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VARIATION IN THE MICROFIBRIL ANGLE IN THE TANGENTIAL WALLS OF THE LARCH WOOD TRACHEIDS (*LARIX DECIDUA* MILL.) FROM PLANTATION CULTURE

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SYNOPSIS. The microfibril angle (MFA) has been examined in the tangent walls of tracheids in the larch wood from a plantation culture, along the width of individual annual rings. MFA measurements have been made by a computer image analyser in tangent preparations cut out of the samples earlier subjected to thermal treatment at 85°C in a 20% solution of $Cu(NO_3)_2$ for 24 hours.

KEY WORDS: larch wood, plantation culture, annual ring, microfibril angle

INTRODUCTION

As has been already established, the microfibril angle in the S_2 layer the secondary cell wall relative to the longitudinal axis of the cell tracheids depends on the cambial age of the annual rings, the cell position in the ring and at the height of the tree and on the ecological conditions of the tree growth in a wide sense, (e.g. Cave and Walker 1994, Ying et al. 1994, Sahlberg et al. 1997, Lichtenegger et al. 1999, Anagnost et al. 2002). In general, the microfibril angle with respect to the longitudinal axis is greater in the walls of the primary cells, produced at the beginning of the vegetation season, than in those produced at the end of the vegetation season (e.g. Abe et al. 1992, Anagnost et al. 2002, Fabisiak et al. 2006 b). A decrease in MFA as a function of the width of the annual rings is significant only in the zone of mature wood. In the zone of juvenile wood the variation of MFA in the cell walls within a single annual ring is small (e.g. McMillin 1973, Lichtenegger et al. 1999, Fabisiak et al. 2006 b, Moliński et al. 2007). The MFA value averaged in an individual annual rings decreases with increasing cambial age (e.g. Zobel and van Buijtenen 1989, Stuart and Evans 1995, Donaldson 1992, Lichtenegger et al. 1999).

The differentiation on the mean value of MFA in the cell wall along the trees radius is distinctly manifested by the shrinkage of the wood along the grain. The juvenile wood characterized with a much greater MFA with respect to longitudinal axis cell, shrinks along the longitudinal direction a few times more than the mature wood (e.g. Barber 1968, Cave 1972, Meylan 1972, Dinwoodie 1981, Ying et al. 1994). In the process of drying the individual fibres in the cellulose pulp show the greater susceptibility to rotation the greater MFA in the secondary cell wall S_2 (e.g. Burgeret et al. 2005).

The orientation of microfibrils in the cell wall influences the mechanical properties of individual fibres and the whole wood tissue. As indicated by many authors, the elasticity constants of wood and its strength, measured parallel to the grain take the higher values the smaller the angle of the helix inclination to the longitudinal axis of the cell (e.g. Cave 1976, Dinwoodie 1981, Cave and Walker 1994, Reiterer et al. 1999, Groom et al. 2002). For spruce wood (*Picea abies*), Reiterer et al. (1999) have shown that the tensile strength of the cell walls along the grain, the elasticity modulus and the strain at failure of the early and latewood tracheids are the same if the MFA value in these two types of cell is the same. Sedighi-Gilani and Navi (2007), who studied the tensile strength of individual tracheids along the fibres, have reported that the relationship between the mean value of MFA and the mechanical strength is not so straightforward. They believe that the reason is the variation in the MFA values (e.g. Anagnost et al. 2002, Khalili et al. 2001, Sedighi-Gilani et al. 2005 and 2006) over the length of individual tracheids and local damages of the matrix, consequently, the stress-strain relationship for individual tracheids and solid wood samples is more complex. Because of the variation in the MFA in the cell walls, the pattern of internal stress in the loaded wood is very complex and the mechanism of the wood failure is complicated.

In view of the above determination, the variation in MFA in the cell walls is believed to be of great significance. Detail recognition of MFA variations within individual annual rings and along the tree radius can be a good indicator of wood inhomogeneity and differentiation of its quality as the raw material for production of cellulose pulp and construction material.

The Department of Wood Science, at the Agricultural University, Poznań, for many years has conducted research variation in selected structural and physical properties of larch wood obtained from plantation culture (Fabisiak et al. 2004, 2006 a and b). As has been established the larch wood from plantation cultures are characterized by the macrostructural features and density similar to those of the dominant trees in the managed stand.

However, having the same density the wood coming from the plantation tree was characterised by about 15% lower compression strength along the grain and by about the same lower value of the elasticity modulus, slightly lower transversal shrinkage and by 40% greater longitudinal shrinkage than the wood from the managed stand. The study reported is a continuation of this research and concerns the variation in MFA as a function of the width of individual annual rings and their cambial age in larch wood (*Larix decidua* Mill.) from plantation culture.

MATERIAL AND METHODS

The MFA measurements were made in a disc cut out at the breast high from a larch wood coming from the plantation established in 1979 in Zielonka Forest Range, by the Experimental Forestry Station of the Agricultural University of Poznań (Moliński et al. 2007). The disk came from the same material in which the variation of microstructural features and some physical properties of this wood had been earlier studied. The plantation was established using the genetically selected planting material on a specially prepared habitat. The trees in this plantation stand were characterized by similar height, and the disk used in the study came from a tree growing in the spacing of 5 × 5 m, 19.9 m height and the breast height diameter in the bark was 32 cm.

From the disk of the height along the grain of about 3 cm, a slab was cut out in the north-south direction; the width of the slab was 5 cm. The front surfaces of the slab were sanding. The widths of the annual rings and zone of latewood were measured by a attachment made by BIOTRONIK to the accuracy of 0.01 mm. From the southern part of the disk a strip of the tangential width and height along the grain of 5 mm, was cut out. The strip was divided into three parts of roughly the same size. These three samples were heated for 24 h in a 20% solution of $Cu(NO_3)_2$ at 85°C. After this time the solution was poured out and the samples were flooded with distilled water and boiled for 3 h at 100°C. The above briefly described procedure, a modification of the method proposed by Wang et al. (2001), was applied to reveal the arrangement of the microfibrils in the cell walls. After this treatment, from the even annual rings (counted from the pith) the tangential, microtome slips of about 20 µm in thickness were cut off to prepare microscope preparations. Depending on the width of the annual rings the number

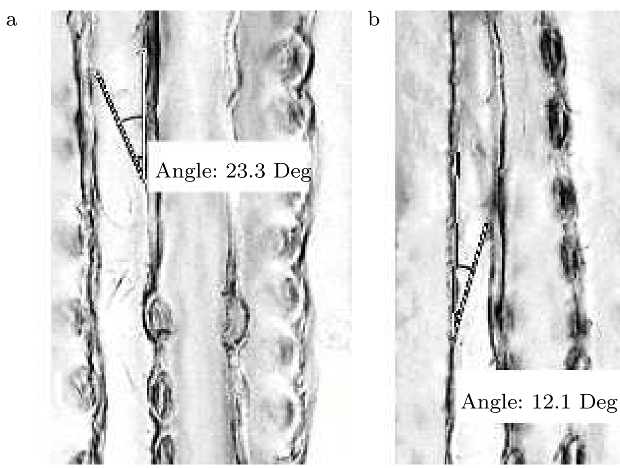

Fig. 1. The tangent slices obtained after exposure to copper nitrate $Cu(NO_3)_2$. The cracks along the microfibrils are well seen: a – large MFA values in early wood, b – small MFA in late wood

of the preparations obtained was from 5 to 14. Measurements of MFA were made on the tangent walls of the tracheids with the use of a computer image analyser (Fig. 1). In each preparation from 20 to 30 MFAs were measured, but no more than two MFAs in one tracheid.

RESULTS AND ANALYSIS

In view of the fact that the arrangement of the microfibrils in the tracheid walls depends not only by the tracheid position in the annual ring but also by their cambial age, at first the macrostructure of the wood was studied. The results are illustrated in Figure 2. In consistence with the earlier published data (Fabisiak et al. 2006 a), the results have shown that the juvenile zone comprised the first 10 annual rings, counted from the pith. The subsequent 8 annual rings can be treated as the maturing tissue and the others make the mature tissue.

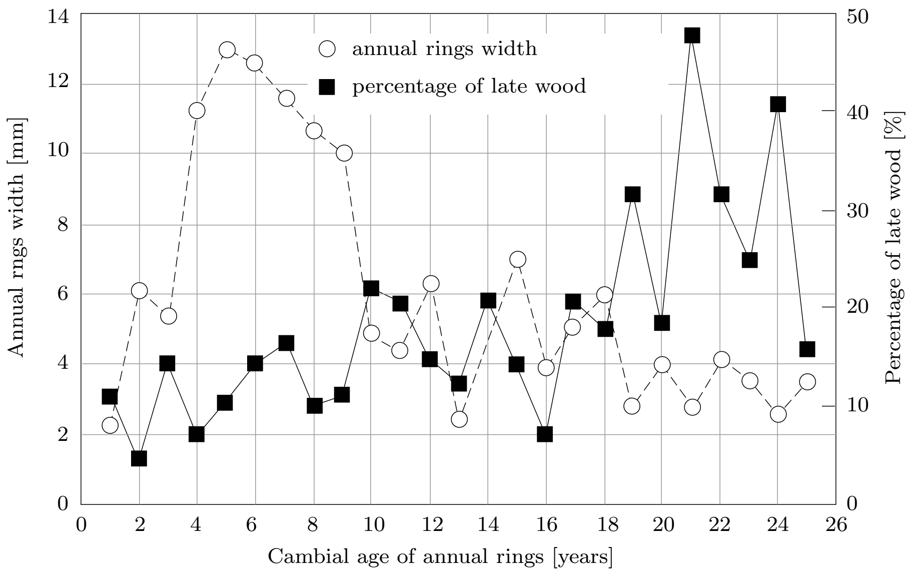

Fig. 2. The width of annual rings and the contribution of late wood in larch wood (*Larix decidua* Mill.) from plantations culture

The variation in MFA in these three types of tissue, on the basis of the measurements at different sites of the annual rings, is illustrated in Table 1. The Table presents the results obtained only for three rings representing a tissue of a given type: for the 8th ring of the juvenile tissue, 16th ring of the maturing tissue and 24th ring of the mature tissue. The MFA variation in these rings is also graphically presented in Figures 3-5, in the form of the frequencies of given MFA values versus the MFA values in a two-degree scaling.

The presentation of results was limited to the above mentioned rings because the variation of MFA along the width of the remaining rings was similar. The

Table 1. MFA values in early and late wood tracheids along the width of selected annual rings of larch wood and basic statistical characteristics

Cambial age of annual rings	Annual ring zone	Position in width of annual rings	x_{min}	x	x_{max}	± s	± m	V
		mm	deg					%
8	early wood	0.0	28.40	36.15	41.70	3.96	0.84	10.96
		1.0	19.20	25.24	31.90	2.70	0.62	10.69
		2.0	21.10	24.52	28.80	2.25	0.44	9.17
		3.0	18.00	23.32	27.70	2.16	0.42	9.25
		4.0	18.60	24.46	32.20	3.62	0.71	14.81
		5.0	19.00	22.90	26.10	1.84	0.36	8.03
		6.0	19.60	23.88	30.00	2.69	0.53	11.25
		6.5	17.60	23.35	31.60	3.86	0.76	16.54
		7.0	19.10	24.55	29.80	3.11	0.61	12.66
		8.0	15.60	22.48	26.70	3.11	0.61	13.83
		9.0	15.20	18.81	23.80	2.55	0.50	13.54
	late wood	9.5	10.20	16.40	21.40	3.01	0.59	18.56
		10.0	10.70	14.41	17.70	1.88	0.37	13.06
		10.5	6.80	12.92	15.90	2.48	0.49	19.23
16	early wood	0	25.70	31.21	41.40	4.01	0.73	12.83
		0.5	19.30	24.02	28.40	2.44	0.45	10.16
		1	16.60	21.31	26.40	2.82	0.52	13.24
		2.2	13.30	20.00	26.30	3.26	0.60	16.30
		2.9	15.50	21.35	25.80	3.11	0.57	14.58
	late wood	3.2	15.00	18.54	24.40	2.49	0.46	13.46
		3.6	13.60	18.22	24.30	3.06	0.56	16.81
24	early wood	0	19.84	29.45	40.99	5.74	1.05	19.48
		0.6	19.32	25.98	33.00	3.32	0.61	12.79
		1	15.37	22.40	31.56	4.24	0.77	18.93
	late wood	1.5	12.34	19.60	24.87	3.23	0.59	16.49
		2.1	14.18	18.97	27.04	3.48	0.63	18.33

± s – standard deviation, ± m – standard error, V – variation coefficient.

total number of MFA measured was 2848, in 12 annual rings from which 103 preparations were made.

Analysis of the data given in Table 1 and displayed in Figures 3-5 has shown that the MFA values in the S_2 layer in the tangent walls of tracheids at more or less the same distance from the annual ring border, measured in individual preparations, are not the constant. The variation coefficient of MFA calculated for the MFA measured in the individual preparations does not exceed 20%. A rather high range of MFA within individual preparations confirmed the earlier results for the wood of Pinus taeda, obtained by Anagnost et al. (2005) who reported the MFA fluctuation in the range 3-29° for earlywood and in the range 3.7-21° for latewood. In our study the highest MFA of about 41° was found in the first earlywood tracheids in all annual rings. More or less the constant value of maximum MFA in the first tracheids, independent of the cambial age of the annual rings, is

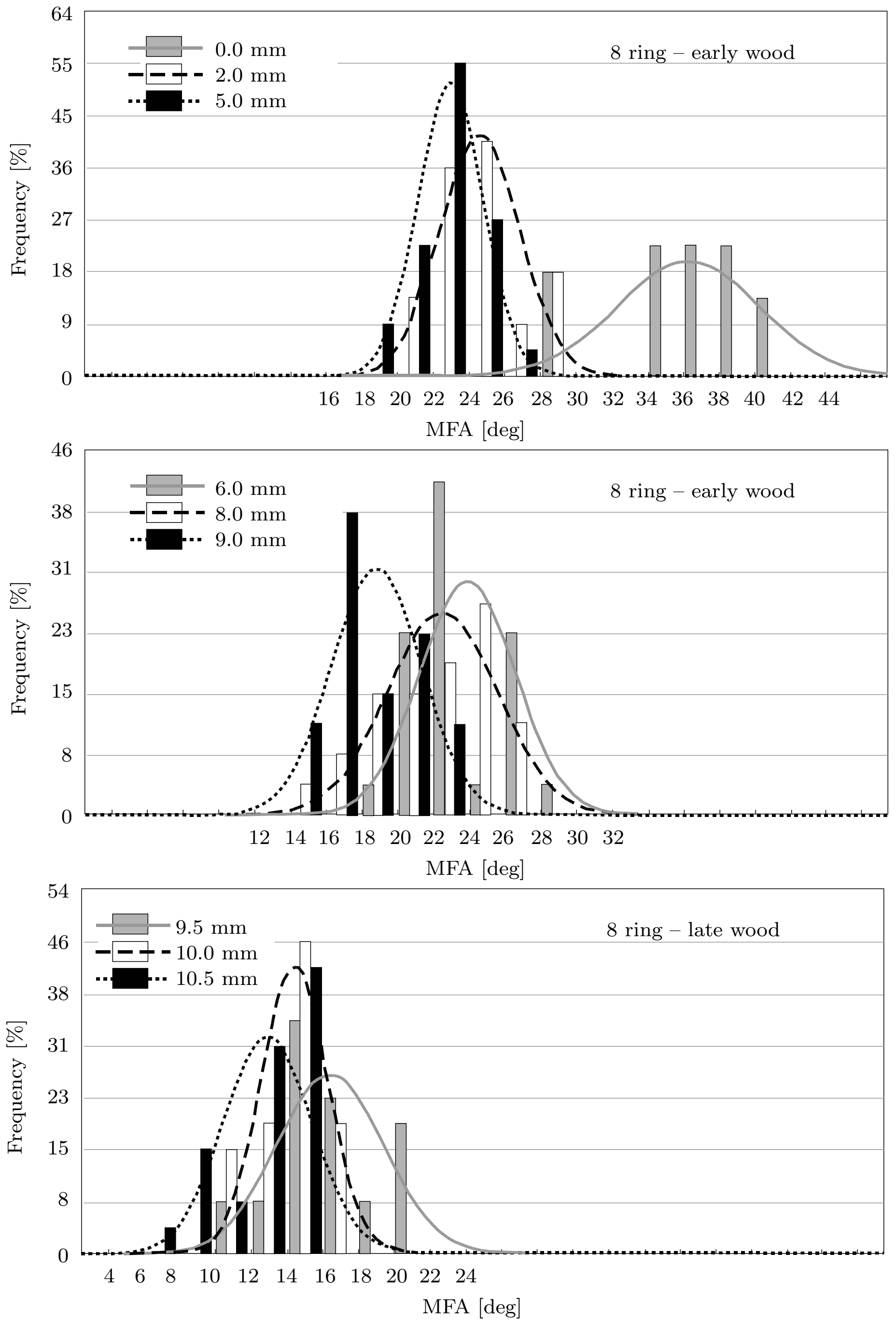

Fig. 3. Variation in the MFA in tangential walls of tracheids versus their location within of 8 annual rings in larch wood (*Larix decidua* Mill.) from plantation culture

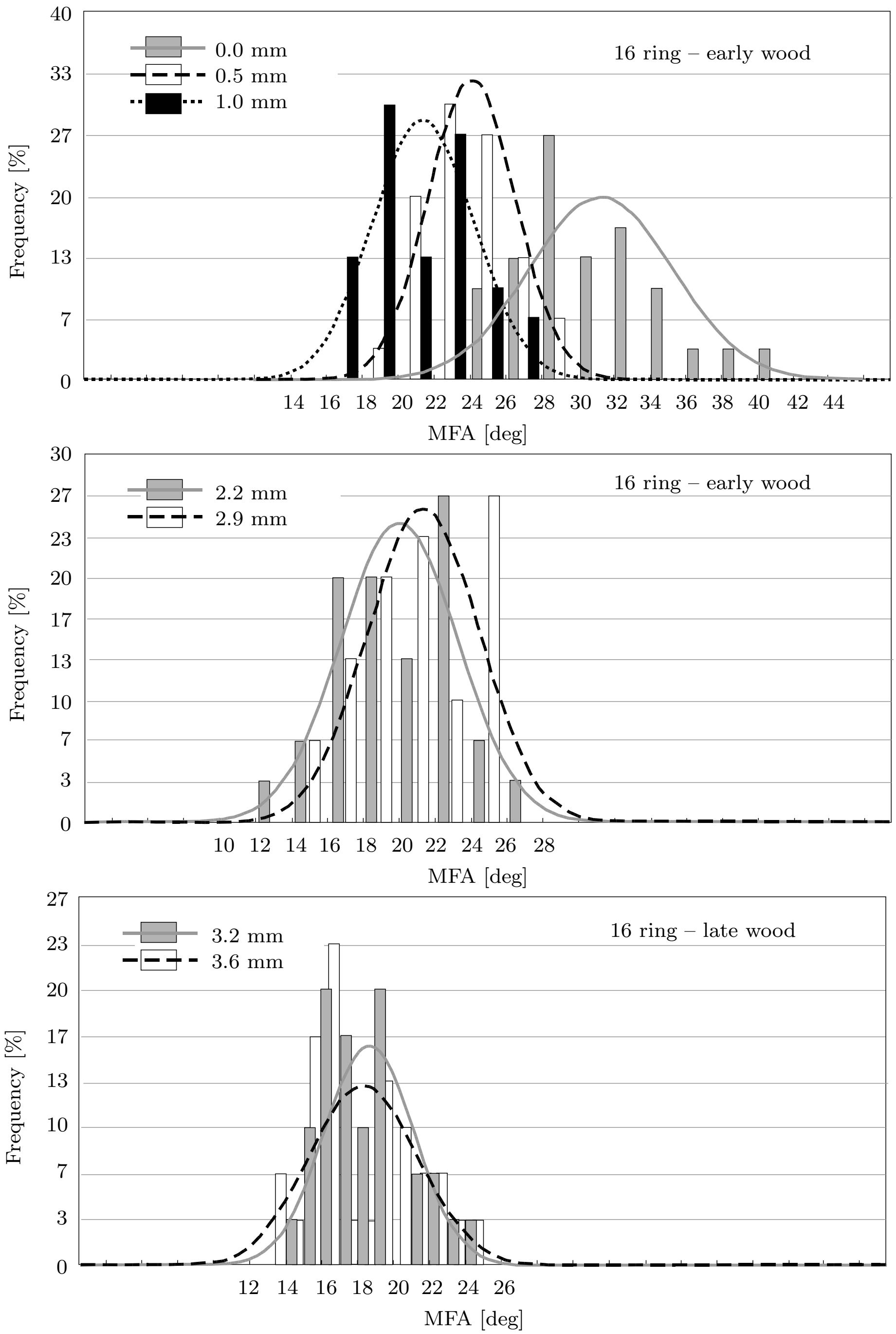

Fig. 4. Variation in the MFA in tangential walls of tracheids versus their location within of 16 annual rings in larch wood (*Larix decidua* Mill.) from plantation culture

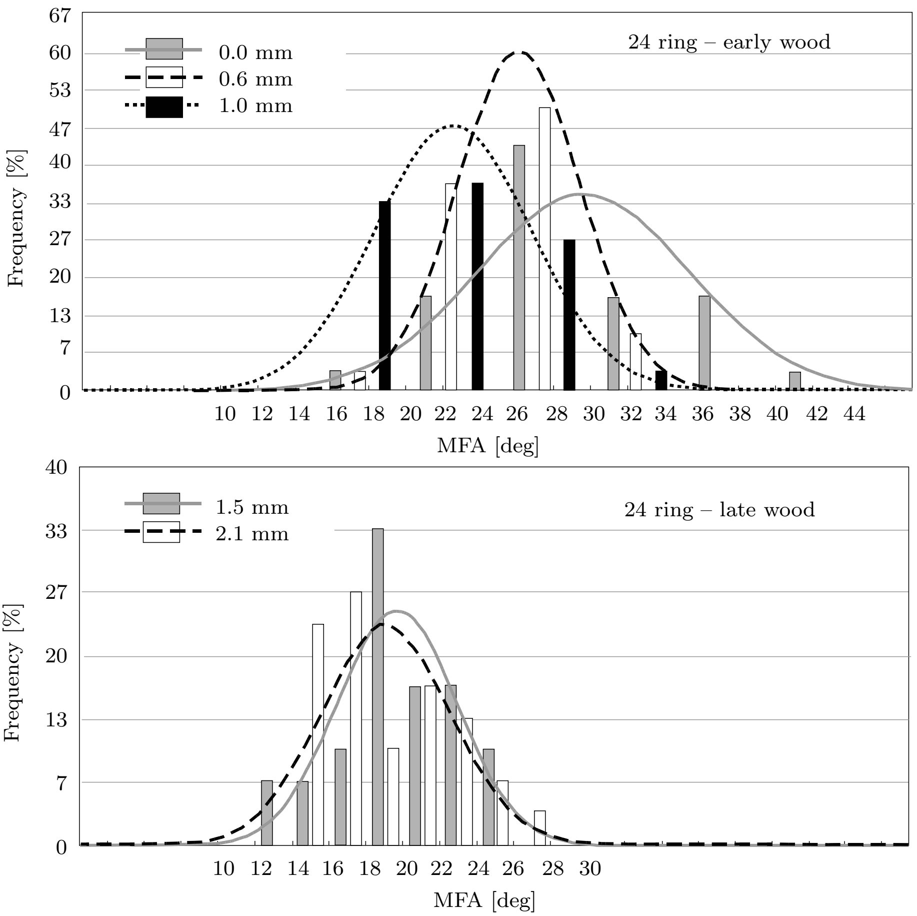

Fig. 5. Variation in the MFA in tangential walls of tracheids versus their location within of 24 annual rings in larch wood (*Larix decidua* Mill.) from plantation culture

probably related to the presence of small bordered pits in the tangential walls of the tracheids as near the pits the MFA values are much greater (e.g. Anagnost et al. 2002).

The mean of MFA values in individual preparations decrease from the beginning of the annual rings to end of the rings. The highest mean MFA are found in the first early tracheids, while the lowest MFA in the late tracheids at the end of the ring. For example, in the 8th ring the mean MFA in the tracheids formed at the beginning of the vegetation season was 36°, while in the last tracheids of the latewood it was of about 13°. Thus, the mean value of MFA in this ring decreased almost 2.8 times. In subsequent rings the MFA changes revealed the same tendency, but the decrease in the MFA mean values was smaller. In the 16th annual ring, at the beginning of the earlywood the mean MFA was 31.2°, and in the last tracheids of the latewood it was 18.2°. In the 24th ring the corresponding values were 29.4° and 19°. These data confirm the earlier reports on the decrease in the

MFA values along the width of annual rings (e.g. ABE et AL. 1992, ANAGNOST 2002, ANAGNOST et AL. 2005) and with increasing cambial age of the rings but only in the tracheids formed at the beginning of the vegetation season. In the last latewood preparations, from the 16th and 24th rings, the mean MFA values were by about 6° greater than those from the 8th annual ring. So high mean MFA values are attributed to the presence of the reaction tracheids in these rings. The reaction tracheids occurred not only in the latewood but also in earlywood in all annual rings starting from the 10th to the circumference. As in the material studied the reaction tissue was generated only through a certain period in the vegetation seasons, this process did not bring a significant increase in the contribution of the latewood in the annual rings 10-24. The illustration of the short period of the reaction tissue formation is given in Figure 6 a, showing a microscopic image of the cross-section of the 18th annual ring. The reaction tissue takes a rather narrow zone formed at the end of the earlywood growth (Fig. 6 b). The microfibrils in the tangential walls of the reaction tracheids (Fig. 6 c) are distinct and make angles of about 40° relative to the longitudinal axis of the cell.

a b c

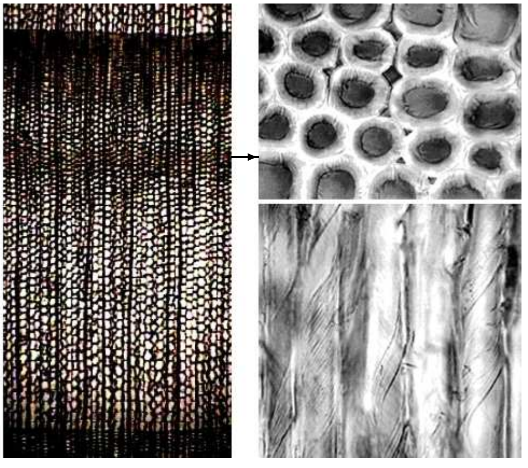

Fig. 6. Microscopic image of the 18th annual ring: a – cross-section whole of annual ring, narrow zone of reaction tissue formed at the end early wood, b – cross-section reaction tissue, c – course of microfibril in tracheids of reaction wood

Because of high MFA values in these tracheids the mean MFA values calculated for the early- and latewood in individual rings showed rather insignificant changes along the radius of the tree (Fig. 7).

The occurrence of narrow zones of the reaction tissue in the 10th to 24th rings was also the reason why the mean MFA value calculated for individual annual rings decreased insignificantly in the direction from the pith to the circumference; for the 2nd ring it was 24° while for the 22nd it was 21.4°.

This small change in the MFA value along the radius of the tree can explain a much smaller effect of the density on the elasticity modulus along the grains in the wood from plantations than the same effect in the wood from a managed

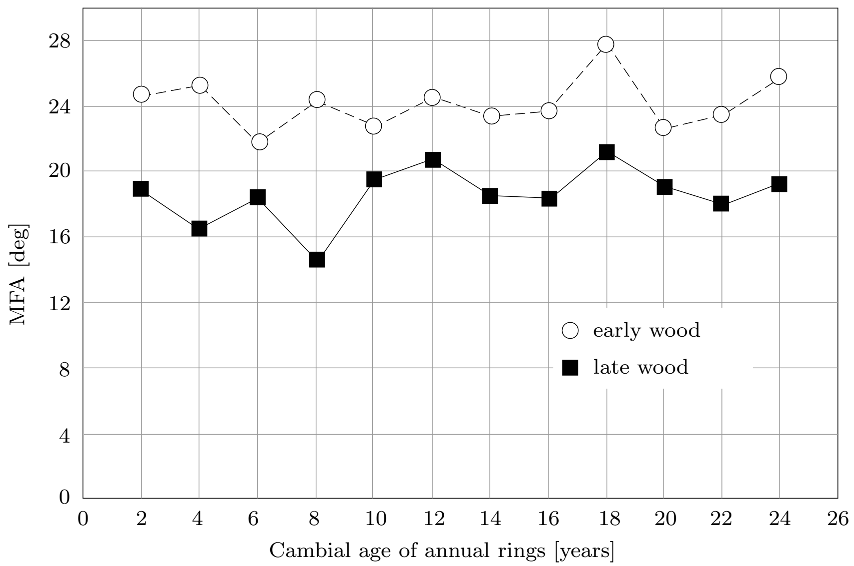

Fig. 7. Radial variation of mean MFA in early and late wood in individual annual rings of larch wood (*Larix decidua* Mill.) from plantation culture

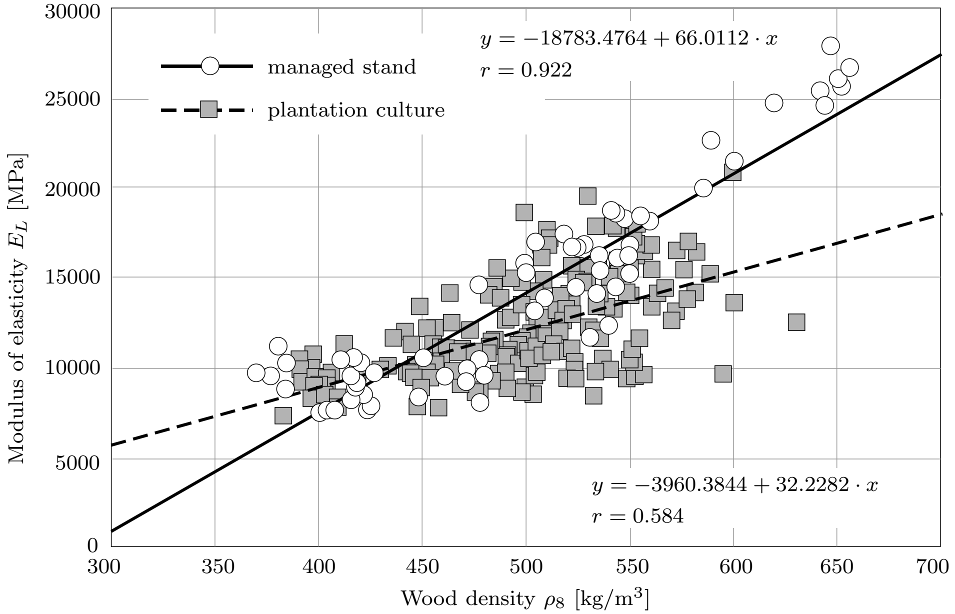

Fig. 8. Modulus of elasticity along the grain versus wood density of larch wood (*Larix decidua* Mill.) from plantation culture and managed stand

stand. The studies of the effect had been performed earlier on compression of the samples obtained from the 0.7 m of blocks cut out directly above the breast height of the respective trees. The results as a function of the wood density are shown in Figure 8. As follows from these results, in the plantation wood the increase in the density from 400 to 600 kg/m^3 (by 50%) caused an increase in the elasticity modulus by about 70%, while in the wood from the management stand the same increase in density caused the elasticity modulus to increase by 173%. In the wood from the managed stand the mean MFA in individual annual rings decreased from about 30° in the 2nd ring to 20° in the 18th ring (Fabisiak et al. 2006 b). Therefore, the differences in the effect of the wood density on the elasticity modulus along the grain can be explained by the differences in the variation of the ring mean MFA values along the tree radius. In the samples taken from near the pith, characterised by low density, the elasticity modulus of the wood from the managed stand was lower than that in the plantation wood. In the near pith zone MFA took greater values in the wood from the managed stand. In the higher density samples, coming from the zones closer to the circumference, the mean MFA in the wood from the managed stand was lower so the elasticity modulus was greater than in the analogous samples from the plantation wood. The results indicate the important role of the MFA variation in characterization of the wood properties and confirm the earlier observations by other authors that the wood density is not sufficiently informative about the wood technological quality.

CONCLUSIONS

1. MFA in the S_2 layer in the tangential walls of larch wood tracheids at more or less the same distance from the annual ring border is not constant. The variation coefficient calculated for the MFA in individual preparations does not exceed 20%.
2. The mean of MFA values in individual preparations decrease from beginning of the annual rings to end of the rings. The highest mean MFA value was found in the first earlywood tracheids, while the lowest in the late tracheids at the end of the ring.
3. The mean MFA values for the early- and latewood change insignificantly along the tree radius.
4. The changes in the mean MFA along the tree radius are well correlated with the changes in the elasticity modulus along the grain.

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Received in August 2007

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