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THE EFFECT OF AGE ON DESORPTION STRESS AND STRAIN RATE IN BIRCH AND ASPEN

Henryk Widłak
Department of Hydrothermal Processing and Modification of Wood, August Cieszkowski Agriculture University of Poznan, Poland

ABSTRACT

The aim of the present study was to establish the value of desorption stresses and the rate of their increase in the samples of juvenile and mature birch wood as well as in aspen samples of different physiological age. The stress value was calculated on the basis of the measurement of the force necessary to restrain shrinkage in the sample being dried. Additionally, moisture strain and mechanical-moisture strain (both real and apparent) were measured during the experiments. The samples were dried at temperatures of 30, 50 and 70°C. It was concluded that both the rate of increase and the absolute values of stress and strain are different in juvenile and mature birch wood. Also in aspen they depend on the physiological age of the wood tissue. Juvenile birch wood and the physiologically younger aspen proved more susceptible to strain caused by desorption stresses. The maximum stress values in samples of birch and aspen were the highest when dried at temperature of 30°C, yet it was the early stage of drying (at 70°C) that was characterised by the greatest rate of stress increase.

Key words: juvenile and mature wood, birch, aspen, drying, desorption stresses and strains

INTRODUCTION

In view of the increasing degradation of man's natural environment, large forest areas - so far the only source of wood - have more and more often played the role of the so-called "protected forests". However, at the same time, there is a growing demand for wood as people-friendly material. Therefore, in recent years scientists have

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become interested in the problems of rationalization of wood processing and use as well as obtaining wood from plantations of the fast-growing species.

Wood drying is a process that is inherently connected with the processing and utilization of wood, and its rationalization, which aims at reducing material losses, is certainly worthwhile [17,18]. The drying of fast-growing species is not particularly difficult, yet it is interesting to consider the effect of desorption stress in wood depending on the age of the wood tissue, especially in the context of the considerable amount of juvenile in the tree cross-section. Desorption stresses, being the result of restrained desorption shrinkage of wood tissue, are unquestionably the main factor influencing the process of wood drying. The problem of stresses and the resulting strains have been the subject of numerous studies, both because of the theoretical interest and practical implications.

In Poland the fast-growing species were first distinguished by Krajewski [3], who compared each of them to pine wood. He relied on the growth criterion, claiming that the fast-growing species were these which up to the age of 40 years give a bigger yield than pine. The following three groups of species were distinguished:

- up to the age of 40 – birch, alder
- between ages 40-60 – larch, Douglas-fir, aspen
- above age 60 – spruce.

Both birch and aspen wood belong to the same group of deciduous, diffuse porous wood, without heartwood, with the characteristics of sap-wood. They are classified as fast-growing species, best suited for plantation growing. However, timber obtained from plantations is characterized by a larger amount of juvenile which is of lesser quality than mature wood [21]. Juvenile wood can be found in each tree as a cylinder of a number of annual rings around the pith, reaching from the butt to the top of a tree. Therefore the top section of a trunk consists mainly of juvenile wood. Regardless of the particular differences in the anatomic structure of juvenile and mature wood, the lesser properties of juvenile softwood can be ascribed to a great width of annual rings and, therefore, to considerably lower density. Hence, the statement claiming that juvenile wood differs in every respect from mature wood refers mainly to softwood [21]. In terms of ring-porous hardwood, the relation between the density and ring width is converse to that of softwood. Yet, no such a relation occurs in case of diffuse-porous hardwood. In such circumstances, details become of the greatest significance: the cells of juvenile wood are three or four times shorter that these of mature wood (this refers to softwood, in terms of hardwood the difference is smaller). As the length of the cells increases, the inclination angle of the fibrils decreases and that affects shrinkage and swelling of wood; close to the pith the growth stresses are higher and, therefore, in case of juvenile wood, compression induced damages of the structure appear more frequently (especially often in case of hardwood) [21].

Birch wood is regarded as relatively easy to dry, however Poskrobko [12] claims that more intensive drying causes excessive warpage in birch lumber, especially at branch knots. He considers aspen wood to be easy to dry, yet also prone to warping when dried too intensively. However, both birch and aspen constitute such a small fraction of the materials being subjected to drying that the above opinion may not be fully reliable. It is important to point out that green aspen wood is generally characterised by a very high moisture content (from 88 to 150 percent), which complicates and prolongs the most difficult stage in the process of drying, namely the period until the wood attains 30 percent moisture content. Moreover, both birch and aspen lumber must be dried immediately because in the green state they are very susceptible to deterioration caused by fungi [5,15].

Unlike birch wood, which has often been applied in desorption stress research, aspen wood is very little known in this regard. It is worth mentioning, however, that aspen was the experimental material in Kass [6] studies. It was on the basis of aspen wood that he formulated the hypothesis that the main factor causing failure in the drying process was not the stress value but rather the strain resulting from long-lasting stress.

The above-mentioned susceptability of birch and aspen wood to warpage during intensive drying may be caused by different rate of change and values of the desorption stresses resulting from differential wood properties in the particular parts of tree cross-section. In view of the above, we have considered it justified to conduct experiments aiming at establishing the influence of the age factor on the development of stresses and strains in birch and aspen wood during the drying process.

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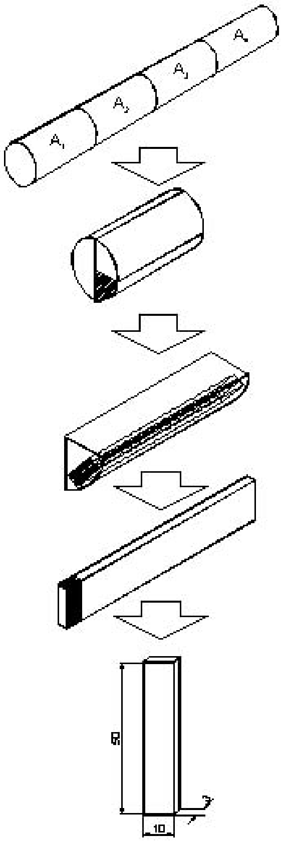
MATERIAL AND METHODS

The experimental material was aspen wood (*Populus tremula* L.) and birch wood (*Betula verrucosa* Ehrh.). Figure 1 illustrates the procedure of sample preparation. The size of the samples was established on the basis of assumptions similar to these made in earlier studies of beech wood [2,19,20]. The thickness of the samples was approximately equal to the double average fiber length, which is 1.2 mm for birch and 1.15 mm for aspen [4].

Fig. 1. Cutting procedures of the samples for the experiments (sizes in mm)



The age differentiation was realised through the selection of samples from different parts of the cross-section and along the log. The aspen samples were cut from two parts of the tree cross-section: between the 15th and 17th and between the 20th and the 22nd growth ring (from the pith), 5 meters from the butt end of the log. In the case of birch wood the samples used were those of mature and juvenile wood. The mature samples were obtained from the parts 3 and 5 meters from the butt end of the log, while the juvenile samples – 15 meters from the butt end of the log, at the apical zone. Samples were obtained each from one birch stem and one aspen stem, each randomly selected from dens stands nearby Poznań.

The characteristics of the experimental material are given in Table 1.

Table 1. The characteristics of experimental material

Kind of wood	Age of wood	Width of annual rings [mm]	Initial moisture content [%]	Density		
				green state 1)	oven-dry volume 2)	green volume 3)
				ρ_m	ρ_0	ρ_g
				[kg/m^3]		
Birch	mature	4 ÷ 6	145	1100 ÷ 1150	560 ÷ 600	–
	mature	3 ÷ 6	146	1100 ÷ 1250	530 ÷ 650	–
	juwenile	4 ÷ 5	160	1100 ÷ 1150	390 ÷ 450	–
Aspen	20 ÷ 22 *)	3 ÷ 4	174	1080 ÷ 1160	470 ÷480	405 ÷ 430
	15 ÷ 17 *)	5 ÷ 7	182	1020 ÷ 1060	420 ÷ 460	380 ÷ 400

***) years**
1) weight, green; volume, green
2) weight, oven-dry; volume, oven-dry
3) weight, oven-dry; volume, green

The experiments were conducted at three different drying temperature values: 30, 50 and 70°C which account for kiln drying as well as air drying conditions. At the initial stage of kiln drying of birch and aspen lumber the recommended temperature is 60-70°C, depending on the thickness of the boards [1]. The adoption of 50°C temperature for the experiment is suggested by the highly interesting observation of Raczkowski et al. [13] that with the increase of temperature from 20°C to 50°C the degree of tissue destruction is decreasing, however higher temperature causes increased tissue destruction. For each temperature level of the drying air, five experiments were conducted, each of which included a study of 1) desorption stresses and mechanical - moisture strains, 2) changes in the moisture content in the samples during drying, and 3) moisture strains.

The method used for measuring desorption stresses was one generally applied so far in similar studies [2,6,9,16,18]: it consisted in measuring the forces necessary for restraining the desorption shrinkage in the sample. The sample is treated here as equivalent to the surface layer of the boards, which tends to shrink at the first stage of the drying process as soon as it acquires the appropriate moisture content. At the same time, the deeper zone of the cross-section, having a higher moisture content, impedes shrinkage in the surface layer thus causing tensile stress in it.

However, the method described above was slightly modified. The innovation followed from the assumption that the shrinkage of the surface layer is not in real conditions completely restrained. Thus, the experiment allowed for a certain degree of shrinkage which would be proportional to the force restraining the shrinkage. This was realised by the use of a spring dynamometer in which axial deformation of 0.0158 mm is caused by a force of 20 N.

The stress value in a sample was calculated as the quotient of the force, measured by a dynamometer by the surface area of the cross-section perpendicular to the direction of the force action.

After Perkitny [10], the following types of strains were dinstinguished:

MS - moisture strain of the sample whose shrinkage was unrestrained,ε_w

$$\varepsilon_w = \frac{l_p - l_{w_i}}{l_p} \cdot 100[\%]$$

where:

l_p - the initial length of a sample, mm

l_{w_i} - length of a sample, when moisture content reaches the value w_i, mm

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RMMS - real mechanical-moisture real strain of the sample where shrinkage was restrained by the dynamometer (the real value of the shrinkage of the restrained sample), $\varepsilon_{mw\,r}$

$$\varepsilon_{mwr} = \frac{l_p - l_{k_h}}{l_p} \cdot 100[\%]$$

where:

l_p - length of the sample whose shrinkage was unrstrained, mm

l_{k_h} - final length of a sample whose shrinkage was unrestrained, mm

LMMS - latent (apparent) mechanical-moisture strain, caused by restraining the shrinkage of the sample (apparent elongation of the sample equal to the value of the shrinkage which had been restrained), $\varepsilon_{mw\,u}$

$$\varepsilon_{mwu} = \varepsilon_w - \varepsilon_{mwr}\ [\%]$$

For each temperature, five experiments were made. The experiments studied desorption stresses and mechanical moisture strain in the tangential direction (3 samples), changes in the moisture content of the samples in the drying process (1 sample) and changes in the moisture strain of wood in the tangential direction (2 samples). The studies of stresses and strains were made only in the tangential direction of wood due to the following reasons:

- the desorption shrinkage in this direction is the greatest; therefore the stresses generated by the attempts to restrain the shrinkage are of the highest values,
- greater values of shrinkage and stress are easily measurable,
- stresses in tangential direction are practically more significant since the damages they induce in the drying process are most common.

The experiments in which shrinkage was restrained had been continued until a marked stress stagnation or decrease occurred.

RESULTS

In all the experiments it was possible to dry both birch and aspen samples restraining their shrinkage up to any final moisture content value without causing failure. It is worth mentioning that in earlier research [18] beech samples failed at about 20 percent moisture content, irrespective of the equilibrium moisture content and the method of restraining desorption shrinkage in the wood. Desorption strains occurred in birch and aspen samples at very high MC levels, considerably above the fiber saturation point. Desorption stresses and moisture strains in juvenile birch samplesoccurred at 45 percent moisture content, while aspen as well as mature birch at moisture content of 60 percent. This confirms the observation by Stevens that shrinkage of wood begins at MC above the fiber satuaration point [7].

The lowest values of desorption stresses appeared in juvenile birch wood samples. This was to be expected because stress value increases with the modulus of elasticity, and thus also with the density of wood, which in the case of juvenile birch wood was the lowest (as indicated in Table 1).

The influence of temperature on the rate and the value of desorption stresses was not as pronounced as expected, yet the regularity previously observed by other researchers [9] that the higher the temperature the lower the stresses was observed in mature birch wood samples, at the butt end, and – to a lesser degree – in juvenile birch samples. The highest stress values in aspen occurred in the samples from the outer parts of the cross-section of the log, which were being dried at 30°C. The average stress was then $77.6 \cdot 10^{-2}$ MPa. During drying at the temperature of 70°C, the stress value was 68.8×10^{-2} MPa. The figures below represent desorption stresses as a function of moisture content depending on temperature in birch (Fig. 2, 3) and in aspen (Fig. 4, 5).

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Fig. 2. Effect of the drying temperature on the value and rate of desorption stresses in mature birch wood

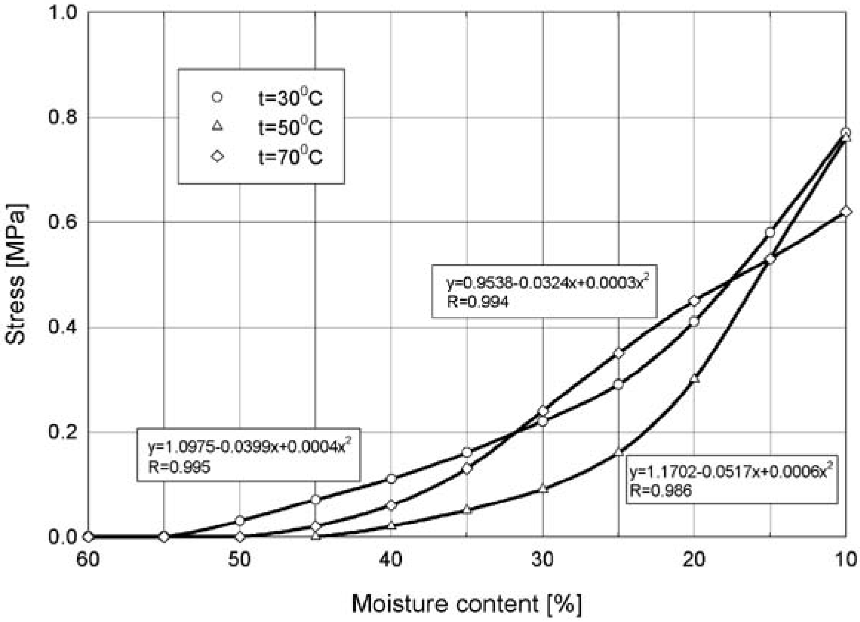

Fig. 3. Effect of the drying temperature on the value and rate of desorption stresses in juvenile birch wood

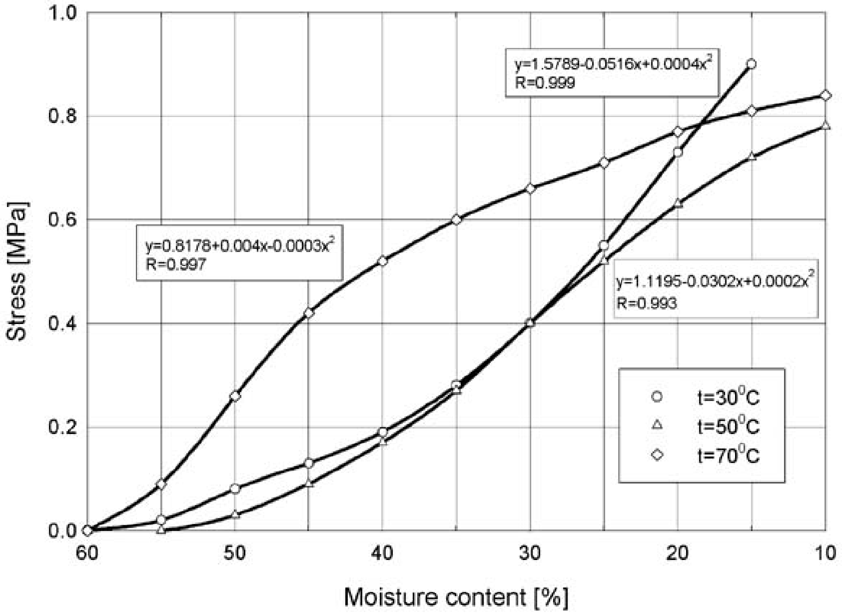

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Fig. 4. Effect of the drying temperature on the value and rate of desorption stresses in the physiologically older aspen wood

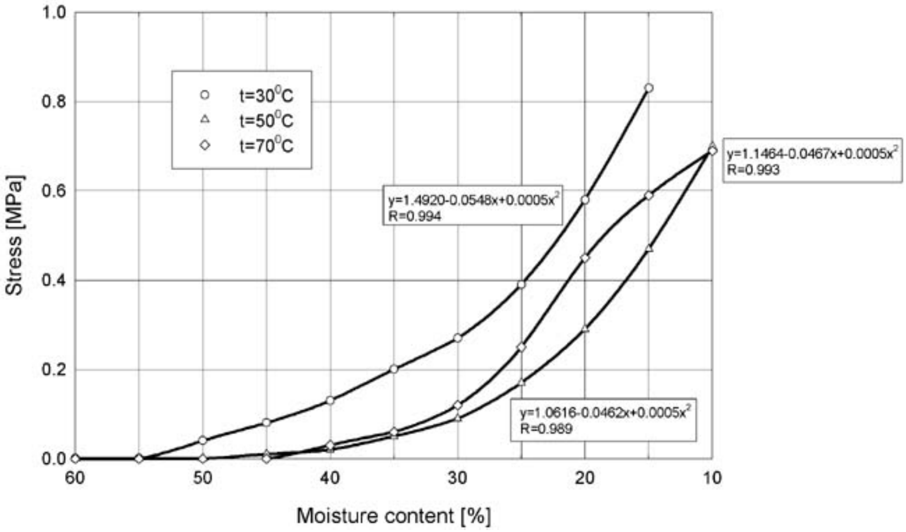
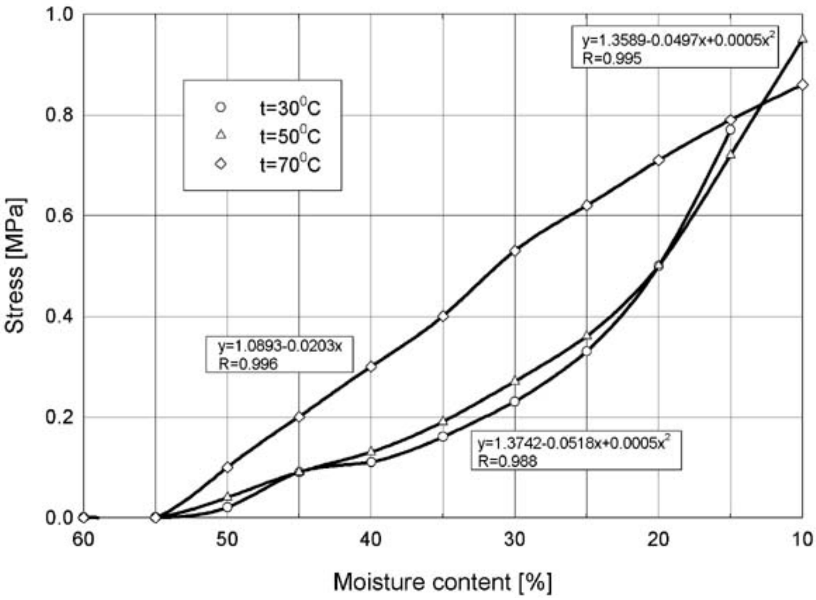


Fig. 5. Effect of the drying temperature on the value and rate of desorption stresses in the physiologically younger aspen wood



The course of the stress curve in Figures 2, 3 seems to suggest that in juvenile birch wood stress relaxation is more pronounced than in mature birch wood. This has been supported by the analysis of mechanical-moisture strains, both real and latent. The RMMS and LMMS values presented in Table 2 show that at a higher temperature the real mechanical-moisture strain was lower than at the lower temperature although in the former case the value of the stress was similar or even lower (at the same moisture contents). It needs to be emphasized that in juvenile samples the 0.12% RMMS at 70°C points to wood deformability higher by about 30% than in the case of RMMS of 0.15% at 30°C and 50°C. Following the analysis of the strains, it has been concluded that the effect of the drying temperature and the age of the wood tissue on stresses and strains would have been more conspicuous if samples with active length (between the grips) longer than 30 mm had been used for the experiment. This condition, however, was very difficult to fulfil as it was essential for the length of the samples to be exactly parallel to the tangential direction. In the case of juvenile birch samples, 30 mm was the maximum length obtainable.

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Table 2. Effect of the drying temperature on the values of mechanical-moisture strain (real – RMMS and apparent – LMMS) in the samples of juvenile and mature birch wood

Kind of the birch wood	Moisture content [%]	Drying temperature [°C]	Strains and its dispersion coefficients					
			RMMS			LMMS		
			averge	standard deviation	variability coefficient	average	standard deviation	variability coefficient
			%	%	%	%	%	%
Mature	30	30	0.10	6.2	0.006	1.45	5.8	0.084
		50	0.10	8.1	0.008	1.45	6.2	0.090
		70	0.09	12.0	0.011	1.46	10.3	0.150
	20	30	0.18	7.3	0.013	3.07	5.8	0.178
		50	0.16	6.4	0.010	3.09	10.2	0.315
		70	0.14	10.4	0.015	3.11	12.0	0.373
	15	30	0.22	12.3	0.027	4.38	12.0	0.526
		50	0.19	11.5	0.022	4.41	14.2	0.626
		70	0.16	16.2	0.026	4.44	14.8	0.657
Juvenile	30	30	0.09	5.8	0.005	1.51	6.4	0.097
		50	0.07	10.2	0.007	1.53	8.6	0.132
		70	0.06	12.2	0.007	1.54	10.2	0.157
	20	30	0.10	12.4	0.012	2.90	14.1	0.409
		50	0.10	10.9	0.011	2.90	12.3	0.357
		70	0.10	14.5	0.015	2.90	14.5	0.421
	15	30	0.15	14.4	0.022	4.00	12.8	0.512
		50	0.15	16.2	0.024	4.00	15.0	0.600
		70	0.12	18.0	0.022	4.03	16.6	0.669

The differences between the rates and the absolute values of the stresses in the aspen samples under comparison, represented in Figures 4, 5, are unexpectedly big. The stress values were considerably higher in the samples obtained between the 15th and the 17th growth ring, that is in the physiologically older wood, than in the samples cut between the 20th and the 22nd growth ring. It is worth mentioning that the same age zone in the American aspen had the characteristics of juvenile wood [14]. It seems probable that the phenomenon demonstrated here may be accounted for by the regularity described by Porzonny and Tischler [11], whose concluded that the strength properties of pine wood increase from the core, attain the maximum value in the intermediate zone only to decrease again towards the outer shell.

The present analysis of aspen wood suggests that the wood that is physiologically younger, closer to the outer shell, is "softer", is more susceptible to deformations. This is implied by the RMMS and LMMS values for aspen samples, presented in Table 3. The variation in strain is related to the differentiation between juvenile and mature birch wood. The physiologically younger aspen wood reacted to stresses in a way similar to juvenile birch wood.

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Table 3. Effect of the drying temperature on the values of mechanical-moisture strain (real – RMMS and apparent – LMMS) in aspen samples of different physiological age

Age of the aspen wood (years)	Moisture content [%]	Drying temperature [°C]	Strains and its dispersion coefficients					
			RMMS			LMMS		
			average	standard deviation	variability coefficient	average	standard deviation	variability coeffcient
			%	%	%	%	%	%
15 – 17	30	30	0.12	8.3	0.010	2.18	10.6	0.231
		50	0.02	7.4	0.001	2.28	14.5	0.331
		70	0.07	12.1	0.008	2.23	15.0	0.335
	20	30	0.25	9.8	0.025	3.80	12.0	0.456
		50	0.10	9.6	0.010	3.95	8,.	0.348
		70	0.12	12.8	0.015	3.93	12.6	0.495
	15	30	0.30	16.3	0.049	4.85	12.8	0.621
		50	0.15	18.4	0.028	5.15	16.0	0.824
		70	0.15	14.6	0.022	5.20	14.0	0.728
20 -22	30	30	0.12	12.0	0.014	1.63	10.2	0.166
		50	0.13	9.6	0.012	1.77	10.8	0.191
		70	0.15	17.2	0.026	1.80	16.5	0.297
	20	30	018	15.4	0.028	2.97	14.2	0.422
		50	0.15	12.8	0.019	3.00	15.2	0.456
		70	0.22	16.1	0.035	2.93	12.8	0.375
	15	30	0.30	17.8	0.053	3.95	16.0	0.632
		50	0.22	14.2	0.031	4.03	13.8	0.556
		70	0.23	16.9	0.039	4.02	15.8	0.635

Some other conclusions concerning the relevance of the age of aspen and birch wood for the rate and the values of desorption stresses are illustrated in Figures 2-5. Quite unexpectedly, especially in view of current research, the figures clearly point to the greater intensity of desorption stresses at the temperature of 70°C than at 30°C. This observation is particularly relevant in the context of the above-mentioned, well-known fact that the value of stresses is inversely proportional to the drying temperature. Formulating the interdependence as above may give rise to the erroneous conclusion that the higher the drying temperature, the less risk of shrinkage cracks is involved, while in fact the higher temperatures of drying usually, though not always, involve a greater rate of desorption and a more abrupt reaction of wood to restraint, and thus a greater intensity of stress increase. The greater intensity of stress increase accompanied by a higher drying temperature escalate creep development, that is they speed up wood deformation leading to structural damage.

Summing up, it seems justified - for practical reasons - to support Kass' thesis that it is the value of wood strain rather than the desorption stress value that is crucial to the phenomenon of wood failure. This conclusion is worth emphasizing in view of the fact that it has long been the aim of many research projects to find a way to measure the value of desorption stresses in wood in order to discover the presumably ultimate solution to the problem of shrinkage cracks.

CONCLUSIONS

1. The rate of development and the absolute values of desorption stresses and mechanical-moisture strains occurring in birch are different in juvenile and in mature wood.
2. The rate of development and the absolute values of desorption stresses and mechanical-moisture strains occurring in aspen wood depend on the physiological age of the wood tissue.
3. The physiologically younger aspen wood and juvenile birch wood are both characterised by greater susceptability to strains caused by desorption stresses.
4. The maximum values of desorption stresses in birch and aspen samples were the highest during drying at the temperature of 30°C, yet it was the initial stage of sample drying process (at 70°C) that may be characterised by the greatest rate of stress development.
5. The shrinkage process both in birch and in aspen began when the moisture content was considerably above the fiber saturation point.

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Henryk Widłak
Katedra Hydrotermicznej Obróbki i Modyfikacji Drewna
Akademia Rolnicza im. A. Cieszkowskiego w Poznaniu
Ul. Wojska Polskiego 38/42
60-627 Poznań, (61)8487444, (61)8487443
hwidlak@woodcock.au.poznan.pl

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