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GLUING STRENGTH OF WOOD MEASURED WITH NONSTANDARD PRESSURE-SHEAR METHOD

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ABSTRACT

This work is a contribution to development and improvement of the methods for testing of gluing strength of wood to shear, and in particular to interpretation of the test results obtained with alternative test method, related to the respective EN and ISO standards.

The study was performed on six groups of the test- specimens obtained by changing the slope of the rings line to the joint in the cross section. The effect on gluing strength was calculated by statistical analysis. Fracture surface of the test-specimens i.e. changes at the starting points of fracture and fracture directions were analyzed. Phototensiometry of the object raster was applied to monitor distribution of the shifts i.e. surface deformities of the test-specimens most exposed to them.

The assumed difference between the mentioned groups of test-specimens has been ascertained, and it proved that these forms of test-specimens can be used in testing of the gluing strength of wood.

KEY WORDS: glued joint, slope of rings line, gluing strength, fracture surface, deforming of test-specimens

INTRODUCTION

Development of various test systems for gluing strength of wood resulted in the 1960s' in the special form of a test-specimen (Bousquet 1970) which, due to the occurrence of specific fracture shifted from the joint, was very quickly abandoned. For that reason the potentials of that test-specimen had not been sufficiently studied or exploited.

A come back of this test-specimen (Bogner 1993, Mihulja et al. 1999) has revealed new facts which point out to the need in additional research into and knowledge of the fracture shifted from the joint as well as to the possibility to remove this influence by modification of its form.

Properties of the glued joints

Basic properties of the glued joints are defined by their strength and durability. Strength of the glued joint implies strength of the construction which makes a joint and depends on the gluing strength and on the joint design, where the construction defines loading of the glued area.

Given the fact that all glued systems are complex structures, strength and any other evaluation criterion is influenced by three distinctive factors: layer of the glue, established joint and glued parts.

Any factor that affects any of these will change the evaluated property, except if the interactions have not neutralized their effect.

Structural diversity of a wood has significant effect on the properties of the glued joint. Consequently, a wood is the least strong in the area of parenchymal cells which are considerably weaker than the surrounding bearing cells. It is, therefore, logical to expect a fracture initiation in the parenchymal area. If the fracture is initiated at any other point within a wood and/or at its surface, it is then most likely that it will expand to the weakest area, either the parenchymal or any other weak zone of a wood, e.g. early wood.

Chemical and physical parameters of wood and glue influence quality of the wood-glue interface (Yavorsky et al. 1955). This implies polarity of wood and glue, their surface energies, presence of any kind of dirt, surface roughness of wood, structure and appearance of the fibres, viscosity of glue, etc. A glued joint and all its elements are subject to frequent changes in moisture content, temperature, load and influence of light and chemical agents during which it ageing i.e. gradually changes its properties.

All these variation causes apply to the forms of test-specimens used for testing of a glued joint. Other causes relate to individual types of test-specimens, depending on their geometry and the loading method. Therefore, the glued joints should be viewed from the point of precisely defined joining modes, when wood exerts maximum resistance to expansion of the fracture i.e. when the tested joint or a test-specimen is focused on the joint surface.

Constructional properties of the test-specimens

When the test-specimen for testing of the glued joint is loaded to fracture, it is important to know that the fracture may occur either on the glue-line, or in wood or on their contact line i.e. in the intermediate layer. Intensity and direction of the forced stress and the weakest point determine at which point the fracture will appear. Thus, different results reflect differences in mechanical properties of wood, glue and wood-glue interface. Big differences in the joint strength are often attributed exclusively to the factors unrelated to gluing quality, but to e.g. geometry of joints and to rheology (Marra 1962).

Shape of the test-specimen being very influential, abrupt changes in the cut, such as notch, causes significant concentrated stress. Torsion moment during test-specimen loading frequently generates big deformities which act on the glued joint. Therefore, a very complicated stress distribution in the usual test-specimen forms should not be surprising. If fracture or delamination occurs, stress distribution within the loaded joint is also uneven. It usually starts with maximum at the ends or along sharp edges to minimum in the centre of a joint. Consequently, the fracture is not attributable to the average stress but to the local concentrated stress that reaches wood strength or wood-glue joints (Northcott 1955).

The analyses have shown that deformities of the overlapping tests cause stresses perpendicular to the joint surface which are more influential than the shear stress. This effect causes early failure of such a joint compared to the block-shear test-specimen with only one half of the strength. The same problem appears with pressure-shear test-specimens. Although the block shear test-specimens do not cause exclusively shear stress they are closest to it (Strickler 1968).

Quality assessment

Majority approaches to quality evaluation of wood gluing require that a glued joint is equally strong or stronger than wood (Yavorsky et al. 1955).

Assessment for gluing quality can be based on relative destruction of an adhesive and wood and/or the required stress which under specific mechanical load causes destruction. In the first case gluing quality is assessed (determined) visually, taking into account relevant quantities of wood and glue on the fracture surface. In the second case gluing quality is assessed according to the joint strength, using the data about forces measured at the moment of fracture.

In some cases strength is, or may not, be a suitable criterion for determination of joint quality because fracture can be due to various factors, such as intense deformity, delamination, loss of consistency or many other factors indirectly related to maximal strength.

Wood fracture cannot be the unconditional indictor of joint quality either, because the values are being changed with moisture content, from 0% at low to 20-30% at higher content, with some indications of maximum at mean values (Marra 1962). This would be possible only if all negative factors are nullified.

Both views must be taken into consideration so as to ensure that quality assessment is as close to the realistic as possible. Strength can show almost accurate figures if fracture surface analysis is used to remove all test-specimens which are incompliant for any reason. Further increase in reliability of gluing quality assessment is possible only by the methods where all influential factors and their share in joint formation and measurement of fracture force are known.

Hypothesis and study goals

the study must take into account the alternative method (herewith referred to as "BN") applied in research into the gluing strength of wood to shear i.e. main influential factors in the tests with this test-specimen form. Analogously, it is assumed that the results will reveal statistically significant difference between the selected test- specimen groups and, thus, show that one of them provides a more reliable assessment of gluing quality of wood.

This work was aimed at identifying reliability of results interpretation with the use of alternative pressure-shear test method, and defines the effect of the slope of rings line to the joint surface on strengths, distribution of deformities and the share of wood fracture.

MATERIAL AND METHODS

Types and forms of test-specimens

Starting parameters of the study were type and form (dimensions) of a test-specimen already used in some other research (Bogner 1993, Mihulja et al. 1999) and representing a sort of synthesis of EN (**** 1991, **** 1983) and ISO standards (**** 2001).

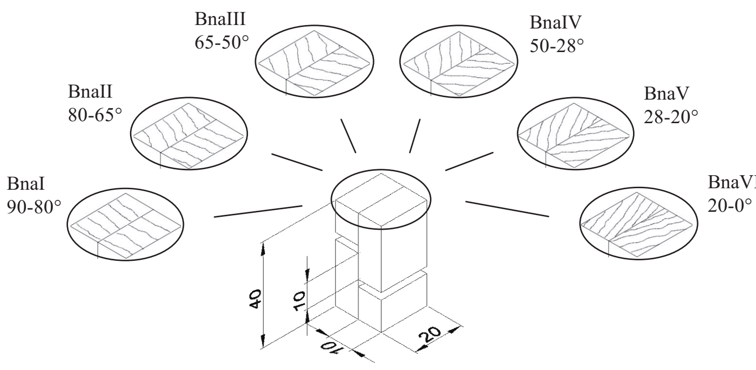

Fig. 1: Forms and groups of test-specimens

Given the fact that in case of shear it is more difficult to create fracture along the joint, all untoward effects must be eliminated. The main one is unsuitable geometry of the test-specimens which due to its stress distribution along with the main stress generates additional stresses that may cause a fracture at the point other than the desired one. On the top of the unsuitable geometry there are also structural wood units especially the parenchymal cells which for their markedly poor mechanical properties represent the points of fracture initiation. Influence of this factor will be studied by varying the slope of rings line to the joint surface.

Selection of wood

The study used beech wood (*Fagus Silvatica*) primarily for its being the standard of the European norms 205 and ISO 6238. Being a diffuse-porous type of wood under load the stress is evenly distributed over its structural elements. Uniformity of structure contributes to finer surface treatment and to uniform thickness of the glue layer in the joint.

The material studied was a commercial one enabling reference of the recorded changes to standard wood pieces. Control of physical properties in the selection of the studied material required minimizing of variability and influential factors and experimental changes conditioned mostly by experimental variables rather than by variability of wood properties. The inspection having not revealed any deficiency caused by drying, it was concluded that the material had been properly pre-dried and dried.

Selection of glue

Based on the previously conducted studies and literature data it was concluded that polyurethane glue was a logical and optimal choice. This glue is known to be less brittle than the available epoxide glues and formaldehyde resins and also meets high criteria for adhesive and cohesive strength when applied to wood and wood composites (Hawke et al. 1992). It does not contain solvents or water which causes wood swelling i.e. the problems related to changes in dimensions of both glue and wood. Isocyanate-based glues penetrate wood sufficiently deep to prevent negative effects of the damaged surface cells (Murmanis et al. 1986).

Present study used a commercial one-component PU glue Klebit PUR 501 made by Kleberit, a member of Klebchemie Group.

Preparation of test-specimens and gluing techniques

The plates of 400 mm x 135 mm x 10 mm (longitudinal, tangential and radial direction) were made by machine planing so that their longer edges were parallel to the growth direction of pre-conditioned wood with 12% moisture content, straight fibres without visible defects, of harmonized volume (~ 731 kg/m^3) and average width of the rings 3.6 rings/cm. Two plates of 170 x 110 mm obtained by sawing were overlapped and glued together. The angle which the rings formed in the cross section with the gluing surface was divided in 6 groups (Fig. 1).

Just prior to gluing and at least 7 days after planing, all joints were treated with the abrasive paper made by Vitex, granulation 120 in the direction of fibres, applying specific pressure of not more than 2 N/mm^2. So finished surface oxidized markedly due to its exposure to standard temperature of 23 ± 2°C and relative air humidity of 50 ± 5%. Sanding was uniform in both directions, parallel to the fibres until removed all trace of planing (cycloids) and the surface became completely refreshed. Thus, the surface was activated and stress concentration at critical points of the test-specimen which might appear by overlapping both cycloid tops was avoided.

The glue was applied from its original 0.5 L packing in the volume of 200 g/m^2 and in the manner selected on the basis of experience which grossly complied with manufacturer's recommendations.

Because of the short open time the glue was spread evenly over the surface of only one joint surface with a toothed spatula having 4 trapezoid tooth per 1 cm,, height of 0.75 mm. The plates were then placed in the mechanical press with constant load and pressure regulation with the weights by 1:20 arm.

The plates were kept under the pressure of 1 N/mm^2 for 24 hours in order to remove the internal stresses which might develop during hardening of the PU glue.

Preparation of test-specimens

All glued test-pieces (plates) were sufficiently long conditioned under standardized conditions (minimum 7 days) at 23 ± 2°C and relative air humidity of 50 ± 5%. After removal of edges (10mm) minimum 30 test-specimens were sawn for each group, according to their appearance and dimensions sated in figure 1.

During wood treatment variations are unavoidable, but the scope and distribution of irregularities can be monitored. Therefore, dimensions of all test-specimens were measured to allow more accurate calculation of strength. Compliance of the test-specimens accuracy with ISO was ± 0.5 mm.

Testing and processing of measurement results

Properties of the glued joints i.e. test-specimens were measured by application of force, a shift of the testing head and the wood fracture portion. Break force was measured with the testing machine «Otto Wolpert- Werke GMBH model U4» at the shift rate of 5 mm/min. Measuring was performed with a digital measuring system at the rate of 10 measurements per second and maximal force deviation corresponding to the change in one tenth of a second.

The results were processed in Microsoft Excel and Statistica software for Windows platform. Maximal force was used to calculate strength. The processed results for all groups of test-specimens and their comparative results showed similarities and differences used to identify the importance of the change in the slope of rings line. ISO analysis of the fracture surface was considered appropriate for these tests, because the results were used only to help identify compatibility of various test-specimen groups in strength analysis.

Strength was analysed by descriptive statistics (arithmetical mean, minimum, median, maximum and standard deviation). The 5% error in all analyses was considered statistically significant. Given the fact that the parameter for results distribution was satisfactory and homogeneity variance was not satisfactory (F test and Leven's test) the Kruskal-Wallise's test was applied (> 2 groups of test-specimens) to determine statistically significant differences between the groups. This test is used only to confirm presence of statistically significant difference between the test-specimen groups; however, it does not identify the groups which make the difference. Consequently, that difference was determined by *post hoc* tests. Variance analysis was carried out by Hockberg's step up algorithm of the analyzed group pairs (Troendle 1995, Sokal and Rohlf 1995). Because of the non-parametric tests the median and 25 and 75 percentiles were applied.

Process modelling by phototensiometry of the object raster

Phototensiometry was applied because it is known as a simple, no-contact and a reliable method for determination of the measurable parameters which are real outcomes of the test-specimen load. Its basic principle is monitoring of the surface points shift. Shifts are detected with the use of the commercial optical technique deformity measurement method of ARAMIS system developed by German «GOM mbH - Gesellschaft für Optische Messtechnik» from Braunschweig. When directions and shift sizes are determined, overall deformity of the material can be calculated.

RESULTS AND DISCUSSION

Strength at different ring slope

Tab. 1: Variance homogeneity test

	Levene's Test for Homogeneity of Variances Effect: form Degrees of freedom for all F's:5, 174			
	MS Effect	MS Error	F	p
Strength	23,52003	1,950319	12,05958	0,000000

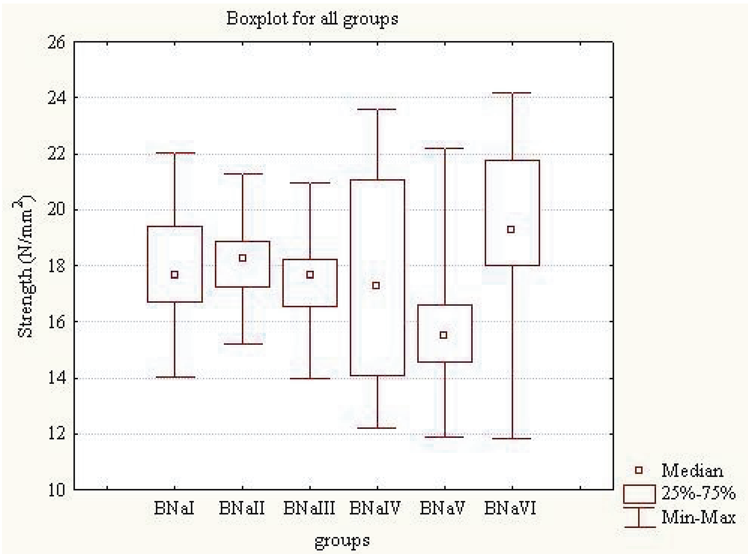

Fig. 2: Strength analysis at different ring slope

Kruskal-Wallis test: H (5, N = 180) = 23,55661 p = 0,0003

Tab. 2: Multiple post hoc comparisons by Hochberg's algorithm

OBS	Tested groups		Mann-Whitneyev U Test	Hochberg's step-up algorithm
			2*1 sided exact P	H0 – absence of stat. significant diff. H1- presence of stat. significant diff.
1	BNaI	BNaII	0.66498	H0
2	BNaI	BNaIII	0.60220	H0
3	BNaI	BNaIV	0.73016	H0
4	BNaI	BNaV	0.00170	H1
5	BNaI	BNaVI	0.01487	H0
6	BNaII	BNaIII	0.10581	H0
7	BNaII	BNaIV	0.78601	H0
8	BNaII	BNaV	0.00011	H1
9	BNaII	BNaVI	0.00730	H0
10	BNaIII	BNaIV	0.78601	H0
11	BNaIII	BNaV	0.00129	H1
12	BNaIII	BNaVI	0.00129	H1
13	BNaIV	BNaV	0.41468	H0
14	BNaIV	BNaVI	0.12295	H0
15	BNaV	BNaVI	0.00008	H1

Fracture surface analysis

Tab. 3: Portion of fracture surface covered by wood

Marking of a test-piece	Share of the fracture surface covered by wood (%)	Share of the test-pieces with fractured surface shifted from the joint (%)	Share of the test-pieces with the whole fracture surface in the glue layer (%)
BNaI	90	80,0	0,0
BNaII	59	43,3	3,3
BNaIII	63	43,3	23,3
BNaIV	1	0,0	90,0
BNaV	2	0,0	80,0
BNaVI	22	10,0	56,7

Phototensiometric method of the object raster

Distribution of total deformities

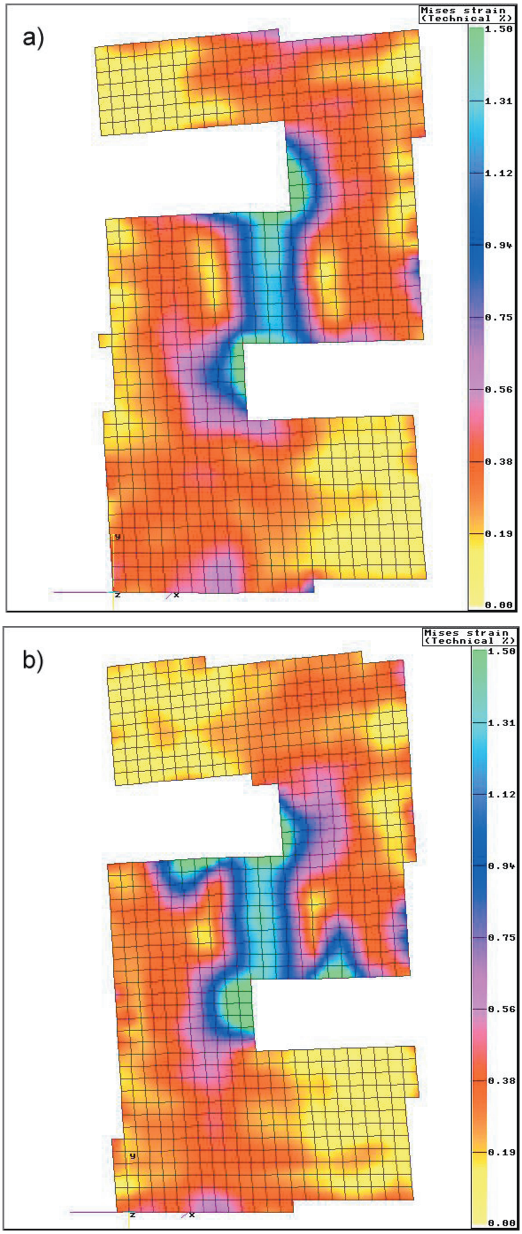

Fig. 3: Comparison of the test-specimens deformities with minor (a) and major (b) rings slope to the joint surface immediately before the fracture

Shifts in the direction vertical to the joint

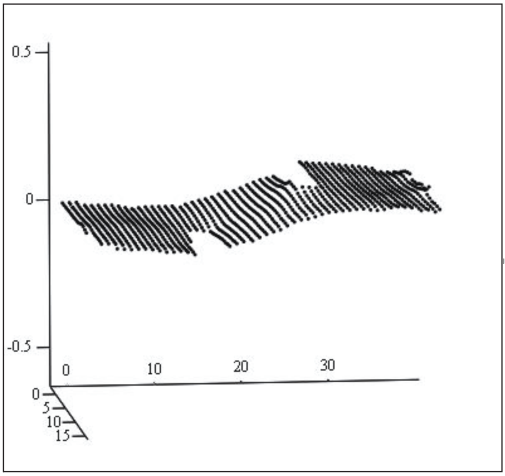

Fig. 4: Shifts in millimetres in the direction of x axis when the fracture is close to the joint

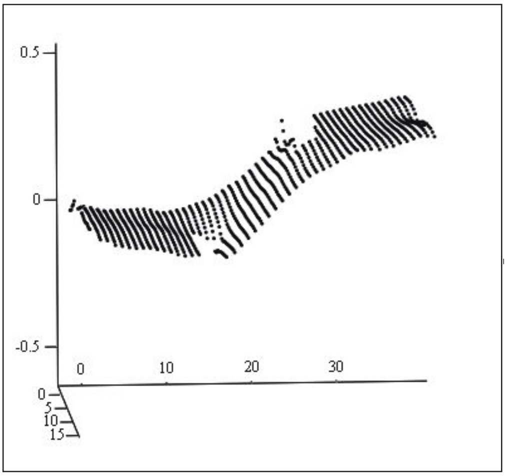

Fig. 5: Shifts in millimetres in the direction of x axis when the fracture is far from the joint

Shifts in the direction of force

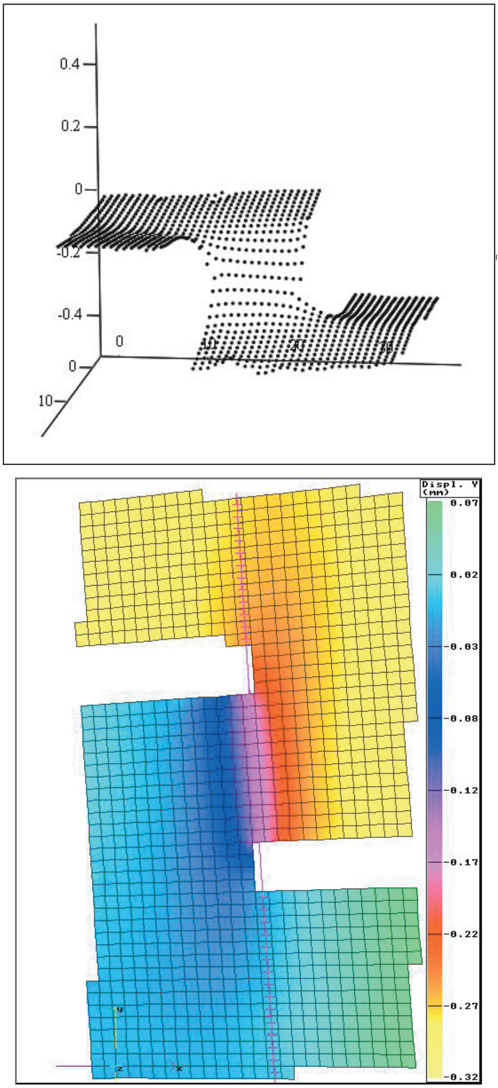

Fig. 6: Shifts in millimetres in the direction of y axis of BNa test specimen form

General observations

The key parameter which defines behaviour of the test-specimens in the gluing strength test is by all means wood rheology. Due to anisotropy, wood produces numerous variabilities so that slight structural changes may cause significant behavioural changes of a joint manifested in the size of standard deviations in all tested groups of the test-specimens.

Pressure-shear test-specimens are prone to the fractures in the area of groove at the surface of the fibres cross-section shifted from the joint surface. This is the primary consequence of the force moment generated by mechanics of the loaded test-specimen. However, this type of the fracture is typical for the test-specimens with wide rings angle to the joint surface. The point of fracture differs in every group. Consequently, a detailed inspection of the fracture area shows that the fracture direction generally follows the plane of parenchymal cells. Apparently, the lignin-pectin bonds between the fibres and the axial conductive cells, being very prone to the action of tensile forces caused by the test-specimen deformities, cannot resist the imposed stresses. However, in the test-specimens where the parenchymal cells plane is under a wider angle to the joint surface, the force does not act in that plane which accounts for bigger strength of wood. This reduces the share of test-specimens with fractured surface shifted from the joint (Tab. 3).

Strength

For the purpose of results impartiality shown as strength, the conditions which lead to the fracture must also be defined. Many factors define the conditions. The biggest issue in results interpretation is their mutual interference. Given the aim of identifying the influence of the rings slope to the joint surface, maximal number of other known influential factors was left unchanged.

The first distinguishable indicator of differences between the compared test-specimen groups is a big difference in strength and in results variances (Fig. 1). Homogeneity of variances between the groups is not satisfactory (Tab. 1). Consequently, the variances were analysed by nonparametric statistical tests (Tab. 2.). The results show statistically significant difference between some groups. Standard deviation in the average value is very big, indicating significant influence of the uncontrolled factors. Apparently, one of them is a high share of test-specimens with the fractured surface shifted from the joint (Tab. 3).

Statistical analysis of all groups clearly shows the existence of a turning point. Comparison of the test-specimens with wider rings slope (BNaI – BNaIII) with those having smaller rings slope (BNaV and BNaVI) shows apparent statistically significant differences. BNaIV test-piece has the rings slope within the range from 50° to 28° shows no statistically significant differences compared with all other groups. So it represents the optimal range for measurement of gluing strength with this type of the test-specimen.

Fractured surface analysis

Fractures of wood surfaces are particularly marked in the tested specimens. This form of a test-specimen under load is prone to the fractures markedly shifted from the joint which gives erroneous measurement result. It has been recorded, however, that change in the rings slope to the joint surface change the share of such a fracture per wood (Tab. 3).

Phototensometry of the object raster

Fig. 3 gives two limit presentations of total deformities distribution where colors indicate their percentage. Major deformities occur at the points which are, due to the test-specimen form, exposed to stress concentration which is the aim of such specific constructions.

Shift distribution diagrams on the test-specimen surface in a three-dimensional coordinate system (Fig. 4, 5 and 6) show the measured parameter on *z* axis. Axes *x* and *y* indicate positioning of the measuring point according to its position on the test-specimen.

Use of this method is of great importance when monitoring glue behaviour in the joint. Consequently, distribution of deformities in the direction of forces (axis *y*, Fig. 6) shows the effects of shear on the joint. There is no indication of joint strength being different from wood strength and manifested in the contact zone of two materials as the size of deformity and an indication of abrupt change. This shows that in the joint area there is no material that markedly differs in strength from wood. As concerns the shifts in the direction of forces, major ones (Fig. 6) and overall deformities (Fig. 3) are in the area of joint which is a positive feature of this type test-specimen.

Shifts on the *x* axis (vertical to the joint) are more marked for the test-specimens with the fracture more distant from the joint (Fig. 4 and 5).

The fractures more distant from the joint in this type of test-specimens cannot be explained by deformities developed during load. It is, therefore, clear that their main cause has already been identified during general observations having shown that they generally follow the parenchymal cells.

CONCLUSIONS

Reduced parallelism of the parenchymal cells with the joint plane ensures higher resistance to fractures and, thus, positioning of the fracture initiation point into the joint.

A very small slope of the rings line to the joint surface enhances the effects of other strength factors of the glued joint where BNaIV is the optimal measuring system.

There are several factors that indicate superiority of the BN-type test-piece with the rings slope to the joint of 30° to 50°:

- very high strength, in the first place;
- outstandingly high share of fraction in the gluing zone, in the second place;
- a good stress on the joint which is ascertained by the object raster method.

REFERENCES

1. Bogner, A., 1993: Modifikacija površine bukovine radi poboljšanja lijepljenja. Doktorska disertacija. Sveučilište u Zagrebu, Šumarski fakultet
2. Bousquet, D. W., 1970: Preliminary study of a notched compression shear test specimen. Forest Prod. J. Technical Note 20(4): 29-30
3. Hawke, R. N., Sun, B. C. H., Gale, M. R., 1992: Effect of fiber mat moisture content on strength properties of polyisocyanate-bonded hardboard. Forest Prod. J., 42(11/12): 61-68
4. Marra, A. A., 1962: Geometry as an independent variable in adhesive joint studies. Forest Products Journal. February
5. Mihulja, G., Bogner, A., Turkulin. H., (1999): Modificiranje površine bukovine ozračivanjem UV svjetlošću. Drvna ind. 50 (3): 133-140
6. Murmanis, L., River, B. H., 1986: Surface and subsurface characteristics related to abrasive-planing conditions. Wood and Fiber Science, 18(1): 107-117
7. Northcott, P. L., 1955: Possibilities of the glueline-cleavage test when applied to hardboard. Forest Prod. J. 5(2): 61-64

8. Schmidt, T., Tyson, J., 2003: Dynamic strain measurement using advanced 3D photogrammetry. Proceedings of IMAC XXI, Kissimmee, FL, Feb. 4, 2003
9. Sokal, R. R., Rohlf, F. J., 1995: Biometry. Freeman and Company. New York
10. Strickler, M. D., 1968: Specimen designs for accelerated tests. Forest Products Journal. 14(1): 8A, 84-90
11. Šonje, Ž., 1992: Untersuchungen über die Festigkeiten von Verklebungen mit reaktiven PUR-Schmelzklebstoffen. Holz als Roh- und Werkstoff 50: 401-406
12. Tyson, J., Schmidt, T., Shahinpoor, M., Galanulis, K., 2002: Biomechanics deformation and strain measurements with 3D image correlation. Experimental Techniques, Vol.26, No.5, Pp. 39-42, Sept./Oct. 2002
13. Troendle, J.F., 1995: A stepwise resampling method of multiple hypothesis testing. Journal of the American Statistical Association; 90(429): 370:378
14. Yavorsky, J. M., Cunningham, J. H., Hundley, N. G., 1955: Survey of factors affecting strength tests of glue joints. Forest Prod. J. 5(10): 306-311
15. **** 1983: DIN EN 205 – Bestimmung der Klebfestigkeit von Längsklebungen im Zugversuch sowie bei statischer Dauerbelastung
16. **** 1991: DIN EN 204 – Beurteilung von Klebstoffen für nichttragende Bauteile zur Verbindung von Holz und Holzwerkstoffen
17. **** 2001: ISO 6238 – Adhesives – Wood-to-wood adhesive bonds – Determination of shear strength by compressive loading

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