power consumed for processing, in kW;
b – cutting width, in mm;
h – cutting height, in mm;
u – feed speed, in m/min.

3. Results and Discussion

The statistical overview of the obtained results is given in Tables 2, 3, 4 and 5. Figures 6 and 7 present the comparative results obtained for frozen and unfrozen wood, concerning the consumed power and the specific resistance to cutting.

Spruce. The power consumed during radial sawing registered an average decrease of 14,09% in case of frozen wood (with variations between 9,48% and 22,28%, as function of the cutting conditions – see Tables 2 and 3) and during the sawing in tangential direction, an average decrease of 15,58% was obtained (with variations between 2,11% and 46,14%, as function of the cutting conditions – see Tables 2 and 3).

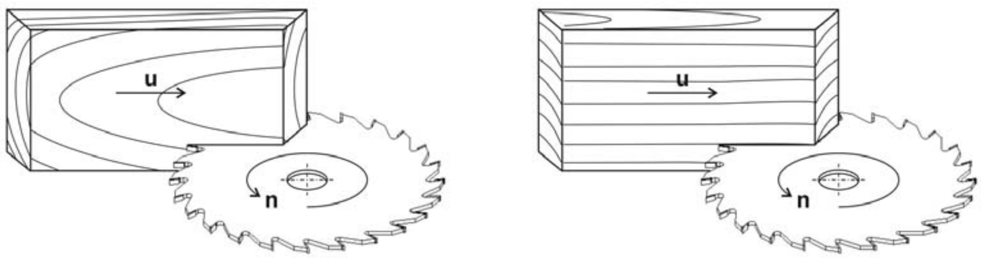


Fig. 2. *Working schemes: a-radial cutting plane; b-tangential cutting plane.*

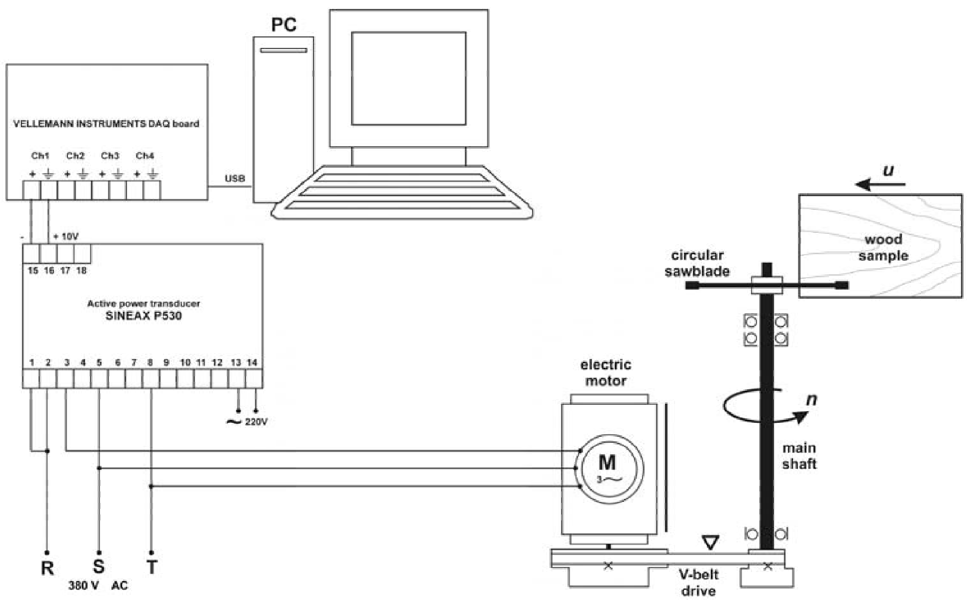


Fig. 3. *Working set-up.*

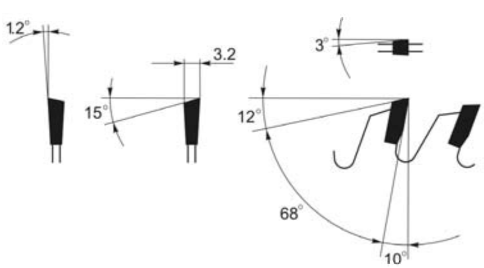


Fig. 4. *The parameters of the circular blade teeth.*

Oak. The power consumed during radial sawing registered an average decrease of 19.10% in case of frozen wood (with variations between 5,10% and 47,17%, as function of the cutting conditions – see Tabs. 4 and 5) and during the sawing in tangential direction, an average decrease of 25.80% was obtained (with variations between 7,93% and 43,85%, as function of the cutting conditions – see Tables 4 and 5).

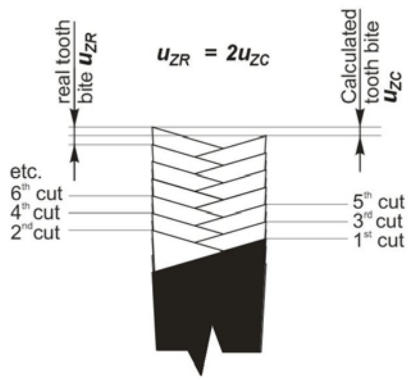


Fig. 5. *The cutting succession as a result of the cutting teeth geometry.*

The differences for both species, in both cutting directions are higher with the higher cutting speed (v=71.49m/s) and with the lower feed speed (u=6 / 12 m/min).

A possible explanation of the different results obtained in comparison to the cited authors (Kivimaa 1950; Kollmann and Cote 1968; Korkeakangas 2005; Orlowski and Sandak 2005; Sandqvist 1986; Taskinen 2005; Vazquez-Cooz and Meyer 2006) [7-9, 12,13, 16,17] is due to the different cutting conditions, especially the cutting height and the different tool. An important element noticed and emphasised by all cited authors refers to the high quantity of sawdust generated during the cutting of frozen logs, which gets stuck on the lateral kerf walls (on the side clearance), increasing the friction forces between the blade and the kerf walls. As a consequence, the active power consumption increases, and sometimes the blade may also get blocked inside the kerf.

The consumed power (P_a in kW) during the sawing of frozen and unfrozen spruce wood (averages/standard deviation) Table 2

	v **= 52.78 m/s**				***v*** **=71.49 m/s**			
	u**, m/min**				***u*****, m/min**			
	6	**12**	**20**	**30**	**6**	**12**	**20**	**30**
RADIAL sawing								
Unfrozen	0.41/0.01	0.60/0.03	0.79/0.03	0.93/0.03	0.56/0.03	0.71/0.04	0.86/0.04	0.97/0.05
Frozen	0.34/0.02	0.51/0.03	0.71/0.02	0.85/0.02	0.46/0.02	0.63/0.05	0.78/0.05	0.88/0.06
Decrease, %	20.28	15.78	10.98	9.48	22.28	13.21	11.19	9.57
TANGENTIAL sawing								
Unfrozen	0.50/0.03	0.75/0.04	0.99/0.02	1.35/0.04	0.71/0.02	0.96/0.02	1.18/0.03	1.29/0.04
Frozen	0.49/0.03	0.66/0.04	0.82/0.07	1.26/0.04	0.48/0.03	0.79/0.06	1.07/0.05	1.26/0.04
Decrease, %	3.81	13.79	20.41	7.02	46.14	21.17	10.21	2.11

The specific resistance to cutting (k in daN/mm^2) during the sawing of frozen and unfrozen spruce wood (calculated averages) Table 3

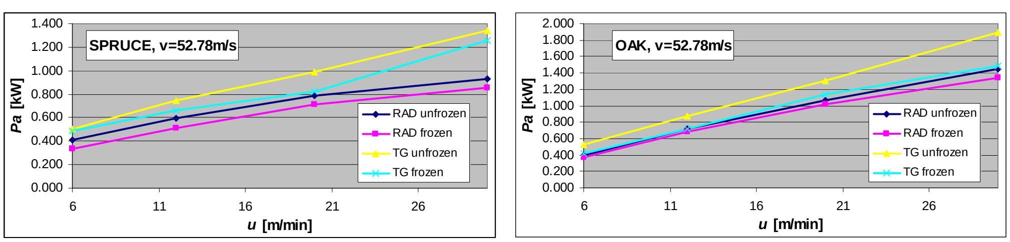
	v **= 52.78 m/s**				***v*** **=71.49 m/s**			
	u**, m/min**				***u*****, m/min**			
	6	**12**	**20**	**30**	**6**	**12**	**20**	**30**
RADIAL sawing								
Unfrozen	4.252	3.101	2.472	1.942	5.862	3.719	2.696	2.012
Frozen	3.535	2.679	2.228	1.774	4.794	3.285	2.424	1.836
Decrease, %	20.28	15.78	10.98	9.48	22.28	13.21	11.19	9.57
TANGENTIAL sawing								
Unfrozen	5.252	3.904	3.091	2.802	7.344	4.975	3.688	2.678
Frozen	5.059	3.431	2.567	2.618	5.025	4.106	3.346	2.623
Decrease, %	3.81	13.79	20.41	7.02	46.14	21.17	10.21	2.11

The consumed power (P_a in kW) during the sawing of frozen and unfrozen oak wood (averages/standard deviations) Table 4

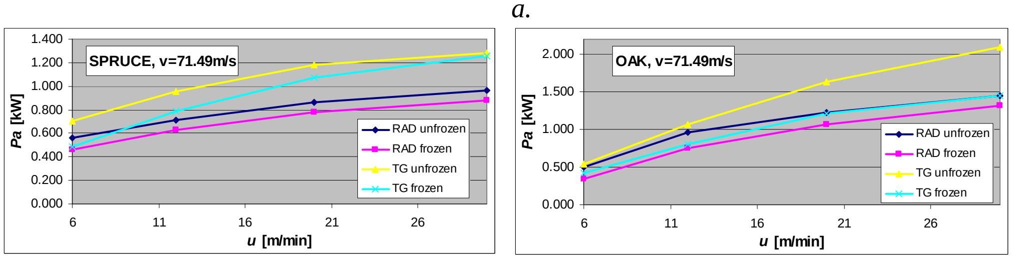
	v = 52.78 m/s				***v*** =71.49 m/s			
	***u*, m/min**				***u*, m/min**			
	6	**12**	**20**	**30**	**6**	**12**	**20**	**30**
RADIAL sawing								
Unfrozen	0.40/0.04	0.72/0.09	1.07/0.10	1.45/0.11	0.51/0.06	0.96/0.18	1.23/0.18	1.44/0.17
Frozen	0.37/0.04	0.68/0.09	1.02/0.11	1.34/0.11	0.35/0.04	0.65/0.09	0.98/0.16	1.32/0.16
Decrease, %	6.45	5.57	5.10	8.38	45.82	47.17	25.36	8.99
TANGENTIAL sawing								
Unfrozen	0.53/0.06	0.87/0.11	1.23/0.19	1.89/0.18	0.54/0.08	1.06/0.08	1.63/0.15	2.09/0.17
Frozen	0.42/0.04	0.81/0.09	1.14/0.11	1.49/0.15	0.43/0.05	0.80/0.09	1.21/0.17	1.46/0.17
Decrease, %	26.19	7.93	8.17	26.71	25.88	32.75	34.93	43.85

The specific resistance to cutting (k in daN/mm^2) during the sawing of frozen and unfrozen oak wood (calculated averages) Table 5

	v = 52.78 m/s				***v*** =71.49 m/s			
	***u*, m/min**				***u*, m/min**			
	6	**12**	**20**	**30**	**6**	**12**	**20**	**30**
RADIAL sawing								
Unfrozen	4.954	4.499	4.018	3.622	6.326	6.009	4.614	3.608
Frozen	4.646	4.262	3.819	3.343	4.343	4.079	3.682	3.309
Decrease, %	6.63	5.56	5.21	8.35	45.66	47.32	25.31	9.04
TANGENTIAL sawing								
Unfrozen	6.627	5.446	4.617	4.721	6.686	6.638	6.113	5.232
Frozen	5.247	5.042	4.266	3.724	5.318	5.002	4.529	3.637
Decrease, %	26.30	8.01	8.23	26.77	25.72	32.71	34.97	43.85



a.



b.

Fig. 6. *Comparative values of the consumed power (P_a) during the sawing of frozen and unfrozen spruce and oak wood.*

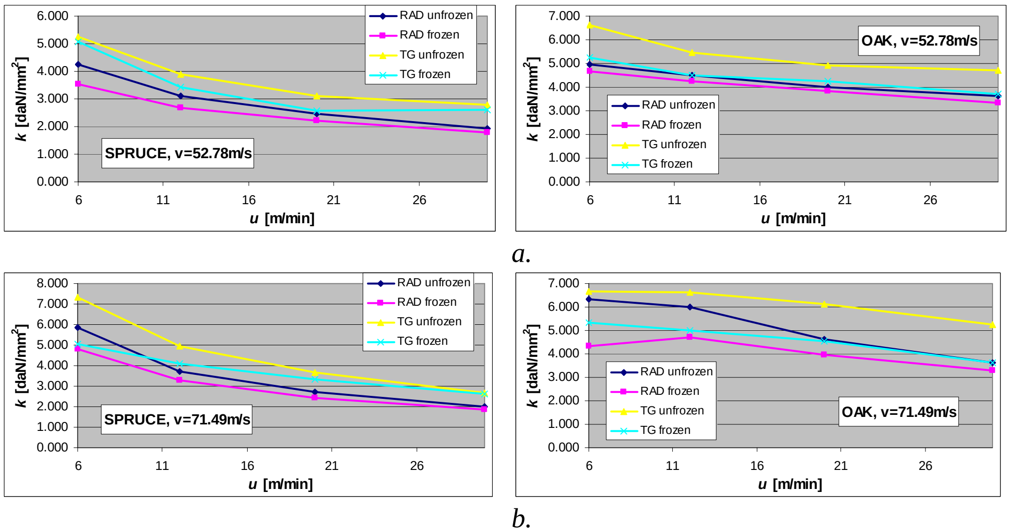


Fig. 7. *Comparative values of the specific resistance to cutting (k) during the sawing of frozen and unfrozen spruce and oak wood.*

On the other hand, the present research was performed with circular blades, and more importantly, at much lower cutting height, so that the evacuation of the chips and sawdust was achieved easier and had no influence upon the active power consumption. Even though at the used feed speeds the tooth bite values were small (see Table 1), the fine dust generated through cutting did not create any accumulation problem in the side clearance, due to the same element previously mentioned: the small thickness of the specimens (meaning a very small quantity of sawdust produced by a tooth on its way through the wood and a quick evacuation).

4. Conclusions

The performed research revealed that freezing has an important influence upon the cutting (by sawing with circular saw blades) behavior of wood. The experimental results performed by sawing frozen and unfrozen spruce and oak wood showed that the necessary cutting power and the specific resistance to cutting is for all considered cutting conditions lower in the case of the frozen wood than for the unfrozen wood. The contradictory results obtained comparatively to other authors must be attributed to the different cutting conditions applied within this research (mainly the low thickness of the specimens that made the evacuation of the sawdust very easy), where the accumulation of sawdust between the saw-blade and the kerf walls (in the side clearance) was no longer an issue.

Thus, according to the obtained results and the studied bibliography, it seems to be obvious that the cutting forces increase when sawing frozen logs not due to a more difficult interaction between the blade and wood, but because of collateral phenomena related to the sawdust evacuation. In order to elucidate this issue, further research with other open wood processing techniques (e.g. thicknessing) is necessary.

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