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IMPACT OF LOADING RATE ON MOR AND MOE OF THE PARTICLEBOARD APPLYING A STANDARD BENDING TEST

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ABSTRACT

According to the European Standard EN 310:1993 for determination of the MOE and MOR of wood-based panels, it is necessary to select the loading rate on test samples, so that the maximum load is reached within 60 ± 30s (30-90s). During the test the sample often breaks after only a few seconds, which is far below the required lower time limit. The results obtained for these samples should be discarded; otherwise the resulting values for MOR and MOE will be biased.

This paper is focused on the impact of loading rate on MOR and MOE of the particleboard in a standard bending test. The test was carried out in two ways: (i) by using the maximum load that can be obtained on the test device, and (ii) by applying a much lower load, for which the sample failure occurs at the prescribed time interval. In either case, the given time for achieving the maximum load was the same, which resulted in significant differences in loading rates. The obtained results for MOR and MOE were compared. Differences in the values obtained in the two applied loading rates indicate a potential error that can be made in determining MOR and MOE if the requirement regarding the time prescribed to reach the maximum force is not met.

Key words: particleboard, bending test, MOE, MOR, maximum load

1. INTRODUCTION

When calculating the elements of particleboard in wooden structures, maximum dimensions of the structural elements should be defined either according to the sizes of the allowed deflections (stiffness criterion) or permissible strength (strength criterion). The most critical values for the construction are mostly the modulus of elasticity in the bending test (MOE) and bending strength (modulus of rupture – MOR). MOE and MOR values of wood based panels depend on the following: (a) the type of particle or strand, its structure (the ratio of layers), the size of particles (Suzuki, and Takeda, 2000), the particles direction (Sumardi, Kojima, Suzuki, 2008), the degree of anisotropy (Lekhnitskii, 1984 Ashkenazi, 1978; Ambartsumyan, 1970; Timoshenko and Woinowsky-Krieger, 1959); (b) density and vertical profile of density (Kelly, 1977; Kollmann and Cote, 1984; Xu, 1999; Chen, Du, Wellwood, 2010; Barbuta, Barbuta, Blanchet, Cloutier, 2012); and (c) the amount and type of adhesive (Hraszky i Kral, 2009). In addition, MOE and MOR of a wood based panel are influenced by the factors related to the test method: the position of the sample in relation to the longitudinal axis of the panel (Jin and Dai, 2010); the number and position of the deflectometer and the calculation method (Souza et al., 2014; Tsen and ESEN, Hüseyin YÖRÜR Jumaat, 2012); the form of specimens (beam, panel) (Thomas, 2001; Thomas, 2002; Thomas, 2003), etc. The values of MOE and MOR are also influenced by the ambient temperature (Zhou et al., 2012), the size and duration of compression in the process of panel manufacturing (Yapici, Essen, Yorur 2013 Warmbier, Wilczyński, Danecki, 2014), the temperature in the panel production process and the percentage of the adhesive used (Maragha, tables, Madanipoor, 2018), load duration, loading rate and load size (Gerhards, 1977; McNatt, 1975; Forest Products Laboratory, 1999; Rowell, 2005; Jacques et al., 2014; Kulman et al., 2017). The research of the rate of loading has revealed that with drop in the loading rate MOE and MOR decrease under the impact of static load.

The testing of MOE and MOR of particleboard samples according to the European standard EN 310 (1994) was carried out so that the selected loading rate produces a force on the sample causing a fracture of the sample over a time interval of 60 ± 30 seconds. The improperly selected loading rate causes breakage of the sample only after a few seconds and before the prescribed lower time limit. Therefore, the purpose of this study is to determine the differences in MOE and MOR sizes at different loading rates, as well as the significance of those differences.

2. MATERIAL AND METHODS

The samples for MOE and MOR testing were cut out of three commercial particleboards with a melamine foil of nominal thickness of 18 mm exposed to the changing atmospheric influences of the temperature and humidity at the warehouse. Before being cut, the boards had been stored in a room with a uniform temperature and humidity (22 ± 2^{0}C and 47 ± 3%) for a period of 10 days. A total of 94 samples were cut out of the boards with dimensions 18 x 50 x 410 mm, out of which 46 in direction parallel to the forming line (||) and 49 in direction perpendicular to the longer side of the board (⊥), 10 samples of 18 x 50 x 50 mm dimensions (4 for moisture content measurement and 6 for density measurement) according to the cutting pattern scheme (Figure 1). Before determining MOE and MOR, the cut samples were kept in the same area where the boards were stored prior to cutting for a period of seven days.

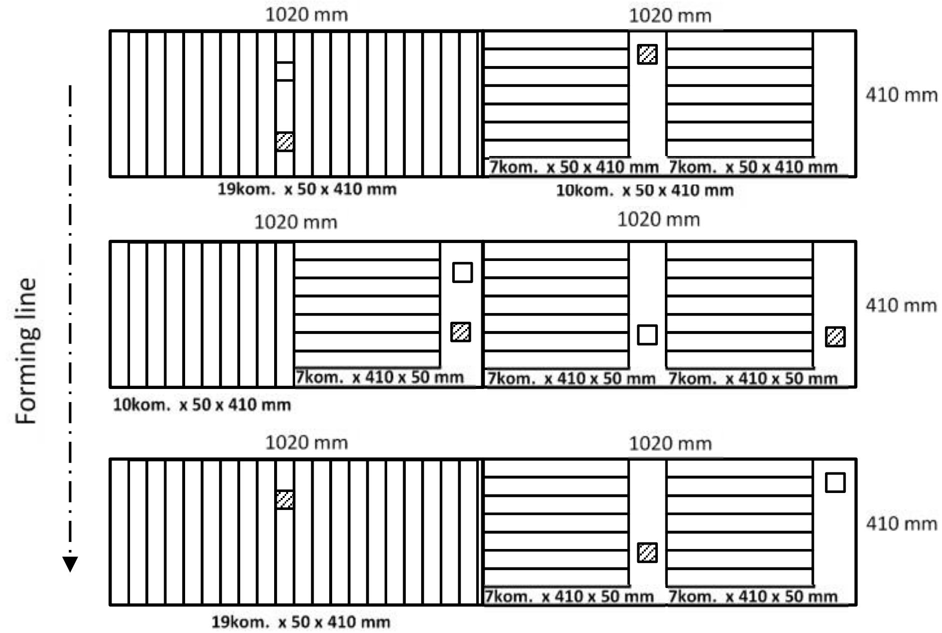

Figure 1. *Cutting pattern (□ – test pieces for determination of moisture content, ▨ – test pieces for determination of density)*

MOE and MOR testing was performed on a hydraulic machine for testing type WT-4 mechanical properties in the Laboratory for Wood Properties at the University of Belgrade - Faculty of Forestry.

The aim of the experiment was to compare the experimental results for MOE and MOR in two cases. The first one, in which the loading rate is selected so that the breakage occurs in less than 30s, and the other one, in accordance with standard EN 310, i.e. with fracture of the sample occurring within the prescribed interval of 60 ± 30 seconds. In accordance with those requirements, different loading rates were tested at the beginning of the experiment, and two of them were selected: (i) 4000/120 (33.33) N/s and (ii) 650/120 (5.41) N/s. (4000 N force is the maximum force that can be produced by the test machine).

Thus, a total of four groups of samples were formed: for the parallel and perpendicular directions, one group of samples for each, and within each of these groups, two subgroups for loading rates of 33.33 and 5.41 N/s. Before the tests, all sample dimensions were measured and the samples were weighed. The testing of moisture content and density of the particleboard was performed according to EN 322 and EN 323.

3. RESULTS AND ANALYSIS

The measured moisture content of the samples according to EN 322 was 6.39 ± 0.61%. The measured density of the particleboard according to EN 323 was 667 ± 3.7%.

The number of samples included in the analysis is shown in Table 1 for both cutting directions and for both loading rates. The number of these samples is lower compared to the initial number of samples, due to the trial testing and elimination of samples in groups with a loading rate of 5.41 N/s that were broken beyond the prescribed interval. Table 1 also shows the mean value and standard deviation of density, the minimum and maximum values of the fracture force, as well as the minimum and maximum values of deflection during fracture for each group of the samples.

Table 1. *Basic Statistical indicators for density, fracture force, deflection and time to failure of the samples cut in the parallel and perpendicular directions at the loading rates of 33.33 N/s and 5.41 N/s*

Cutting direction	Loading rate (N/s)	Number of samples	Density (kg/m^3)		Fracture force (N)		Deflection (mm)		Time to failure (s)	
			Mean	St. dev.	Min	Max	Min	Max	Min	Max
∥	33.33	20	676	9.63	339	441	5.71	7.69	12	16
	5.41	17	668	15.03	309	426	5.08	7.51	57	90
⊥	33.33	21	667	7.22	296	398	5.47	8.55	11	17
	5.41	22	673	14.48	267	375	4.39	7.85	50	88

It is a common knowledge that an increase in board density leads to an increase in the modulus of elasticity and bending strength (Kollmann and Cote, 1984). For these reasons, the density of the individual samples used for MOE and MOR testing was also established in this paper. For each of the cutting directions, the density variation between the groups of samples broken at the loading rates of 33.33 and 5.41 N/s was tested using the Single Factor ANOVA. Density variation was also checked between all samples cut in the parallel and perpendicular directions.

It was found that the significance threshold was $\alpha = 0.05$, and for the same cutting direction the differences in density between the groups of samples studied at different loading rates were not statistically significant. In addition, variations in density between the groups of samples cut in the parallel and perpendicular directions were not statistically significant (Table 2). Therefore, density variations can be considered not to significantly affect MOE and MOR.

Table 2. *One-Way ANOVA to determine the significance of differences between the density of sample groups of the same direction that were broken at the selected loading rates and between the densities of all samples cut in one and the other cutting direction*

Cutting direction	F	P-value	F crit
∥	3.884	0.057	4.121
⊥	3.277	0.078	4.078
Between the directions	0.561	0.456	3.963

Table 1 shows that the samples exposed to higher loading rate broke at a higher fracture force with higher deflections and much sooner than the samples that were exposed to lower loading rate. Therefore, and based on the known expressions for calculating he MOE and MOR (EN 310), at a higher loading rate of 33.33 N/s, MOE and MOR values will be higher than at a loading rate of 5.41 N/s.

Table 3 shows the basic descriptive statistics (mean, standard deviation, coefficient of variation, Cv and skewness coefficient, Cs) and MOE and MOR for the sample groups with a loading rate of 33.33 N/s and 5.41 N/s for the parallel and perpendicular cutting directions. The last two columns show the differences between the mean values of MOE and MOR for groups of samples that are loaded with different loading rates. Hereinafter, the modulus of elasticity for the parallel and perpendicular directions will be shown as $MOE_{\parallel}$ and $MOE_{\perp}$ and the modulus of rupture as $MOR_{\parallel}$ and $MOR_{\perp}$.

It is evident that the mean values of MOE and MOR for loading rate of 5.41 N/s are lower than the mean values for loading rate of 33.33 N/s. The standard deviations show the approximate values for the same direction, as well as the coefficients of variation.

Table 3. *Mean value, standard deviation, coefficients of variation and skewness coefficient $MOE_{\parallel}$ and $MOE_{\perp}$,$MOR_{\parallel}$ and $MOR_{\perp}$ for loading rates of 33.33 N/s and 5.41 N/s*

	Loading	MOE (MPa)				MOR (MPa)				Difference between the mean values (MPa)	
Cutting direction	rate (N/s)	Mean	St. dev.	Cv	Cs	Mean	St. dev.	Cv	Cs	MOE	MOR
∥	33.33	3163	115.6	0.037	-0.50	13.04	0.97	0.074	-0.03	95 (3.1 %)	0.66 (5.3 %)
	5.41	3068	101.3	0.033	0.48	12.39	1.27	0.103	0.28		
⊥	33.33	2678	196.0	0.073	0.67	11.50	0.93	0.081	0.17	167 (6.6 %)	0.45 (4.1 %)
	5.41	2511	219.6	0.087	-0.29	11.05	0.94	0.085	-0.43		

Figure 2 shows the results for MOE and MOR and the time to failure for all the samples from the four groups examined. Figure 2 on the left shows the $MOE_{\parallel}$ and $MOE_{\perp}$ and Figure 2 on the right the $MOR_{\parallel}$ and $MOR_{\perp}$ for both loading rates. The x-axis represents the time to failure, and the time to failure prescribed by the standard EN 310 (60 ± 30 s) is shown in grey in the diagram. The samples exposed to higher loading rate (33.33 N/s) broke after a much shorter period of time than the time prescribed by the standard, and also during a short time interval ranging from 11 to 17s for both cutting directions. The samples in which loading rate was lower (5.41 N/s) were broken in the interval prescribed by standard EN 310, in a much longer interval than the previous group, i.e. from 50 to 90s for both cutting directions, (see also Table 1).

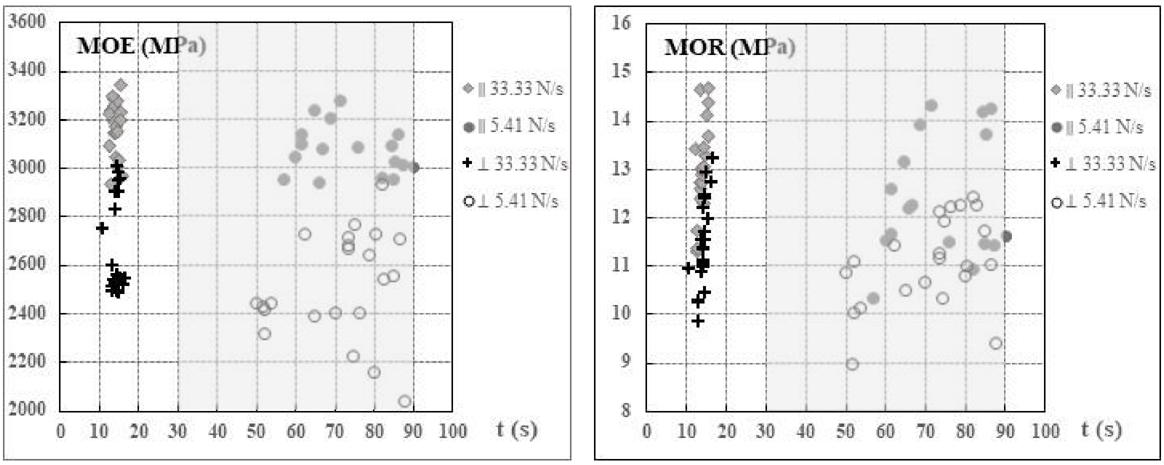

Figure 2. *$MOE_{\parallel}$ and $MOE_{\perp}$, and $MOR_{\parallel}$ and $MOR_{\perp}$ and the time to failure for the four groups of samples at loading rates of 33.33 N/s and 5:41 N/s*

In order to get a better insight into the distribution of MOE and MOR results within the tested groups of samples, and in order to visually compare the results between the groups, Figure 3 shows a Box - Whisker plot for MOE and MOR. The Box - Whisker plot for $MOE_{\parallel}$ and $MOE_{\perp}$ is shown in Figure 3 on the left, and for $MOR_{\parallel}$ and $MOR_{\perp}$ in Figure 3 on the right. The diagrams also show the points representing the mean values of MOE and MOR from Table 3. From Figure 3 it can be seen that for loading rate of 5.41 N/s, the mean values of MOE and MOR, as well as the values for the median, the minimum and the maximum values, are lower than for loading rate of 33.33 N/s. In addition, the range of the percentile from 25 to 75 is lower for both MOE and MOR for all sample groups that were exposed to loading rate of 5:41 N/s, except for $MOR_{\parallel}$.

Figure 3 also shows a visible pronounced asymmetry of results for MOE at loading rate of 33.33 N/s. The median is considerably below the mean value, i.e. for most of the samples in this group, the measured MOE is lower than the mean value for the group. (In Table 3 it can be seen that a series of $MOE_{\perp}$ has the highest asymmetry coefficient, Cs = 0.67.)

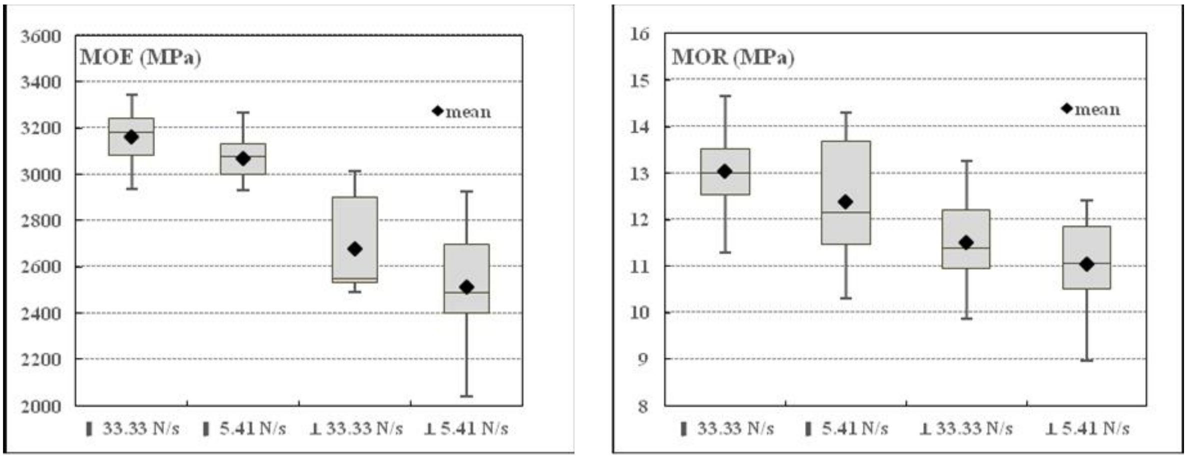

Figure 3. *The Box-Whisker plot of $MOE_{\parallel}$ and $MOE_{\perp}$ and $MOR_{\parallel}$ and $MOR_{\perp}$ for loading rates of 33.33 N/s and 5.41 N/s*

As expected, the mean values of $MOE_{\perp}$ and $MOR_{\perp}$ are lower than the mean values of $MOE_{\parallel}$ and $MOR_{\parallel}$ as a result of non-homogeneous structure and anisotropy of particleboards. These differences are greater than the differences obtained for different loading rates (see also Table 3).

The single-factor ANOVA was applied to determine the statistical significance of the differences between MOE and MOR obtained by the experiment at lower and higher loading rate. The results are shown in Table 4. ANOVA showed that the differences between the mean values of MOE within the same direction at loading rates of 33.33 N / s and 5.41 N/s are statistically significant (although the percentage is low: 3.1% for the parallel direction and 6.6% Table 3), while for MOR there are no significant differences (the percentage differences are 5.3% for the parallel direction and 4.1% for the perpendicular direction).

Table 4. *Results of the ANOVA test of the significance of differences for MOE and MOR between groups of samples exposed to loading rates of 33.33 N/s and 5.41 N/s (the significant differences are highlighted)*

Cutting direction	Loading rate (N/s)	MOE(MPa)			MOR(MPa)		
		F	p	F crit	F	p	F crit
‖	33.33	**6.934**	**0.013**	**4.121**	3.148	0.085	4.121
	5.41						
⊥	33.33	**6.886**	**0.012**	**4.079**	2.449	0.125	4.079
	5.41						

The mean values for density (671 kg/m^3) and for MOE (2855 kg/m^3) obtained in this experiment are similar to the properties that can be found in respective literature. According to [10] the density of a particleboard varies from 600 to 800 kg/m^3 and MOE is from 2760 to 4140 MPa. However, the mean value of MOR (11.99 MPa) is below the lower limit known in relevant literature [10]: 15.17 to 24.13 MPa.

4. CONCLUSION

This experiment has shown that there is a difference between the mean values of MOE and MOR for both cutting directions depending on loading rate. A higher loading rate causes higher values of MOE and MOR.

The differences between the mean values of MOE at the loading rates of 33.33 N/s and 5.41 N/s are 3.1% for the parallel direction and 6.6% for the perpendicular direction. As far as MOR is concerned, the differences between the mean values at loading rates of 33.33 N/s and 5.41 N/s are 5.3% for the parallel direction and 4.1% for the perpendicular direction.

The results of the ANOVA test of statistical significance of these differences are not consistent. More precisely, statistically significant differences were obtained for MOE, and they were not found for MOR, although both mechanical characteristics were expected to be expressly dependent on the rate of loading.

The deviation from the expected results was probably caused by the different distribution of experimental results per groups due to a relatively low number of samples. More precisely, pronounced variability and asymmetry were found in the group of samples for MOE testing cut out in the perpendicular direction examined at loading rates of 33.33 N/s and 5.41 N/s, as well as for MOR testing group of samples cut in the parallel direction that were tested at loading rate of 5.41 N/s.

In addition to that, the expressions for MOE and MOR calculation are valid only for the field of elasticity, while at higher levels of load above the elastic limit, plastic deformations are inevitable, especially in close proximity to the point of fracture.

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