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Influence of veneer moisture content on shear strength of plywood adhesive bond

Utjecaj sadržaja vode furnira na čvrstoću na smik lijepljenog spoja uslojenih ploča

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SUMMARY • In the formation of wood-adhesive bond numerous factors are involved, and the influence of some of them is still not sufficiently explained. In this frame, another important factor is also wood moisture content (MC) during the gluing process. It influences a number of processes, which take place during adhesive curing, among others also penetration depth and thus mechanical adhesion or strength of adhesive bond. The article presents the results of a research in which the influence of MC of peeled beech veneer during the gluing process of plywood board adhesive bond shear strength was studied. Melamine-urea-formaldehyde adhesive was used for hot gluing. Veneer moisture content during the gluing process ranged between 4 and 14%. Shear strength was determined by using test specimens prepared according to the EN 314-1 and EN 314-2 standards. The results show that (1) veneer moisture content within the range studied did not influence shear strength of dry (exposed to a standard climate) tested specimens, that (2) shear strength of test specimens decreased after the boiling as veneer moisture content increased and that (3) variation coefficients for shear strength of specimens prepared according to the boiling method are on the average much higher than in the case of specimens prepared in standard climate.

Key words: peeled beech veneer, melamine-urea-formaldehyde adhesive, hot gluing, glue-bond shear strength

SAŽETAK • Mnogobrojni činitelji djeluju na stvaranje spojeva drva i ljepila, a utjecaj pojedinih od tih činitelja nije u potpunosti objašnjen. Jedan od važnih faktora je sadržaj vode

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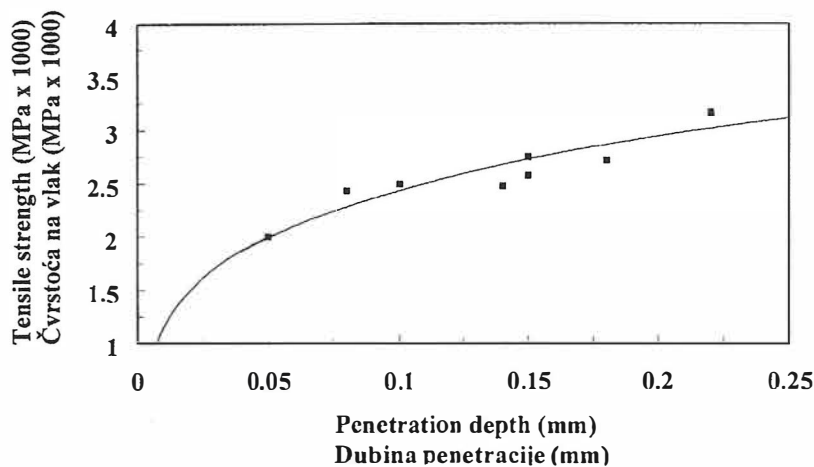


Figure 1
Influence of MDI adhesive penetration depth on glue-bond tensile strength (Phanopoulos, 1996). • Utjecaj dubine penetracije MDI ljepila na vlačnu čvrstoću slijepljenih spojeva (Phanopoulos, 1996).

sive bond strength and quality. Thus Rowell (1996) found that adhesive bond failure in composite wood can be attributed to several factors. Among the major causes is a weak chemical and physical reaction between wood and adhesive and the variations in adhesive and wood swelling associated with humidity absorption, and these are followed by environmental impacts and poor stress distribution. In the adhesive-wood system, adhesion depends primarily on surface wetting, adhesive penetration, chemical reaction, porosity, pH, moisture content, extractives, chemical interactions, surface tension and anatomical orientation. Gardner et al. (1995) found that problems with bad adhesion occur primarily in connection with old surfaces and overdry or casehardened wood. In such cases, wood surface is non-reactive, which may be due to several factors resulting from surface oxidation or migration of extractives to wood surface. Scheikl et al. (1996) found that what is important for strong adhesive bond is primarily a high percentage of adhesive bonds between adhesive and wood molecules. As adhesive forces act over short distances, for a good adhesive bond it is essential to bring adhesive and wood as close to each other as possible. The

basic condition for good gluing quality, then, is that the surface is appropriately wetted by adhesive, and this depends on surface tension. Phanopoulos et al. (1996) studied the factors that influence the penetration and adhesive strength of polyurethane adhesive (MDI). They found that tensile strength increases with the depth of penetration of MDI adhesive (Figure 1).

3. MATERIALS AND METHODS 3. MATERIJALI I METODE

In the experiment 2.2 mm thick peeled beech veneer (*Fagus sylvatica*, L.) was used. Veneer was divided into four groups, which were then conditioned in a climate chamber until equilibrium moisture content was reached, as shown in Table 1.

For gluing, melamine-urea-formaldehyde (MUF) adhesive was used, such as is used in industrial manufacture of water-resistant plywood boards. Physical and chemical properties of MUF resin, composition and major properties of adhesive mixture are shown in Tables 2 and 3.

Veneer conditioning was followed by the gluing of three-layer veneer boards of 500 x 500 x 6.6 mm dimensions (Figure 2).

Target moisture content (%)	4	6	9	14
Predvidjeni sadržaj vode (%)				
Relative air humidity (%)	20	39	58	85
Relativna vlažnost zraka (%)				
Temperature (°C)	20	20	20	20
Temperatura (°C)				
Moisture content achieved (%)	4.1	6.0	9.0	13.8
Postignuti sadržaj vode (%)				

Table 1
Veneer conditioning ensuring the desired moisture content levels. • Uvjeti kondicioniranja furnira i postignute vrijednosti sadržaja vode

Table 2

Glue-mixture composition • Receptura ljepila

Glue-mixture components Sastojci pripremljenog ljepila	Parts Udio
MUF resin MUF smola	100
Wheat flour Type 500 Pšenično brašno tip 500	6
Ammonium chloride (NH ₄ Cl) Amonijev klorid (NH ₄ Cl)	1

Table 3

Glue-mixture properties • Svojstva pripremljenog ljepila

Properties Svojstva	Value Vrijednost
Solid content (%) Suha tvar (%)	58.75
Viscosity by Ford ϕ 6 mm (s) Viskoznost po Fordu ϕ 6 mm (s)	81.33
Dynamic viscosity (cP) Dinamična viskoznost (cP)	990.89
Gel time (s) Vrijeme želiranja (s)	65.20
pH value pH vrijednost	6.95

Adhesive was applied by means of a rubber roller at the average rate of 200 g/m². Open assembly time was 5 minutes, average relative air humidity in the laboratory was 33%, and average air temperature 20°C. The pressing time was 7 minutes and was carried out by means of a laboratory press at the temperature of 130 (\pm 3) °C and the pressure of 1.8 MPa. For each veneer moisture content group six boards were made.

Shear strength of test specimens was determined according to the EN 314-1:1996

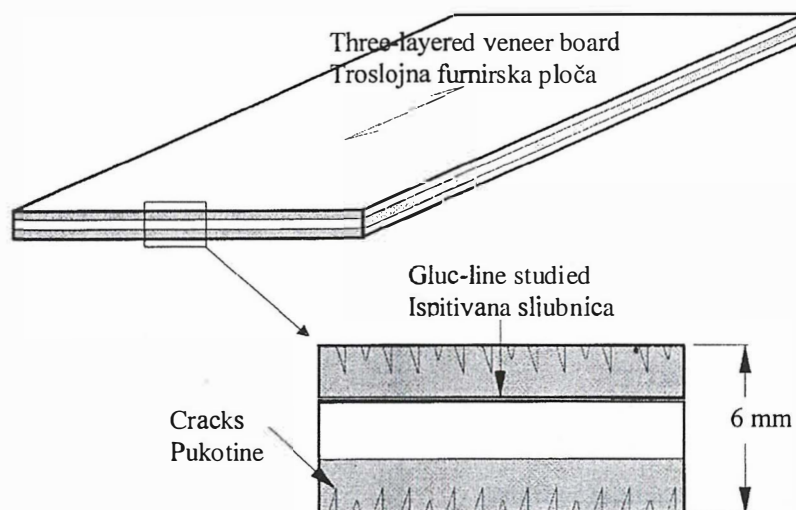
standard. For each group of test boards 60 test specimens were prepared (10 per board), giving the total of 480 test specimens (60 x 4 moisture content groups x 2 methods of treatment before testing).

Test specimens were treated prior to testing in two ways:

- dry tested specimens: conditioning (14 days) in standard climate (relative air humidity 65% and air temperature 20°C),
- wet tested (boiled) specimens: boiling for 4 hours, drying for 17 hours at the tem-

Figure 2

Three-layered veneer board • Troslojna furnirska ploča



perature of 60°C, boiling for 4 hours and cooling in water at 20°C for 1 hour (EN 314-1, Section 5.1.3).

4. RESULTS AND DISCUSSION
4. REZULTATI I DISKUSIJA

Preparation of test specimens in standard climate
Priprema proba u standardnim klimatskim uslovima

It was found that veneer moisture content during the gluing (range between 4.1% and 13.8%) exerts very little impact on shear strength of test specimens prepared in standard climate (Table 4). Wood failure was found to be 93%, which means that the shear strength of beech veneer was actually recorded.

Preparation of test specimens by boiling-drying-boiling
Priprema uzoraka kuhanjem-sušenjem-kuhanjem

A consequence of preparing test specimens by boiling was a 61% decrease in shear strength of the first veneer moisture content group and a weakening of adhesive bond, with wood failure spreading entirely within adhesive film. An obvious impact of veneer moisture content during the gluing on shear strength was also observed, which decreased linearly with a moisture content increase. Decrease of shear strength was almost linear

with respect to the increase in veneer moisture content during the gluing (Table 5). The coefficient of decrease of shear strength was 0.106 N/mm² per 1% of moisture content increase.

Comparison and discussion

The glue-bond shear strength values obtained for the test specimens prepared in standard climate and by boiling are shown in Figure 3.

Comparison of shear strength values obtained for the test specimens prepared according to the two methods mentioned above shows statistically significant differences, for class 0.05, in the case of all of the veneer moisture content groups. When considering the absolute range, shear strength of test specimens from standard climate depends very slightly on veneer moisture content during the gluing, for the absolute difference is only 0.2 N/mm² or 6.2% of maximum value. Variation coefficient is also acceptable, for it varied between 7.7 and 12.6, and its lowest value was obtained in the case of the highest veneer moisture content level. On the other hand, in the case of preparing test specimens by boiling, a strong linear decrease in shear strength was observed, that is, from 1.25 N/mm² at 4.1% moisture content to just 0.22 N/mm² at 13.8% moisture content. Thus, test specimens made of veneer with the highest moisture content were characterised by just

Moisture content (%) Sadržaj vode (%)	4.1	6.0	9.0	13.8
Number of specimens Broj proba	60	60	60	60
Mean value Srednja vrijednost	3.23	3.16	3.03	3.13
Standard deviation Standardni odklon	0.32	0.30	0.38	0.24
Variation coefficient (%) Koeficijent varijacije (%)	9.95	9.63	12.57	7.66

Moisture content (%) Sadržaj vode (%)	4.1	6.0	9.0	13.8
Number of specimens Broj proba	60	60	60	60
Mean value Srednja vrijednost	1.25	1.06	0.62	0.22
Standard deviation Standardni odklon	0.38	0.52	0.49	0.31
Variation coefficient (%) Koeficijent varijacije (%)	30.40	49.21	79.45	139.44

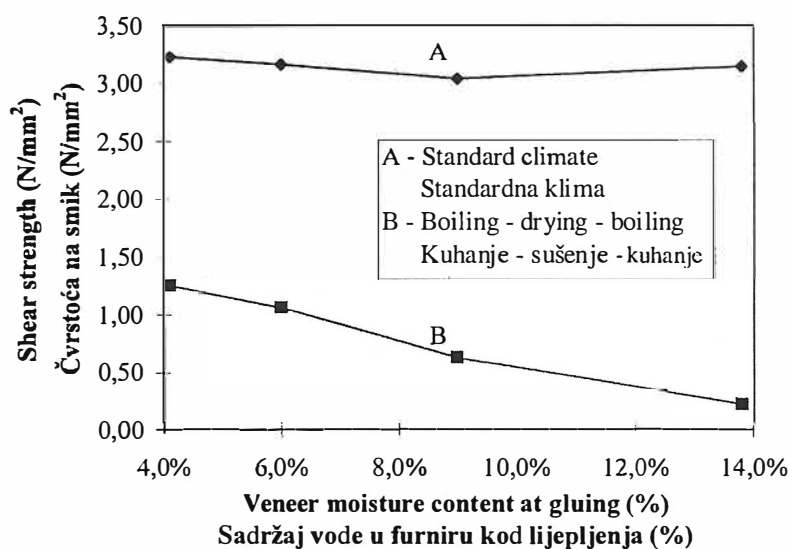
Table 4

Dependence of glue-bond shear strength (N/mm²) on veneer moisture content during the gluing – dry tested specimens • Ovisnost čvrstoće na smik ljepljenja (N/mm²) o sadržaju vode furnira prije lijepljenja – suho ispitane probe

Table 5

Dependence of glue-bond shear strength (N/mm²) on veneer moisture content during the gluing – wet tested specimens • Ovisnost čvrstoće na smik ljepljenja (N/mm²) o sadržaju vode furnira prije lijepljenja – mokro (nakon kuhanja) ispitane probe

Figure 3
 Dependence of glue-bond shear strength on veneer moisture content during the gluing and on the method of specimen preparation • Ovisnost čvrstoće na smik ljepila o sadržaju vode furnira pri lijepljenju i o tehnici pripreme proba



17.6% shear strength of the test specimens from 4.1% moisture content group. Wood failure after the boiling occurred 100% within adhesive film for all moisture content groups, and many test specimens from higher moisture content groups delaminated by the time the shear strength was determined. With this group, variation coefficients were much higher, ranging from 30.4 to 139.5, and the highest variation coefficient was observed in the case of veneer moisture content group 13.8%. It can be assumed that curing temperature used in the experiment was too low for the MUF adhesive, which resulted in undercured melamine resin. Although the temperature in the boards was not measured, it can be expected that it is decreasing with the increase in the veneer moisture content. Thus, low temperature problem was more distinctive as a low glue-bond shear strength in case of a higher veneer moisture content. With regard to the requirements of the EN 314-1:5.1.3 standard, only veneer moisture content levels 4.1% and 6.0% could be classified as water-resistant plywood boards, if at the same time a high variation coefficient is disregarded.

It is obvious that with the MUF adhesive used in the experiment it is capable of providing only adhesive bonds of limited water-resistance. In this connection it should be observed that shear strength of test specimens subjected to the requirements of EN 314-1:5.1.3 standard is strongly dependent on veneer moisture content during the gluing.

5. CONCLUSIONS
5. ZAKLJUČAK

On the basis of the results of the research on making plywood boards by gluing peeled veneers with different moisture content by means of MUF adhesive, and of tests carried out according to EN 314-1 standard, it may be concluded that (1) veneer moisture content during the gluing in the range between 4.1 and 13.8% has very little influence on shear strength of dry tested specimens (prepared in standard climate), that (2) shear strength of test specimens prepared by boiling-drying-boiling strongly linearly decreases with veneer moisture content increase from 4.1 to 13.8% during the gluing, and that (3) variation coefficients for shear strength of specimens prepared according to the cooking method are on the average seven times higher than in the case of specimens prepared in standard climate.

6. LITERATURE
6. LITERATURA

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