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Identification of Defective Joints in Beams via Torsional Vibration

Identifikacija neispravnih spojeva u gredama uz pomoć torzijskih vibracija

ORIGINAL SCIENTIFIC PAPER

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ABSTRACT • *The determination of the shear dynamic modulus in wood product panels is of greater importance than its determination in wood beams. Yet with regards to the effect of defects on the obtained values of shear modulus, this factor is used to detect the defects and the degree of the defects. In this study, the effect of gluing defects in two joint shapes (scarf (45°) and finger joints (10 mm length and 3 mm pitch) were evaluated non-destructively using the torsional vibration method. Rectangular wood specimens with dimensions of 20 mm × 40 mm × 360 mm (R × T × L) were prepared from clear eastern beech. The joints were located at similar positions in the middle of the beams. The results showed that creating a healthy joint did not significantly change the values obtained for the shear modulus in either of the joint shapes. However, reducing the adhesion level in both types of joints caused a significant reduction in the shear modulus values. The results show that the changes in the dynamic shear modulus values in both joint types, as a result of changes in the glue coverage rating (fully, medium and low-glued joints) allows the detection of the defects as well as the degree of the defects.*

KEYWORDS: *joint; prediction; defect; torsional vibration; beech; adhesive*

SAŽETAK • *Određivanje dinamičkog modula smicanja u drvnim pločama važnije je od određivanja tog modula u drvenim gredama. Ipak, s obzirom na utjecaj grešaka na vrijednosti modula smicanja, određivanje tog faktora važno je za otkrivanje grešaka i njihova stupnja na drvnim proizvodima. U ovom je istraživanju metodom torzijskih vibracija nedestruktivno procijenjen utjecaj grešaka lijepljenja u dva oblika spoja: kosim sljubom (45°) i klinastim zupcima (duljine 10 mm i koraka 3 mm). Uzorci drva dimenzija 20 mm × 40 mm × 360 mm (R × T × L) izrađeni su od čiste bukovine, a spojevi su izvedeni na približno istim mjestima na sredini greda. Rezultati su pokazali da izrada zdravog spoja nije bitno promijenila vrijednosti modula smicanja ni za jedan od primijenjenih tipova spoja. Međutim, smanjenje razine adhezije u obje vrste spojeva uzrokovalo je znatno smanjenje vrijednosti modula smicanja. Rezultati pokazuju da promjene vrijednosti dinamičkog modula smicanja u oba tipa spoja kao rezultat promjene stupnja pokrivenosti ljepilom (potpuna, srednja i slaba pokrivenost) omogućuju otkrivanje grešaka lijepljenja, kao i stupnja grešaka drvnih spojeva.*

KLJUČNE RIJEČI: *spoj; predviđanje; greška; torzijske vibracije; bukovina; ljepilo*

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1 INTRODUCTION
1. UVOD

The application of adhesive joints has become widespread in many wood utilization fields since their first commercial use in the late 1950s. It has become one of the most frequently used jointing methods to produce larger products while using short pieces of lumber. Adhesive joints have numerous applications in structural members, e.g., glulam and end to end joints, which were developed to reduce the waste of high-quality lumber, and are some of the most economically valuable ways to utilize wood. Low-grade wood can be used to produce high quality final products with improved strength and appearance, and without undesirable characteristics (Roohnia *et al.,* 2012). However, some of the bonding joints may lose their efficiency due to environmental factors (temperature changes or moisture absorption/desorption) or mechanical stresses that occur during service time. Thus, as producing reliable joints is important, improving them throughout service time would be equally important (Biechele *et al.,* 2010). Various techniques are used for the quality control of bonding joints. According to the type of joint, some standards have been edited (ASTM D905, ASTM D906 2004; ASTM D1073 2012), but these methods are time-consuming and destructive, so controlling and inspecting of all the joints might not be possible (Ayarkwa et al. 2001). In addition, destructive techniques are not applicable throughout service time. Non-destructive testing (NDT) is an effective method for quickly testing and evaluating the properties of materials, and does not alter the physical, chemical, and mechanical properties of the materials. Furthermore, it has no influence on future performance. The exploitation and application of this technology has been quickly developed in the field of wood and wood-products, evidencing its advantages (Ross and Pellerin 1994). In recent years, nondestructive techniques have been used by many researchers to identify the defects in wood and wood products (Lee et al. 2000; Axmon et al. 2004; Baskaran and Janawadkar 2005). Most of the research on joints and non-destructive testing is related to the changes in the modulus of elasticity; some of these studies are outlined below. Rohnia et al. (2012) stated that defects in the joint adhesion (scarf and finger joints) reduce the modulus of elasticity due to longitudinal and flexural vibration. In 2014, Roohnia et al. reported that, by reducing the joint angle in the scarf joints species of oak wood (Quercus Castaneifolia), the modulus of elasticity of this species was reduced (the study of joint angles of 60, 65, 70 and 75 degrees). They also stated that joining with isocyanate adhesive causes a greater drop in dynamic modulus values than polyvinyl acetate adhesive. In 2017, Lara-Bocanegra et al. examined the effect of adhesive type on the flexural strength of Eucalyptus globulus-type finger joints. They stated that the use of 1C-PUR glue significantly increases the finger joint strength in this species. Although torsional properties are considered in the plates, they are less considered in vibrating beams (Bodig and Jayne 1993). However, during troubleshooting, the dynamic response of the beams can be discussed in terms of the healthiness or unhealthiness of the beams. Roohnia and Kohantorabi (2015) discussed the efficiency of the torsional vibration method, which was based on the ASTM standard C1548-02 (2002), and is used to determine the value of the shear modulus of wooden beams and plates turned into beams. The main purpose of this study was to investigate the impact of joint disadvantages on the dynamic shear modulus of the structure with different glue covering values for beech wood (*Fagus orientalis* L.). If the applied techniques in this study were effective in detecting defected joints, they would be valuable for grading the joints in structures during service time.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Materials
2.1. Materijali

Fifty five samples without any visual defects were prepared from eastern beech (*Fagus orientalis* L.) commercial lumber with dimensions of 20 mm × 40 × mm × 360 mm (R × T × L), according to ISO standard 3129 (2019). In the selection procedure, all visually sound beams with clear radial and tangential surfa˝wces were accepted. The samples were placed in a conditioning room at 21 °C and a relative humidity of 65 % until reaching equilibrium moisture content (EMC). The specimens were subjected to free flexural vibration via a both-end free beam test. Considering the three initial vibration modes, and based on Timoshenko's bending theory, the specimens with the highest Timoshenko's correlation coefficient in the initial vibration modes were selected for further experiments. This selection criterion was based on the procedure described in the published literature (Brancheriau and Baillères, 2002; Roohnia *et al*., 2012). Accordingly, the total number of specimens decreased to 42. The selection procedure seemed to be necessary to ensure the clarity of the specimens. Therefore, any extra footprints were calibrated as a result of the positive or negative perfectness of the joints. Each sample was then individually subjected to the torsional vibration test (Figure 1). The torsional vibration was performed on the samples according to ASTM standard C1548 (2002). The selected specimens were divided into two groups, based on the differences in joint shape, i.e., scarf and finger joint. Three different amounts of gluing coverage were applied to the surface of each type of joint. The length of the finger joint was selected at 10 mm, the pitch was selected at 3 mm, and the total number of fingers was 7, with a joint member every 6 in. across the joint width. The joints were created with maximum accuracy using sharp blades manufactured by Makita® Co. (Aichi, Japan) for scarf joints and by Laguna Tools (Grand Prairie, TX) for finger-joints. The separated members were re-assembled in three different manners: fully glued (100 % of the surface glued), medium glued, and low glued. The medium glued and low glued joints for both joint types were considered defective in this study (Figure 2 and Table 1). The glue used in this study was conventional white glue (polyvinyl acetate, with the concentration of 65 %, pH of 5, and hardening time of 20 min) (Chasb Chob Shomal, Tehran, Iran). The glue solution was spread on the joint surfaces at a rate of 150 g/m² to 200 g/m², based on joint surface area. The joint surfaces were pressed in a constant mechanism during the hardening time. For the scarf joints, two lateral supports were also applied to ensure the exact axial orientation of the joint members without any unwanted shear movement by the joint surfaces.

2.2 Methods
2.2. Metode

Finally, each specimen set was individually subjected to the torsional vibration test. The shear modulus values were evaluated according to the equations in ASTM standard C1548-02 (2002) and the individual sets were compared. These evaluations were made using NDTlab® Software (Islamic Azad University-Karaj Branch, v.2.03, Karaj, Iran) (Roohnia *et al.*, 2006). The shear modulus was calculated according to Eq. 1, Eq. 2, and Eq. 3,

$$G=\left\{\frac{4\cdot L\cdot m\cdot f_t^2}{b\cdot t}\right\}\left\{\frac{B}{1+A}\right\} \tag{1}$$

$$A=\left\{\frac{0.5062-0.8786\cdot\left(\frac{b}{t}\right)+.03504\cdot\left(\frac{b}{t}\right)^2-0.0078\cdot\left(\frac{b}{t}\right)^3}{12.03\cdot\left(\frac{b}{t}\right)+9.892\cdot\left(\frac{b}{t}\right)^3}\right\} \tag{2}$$

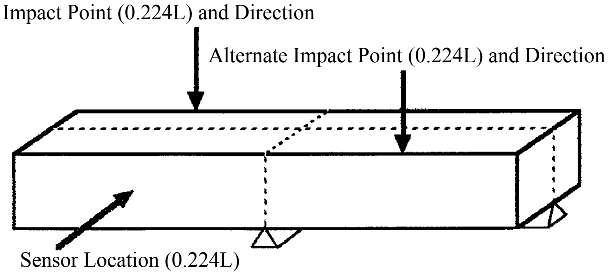

Figure 1 Experimental setup of torsional vibration test
Slika 1. Eksperimentalne postavke ispitivanja torzijskih vibracija

$$B=\left\{\frac{\left(\frac{b}{t}\right)+\left(\frac{t}{b}\right)}{4\cdot\left(\frac{t}{b}\right)-2.52\cdot\left(\frac{t}{b}\right)^2+0.21\cdot\left(\frac{t}{b}\right)^6}\right\} \tag{3}$$

Where G is the shear modulus (Pa), L is the total length of the beam (mm), m is mass of the bar (g), f_t is the fundamental resonant frequency of the bar in torsion (Hz), b is the width of the beam (mm), t is the thickness of the bar (mm), and A and B are the correction coefficients.

The correlation among the obtained values of the dynamic shear modulus of the clear beech beams, jointed in two shapes and three amounts of glue, i.e., fully glued, medium glued, and low glued, was assessed via the Pearson correlation test and the regression fit model. A comparison of each shear modulus obtained from each test stage was also made via a statistical *T*-test at a 95 % confidence level. The SPSS software (Version 11.5, IBM Co., Armonk, NY) was used for the statistical tests and Microsoft Excel 2013 was used to draw the regression lines and diagrams. The comparison was based on the clarity of the wood.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Prior to presenting the research findings, a discussion on the definition of elastic properties is necessary. Elastic properties are material properties that do

Table 1 Description of joints and glued areas (as shown in Figure 2a and 2b)
Tablica 1. Opis spojeva i područja lijepljenja (prikazano na slikama 2.a i 2.b)

Joint *Spoj*	**Total nominal joint area** *Ukupna nominalna površina spoja* mm × mm	**Fully glued joint area** *Potpuna pokrivenost površine spoja ljepilom* mm × mm	**Medium glued joint area** *Srednja pokrivenost površine spoja ljepilom* mm × mm	**Low glued joint area** *Slaba pokrivenost površine spoja ljepilom* mm × mm
Scarf 45° *kosi sljub od 45°*	55 × 20 (width × height) *(širina × visina)*	55 × 20 (100 %)	5 × 20 near both edges + middle *5 × 20 blizu oba ruba + sredina* (27.3 %)	5 × 20 near both edges *5 × 20 blizu oba ruba* (18.2 %)
Finger *zupci*	120 × 20 (width x height) *(širina × visina)*	120 × 20 (100 %)	10 × 20 edge fingers + two middle fingers / *10 × 20 krajnji zupci + 2 srednja zupca* (33.3 %)	10 × 20 edge fingers only *10 × 20 samo krajnji zupci* (16.7 %)

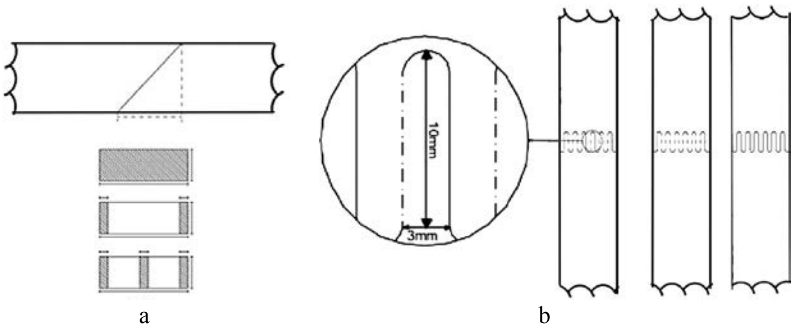

Figure 2 Joint shapes and glue coverage (view from the wider surface of the beam): a) Group one, 45° scarf joint; and b) Group two, finger joint (Note: -.-.- indicates the area without glue)
Slika 2. Tipovi spojeva i pokrivenost ljepilom (pogled na širu površinu grede): a) prva skupina, kosi sljub od 45°; b) druga skupina, spoj zupcima (-.-.- označava područje bez ljepila)

not change after geometrical and artificial manipulations of the beam. However, in this study, these properties have been specifically defined as the dynamic response of a beam, even though the dynamic response of the bar would be affected (Roohnia *et al*., 2012; Kohantorabi *et al*., 2015).

The shear moduli values of the fully glued specimens with the scarf joint and finger joint are plotted against a solid beam in Figure 3 and 4.

There was no significant difference between the solid wood and the fully glued specimens in terms of the dynamic shear modulus (Figure 3).

Statistically equivalent results of dynamic shear modulus values of solid beams and jointed beams (healthy joint without defect in glue coverage), obtained from ASTM C 1548 standard, has not been previously studied. However, according to the results of the first part of this study, which was published in 2012, the dynamic modulus of elasticity of the specimens remained unchanged due to the creation of both types of joints (Roohnia *et al*., 2012). In a similar study, Yavari *et al.* (2015) stated that finger joint and scarf joint in oak beams did not alter the values of dynamic modulus of elasticity compared to solid beams (Yavari *et al*., 2015). Therefore, according to the results of this study, it can be said that the creation of these two types of joints, if they are without defects in glue coverage, does not change significantly the values of the dynamic shear modulus.

The dynamic response of the shear modulus values for the medium glued specimens are plotted against a solid beam with respect to finger and scarf joints in Figure 5 and 6. When the glued members were assembled with a medium amount of glue, the values of the dynamic shear moduli decreased by 5 % in the finger

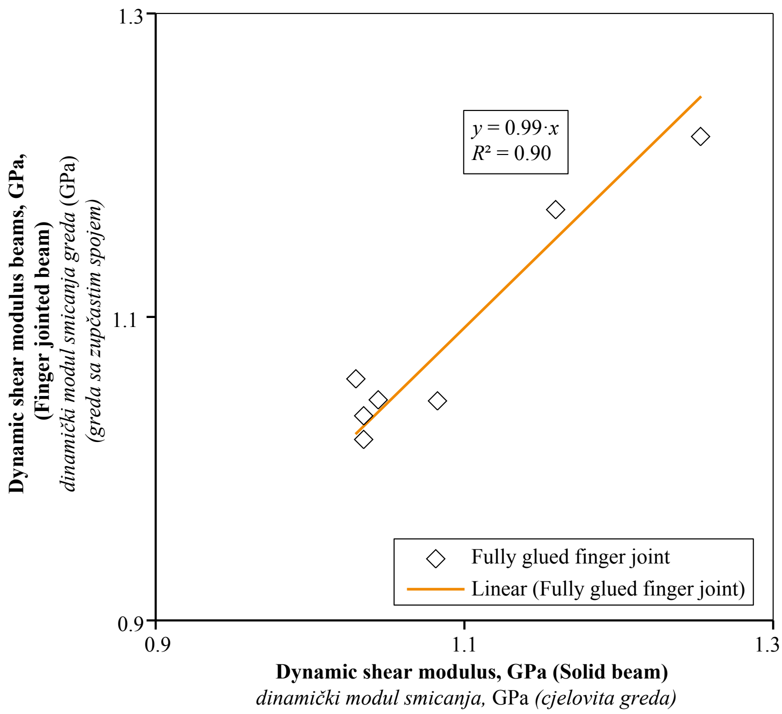

Figure 3 Shear modulus values of fully glued finger jointed specimens against a solid beam after torsional vibration test
Slika 3. Vrijednosti modula smicanja uzoraka spojenih zupcima, uz potpunu pokrivenost površine spoja ljepilom, u odnosu prema cjelovitoj gredi nakon ispitivanja torzijskih vibracija

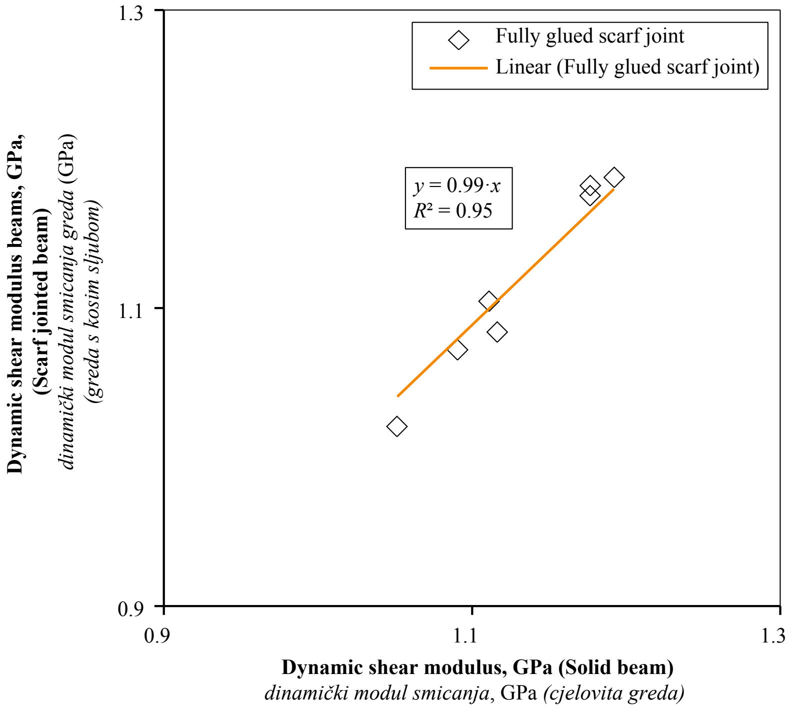

Figure 4 Shear modulus values of fully glued scarf jointed specimens against a solid beam after torsional vibration test
Slika 4. Vrijednosti modula smicanja uzoraka spojenih kosim sljubom, uz potpunu pokrivenost površine spoja ljepilom, u odnosu prema cjelovitoj gredi nakon ispitivanja torzijskih vibracija

joint samples and by 12 % in the scarf joint samples. The reason for this, in addition to the amount of glue used in the finger joint, could also be related to the physical shape of the finger joint.

The dynamic changes of the shear modulus values of the low glued specimens in finger and scarf joints are plotted against a solid beam with respects to finger and scarf joints in Figure 7 and 8. When the glued members were assembled with a low amount of glue, the values of the dynamic shear modulus decreased by 10 % in the finger joint samples and by 27 % in the scarf joint samples. As shown in Table 1, in

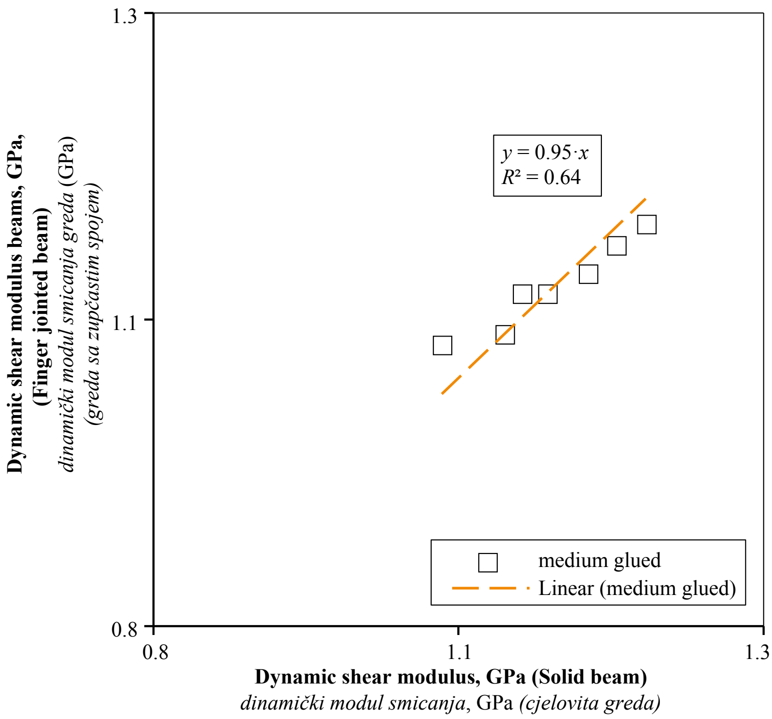

Figure 5 Shear modulus values of medium glue finger jointed specimens against a solid beam after torsional vibration test
Slika 5. Vrijednosti modula smicanja uzoraka spojenih zupcima, uz srednju pokrivenost površine spoja ljepilom, u odnosu prema cjelovitoj gredi nakon ispitivanja torzijskih vibracija

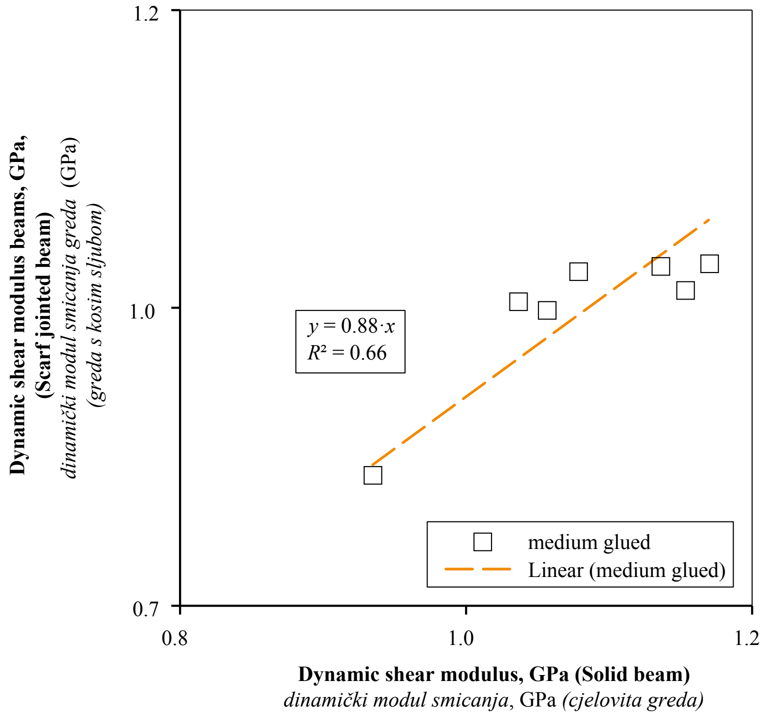

Figure 6 Shear modulus values of medium glue scarf jointed specimens against a solid beam after torsional vibration test
Slika 6. Vrijednosti modula smicanja uzoraka spojenih kosim sljubom, uz srednju pokrivenost površine spoja ljepilom, u odnosu prema cjelovitoj gredi nakon ispitivanja torzijskih vibracija

the low glued joint samples, the amount of adhesive used in the finger joint samples was greater than that in the scarf joint samples. However, it seems that the physical shape of the finger joint and fingers interlock had a greater effect on the dynamic shear modulus.

In previous researches on the elastic properties of the jointed beams, cases such as the effect of finger length, the effect of the type of adhesive, the effect of the angle of joint, etc. have been investigated. Each of the above has a different effect on the dynamic properties of the jointed beams (Ayarkawa *et al*., 2000; Bustos *et al*., 2003; Ozcifci and Yapici, 2008; Hemmasi *et al*., 2014; Roohnia *et al*., 2012, 2014; Yavari *et al*., 2015). The effect of the dimensions of adhesion defects

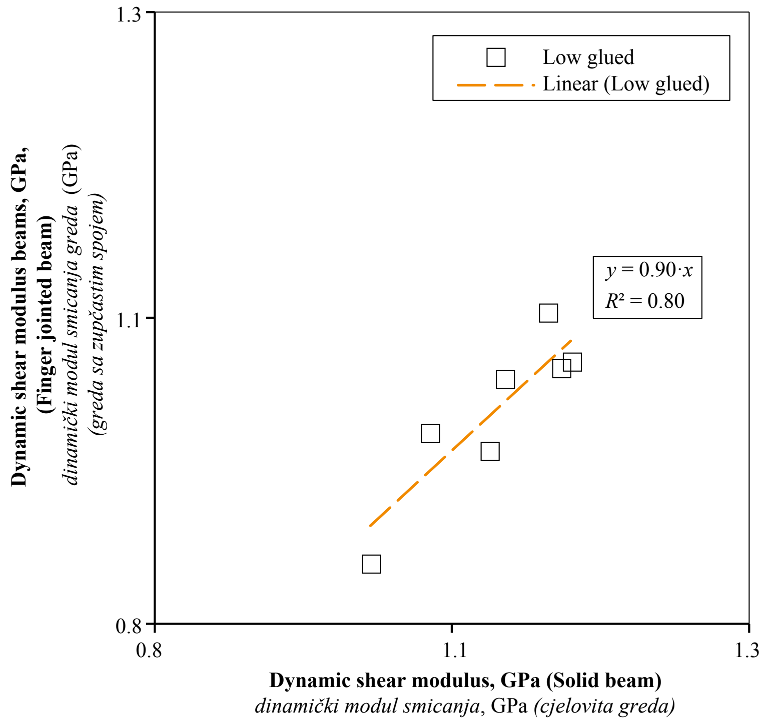

Figure 7 Shear modulus values of low glue finger jointed specimens against a solid beam after torsional vibration test
Slika 7. Vrijednosti modula smicanja uzoraka spojenih zupcima, uz slabu pokrivenost površine spoja ljepilom, u odnosu prema cjelovitoj gredi nakon ispitivanja torzijskih vibracija

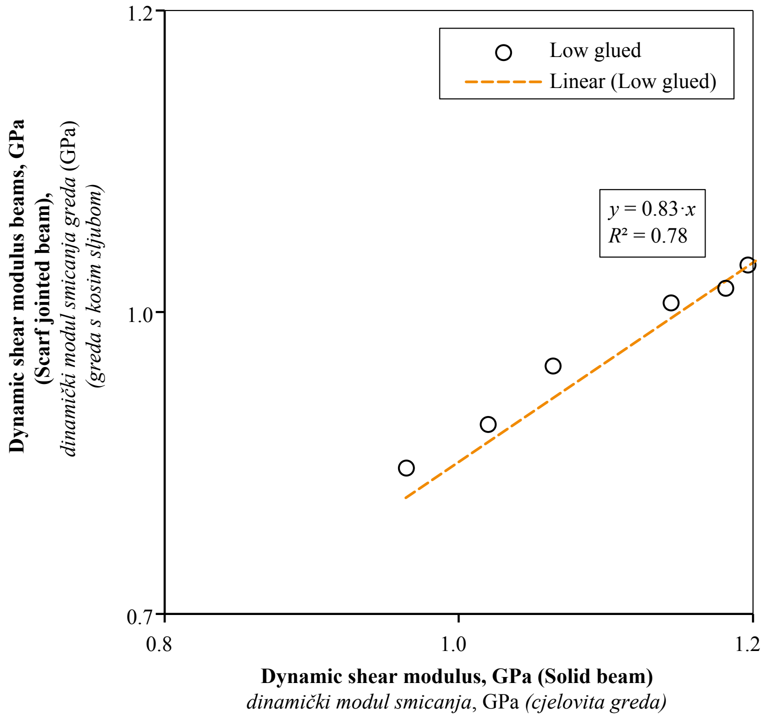

Figure 8 Shear modulus values of low glue scarf jointed specimens against a solid beam after torsional vibration test
Slika 8. Vrijednosti modula smicanja uzoraka spojenih kosim sljubom, uz slabu pokrivenost površine spoja ljepilom, u odnosu prema cjelovitoj gredi nakon ispitivanja torzijskih vibracija

on the dynamic properties has been frequently obtained by ultrasound test. Research has shown that the size of the defects in the adhesive has a significant effect on the values of elastic parameters of ultrasound tests (Tucker *et al*., 2003; Grimberg *et al.,* 2005; Baskaran and Janawadkar, 2007). In the first part of this study, the size of the defects in adhesive had a significant effect on the dynamic modulus of elasticity. As results indicate, the dimensions of defects in adhesive cause a significant reduction of the dynamic shear modulus in the jointed beams with defects. These changes in values are considered efficient in detecting the defect and its degree in scarf and finger joints.

4 CONCLUSIONS
4. ZAKLJUČAK

No significant differences were found between the calculated dynamic shear modulus values in terms of the fully glued specimens and the solid wood sample for both types of joint (scarf and finger joints). It seems that this lack of significant difference is a suitable criterion for identifying healthy glued joints.

Weaker joints, in both types of joints, showed unequal response to the evaluated dynamic shear modulus of the medium and low glued specimens obtained from the results of torsional vibration test.

The amount of reduction in the values of the dynamic torsional modulus in the scarf joint samples was greater than in the finger joint samples, which could be attributed to the physical shape of this joint.

Due to the inhomogeneous dynamic response received from both adhesion levels in both types of joints, when utilizing the torsional vibration method, in addition to the defective scarf and finger joints, the amount of defects in these two types of joints can be determined.

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5 REFERENCES
5. LITERATURA

1. Axmon, J.; Hansson, M.; Sörnmo, L., 2004: Experimental study on the possibility of detecting internal decay in standing Picea abies by blind impact response analysis. Forestry, 77 (3): 179-192. https://doi.org/10.1093/forestry/77.3.179
2. Ayarkwa, J.; Hirashima, Y.; Sasaki, Y., 2001: Predicting modulus of rupture of solid and finger-jointed tropical African hardwoods using longitudinal vibration. Forest Products Journal, 51 (1): 85-92.
3. Baskaran, R.; Janawadkar, M. P., 2007: Imaging defects with reduced space inversion of magnetic flux leakage fields. NDT & E International, 40 (6): 451-454. https://doi.org/10.1016/j.ndteint.2007.01.002
4. Beaulieu, C.; Verreault, C.; Gosme, C.; Samson, M., 1997: Experimental assessment of the effect of length on the tensile strength of structural finger-joined lumber. Forest Products Journal, 47 (10): 94-100.

5. Biechele, T.; Chui, Y. H.; Gong, M., 2010: Assessing stiffness on finger-jointed timber with different non-destructive testing techniques. In: Proceedings of the final conference of COST Action E53: Quality Control for Wood & Wood Products. Edinburgh, United Kingdom, pp. 522-528.
6. Bodig, J.; Jayne, B. A., 1993: Mechanics of wood and wood composites (Persian Translation by Ebrahimi G.). University of Tehran Press, Tehran, Iran.
7. Brancheriau, L.; Baillères, H., 2002: Natural vibration analysis of clear wooden beams: a theoretical review. Wood Science and Technology, 36: 347-365. http://dx.doi.org/10.1007/s00226-002-0143-7
8. Bustos, C.; Beauregard, R.; Mohammad, M.; Hernandez, R., 2003: Structural performance of finger jointed black spruce lumber with different joint configurations. Forest Products Journal, 53 (9): 1-6.
9. Byeon, H. S.; Park, H. M.; Kim, C. H.; Lam, F., 2005: Nondestructive evaluation of strength performance for finger-jointed wood using flexural vibration techniques. Forest Products Journal, 55 (10): 37-42.
10. Grimberg, R.; Savin, A.; Steigmann, R.; Bruma, A., 2005: Ultrasound and visual examination of wood based products. In: Proceedings of 8th International Conference of the Slovenian Society for Non-destructive Testing. Portoro, Slovenia, pp. 109-115.
11. Hemmasi, A. H.; Khademi-Eslam, H.; Roohnia, M.; Bazyar, B.; Yavari, A., 2014: Elastic properties of oak wood finger joints with polyvinyl acetate and Isocyanate adhesives. BioResources, 9 (1): 849-860. https://doi.org/10.15376/biores.9.1.849-860
12. Kohantorabi, M.; Hemmasi, A.; Talaeipour, M.; Roohnia, M.; Bazyar, B., 2020: Effect of artificial inhomogeneity of density and drilling on dynamic properties developed by Poplar block species (*Populus nigra*) jointed with oak wood (*Quercus castaneifolia*) beams. BioResources, 15 (3): 4711-4726. https://doi.org/10.15376/biores.15.3.4711-4726
13. Kohantorabi, M.; Hossein, M. A.; Shahverdi, M.; Roohnia, M., 2015: Vibration based NDT methods to verify wood drying efficiency. Drvna industrija, 66 (3): 221-228. https://doi.org/10.5552/drind.2015.1352
14. Lara-Bocanegra, A. J.; Majano-Majano, A.; Crespo, J.; Guaita, M., 2017: Finger-jointed Eucalyptus globulus with 1C-PUR adhesive for high performance engineered laminated products. Construction and Building Materials, 135: 529-537. https://doi.org/10.1016/j.conbuildmat.2017.01.004
15. Lee, J.; Lyo, S.; Nam, Y., 2000: An algorithm for the characterization of surface crack by use of dipole model and magneto-optical non-destructive inspection system. KSME International Journal, 6 (1): 1072-1080. https://doi.org/10.1007/BF03185061
16. Ozcifci, A.; Yapici, F., 2008: Structural performance of the finger-jointed strength of some wood species with different joint configurations. Construction and Building Materials, 22 (7): 1543-1550. https://doi.org/10.1016/j.conbuildmat.2007.03.020
17. Roohnia, M.; Kohantorabi, M., 2015: Dynamic methods to evaluate the shear modulus of wood. BioResources, 10 (3): 4867-4876. https://doi.org/10.15376/biores.10.3.4867-4876
18. Roohnia, M.; Hemmasi, A. H.; Yavari, A.; Khademi-Eslam, H.; Bazyar, B., 2014: Modulus of elasticity in scarf-jointed wooden beams: A case study with polyvinyl acetate and Isocyanate adhesives. Journal of Wood Science, 60 (5): 321-326. https://doi.org/10.1007/s10086-014-1413-3
19. Roohnia, M.; Brémaud, I.; Guibal, D.; Manouchehri, N., 2006: NDT_Lab; Software to evaluate the mechanical properties of wood. In: Proceedings of the International Conference on Integrated Approach to Wood Structure Behaviour and Applications: Joint meeting of ESWM and Cost Action E35. Florence, Italy, pp. 213-218.
20. Roohnia, M.; Kohantorabi, M.; Jahan-Latibari, A.; Tajdini, A.; Ghaznavi, M., 2012: Nondestructive assessment of glued joints in timber applying vibration-based methods. European Journal of Wood and Wood Products, 70 (6): 791-799. https://doi.org/10.1007/s00107-012-0616-9
21. Roohnia, M.; Hemmasi, A.; Yavari, A.; Khademieslam, H.; Bazyar, B., 2014: Modulus of elasticity in scarf-jointed wooden beams: A case study with polyvinyl acetate and isocyanate adhesives. Journal of Wood Science, 60: 321-326. https://doi.org/10.1007/s10086-014-1413-3
22. Ross, R. J.; Pellerin, R. F., 1994: Nondestructive testing assessing wood members in structures (FPL-GTR-70). U. S. Department of Agriculture, Forest Products Laboratory, Madison, WI.
23. Timoshenko, S. P., 1921: LXVI. On the correction for shear of the differential equation for transverse vibrations of prismatic bars. The London, Edinburgh and Dublin Philosophical Magazine and Journal of Science, 41 (6): 744-746. https://doi.org/10.1080/14786442108636264
24. Yavari, A.; Hemmasi, A. H.; Roohnia, M.; Marušák, R., 2015: Dynamic Young's modulus of scarf- and finger-jointed beams using longitudinal vibration method. BioResources, 10 (4): 6886-6895. https://doi.org/10.15376/biores.10.4.6886-6895
25. ***ASTM C1548-02, 2002: Standard test method for dynamic Young's modulus, shear modulus and Poisson's ratio of refractory materials by impulse excitation of vibration. ASTM International, West Conshohocken, PA.
26. ***ASTM D905-98, 2004: Standard test method for strength properties of adhesive bonds in shear by compression loading. ASTM International, West Conshohocken, PA.
27. ***ASTM D906-98, 2004: Standard test method for strength properties of adhesives in plywood type construction in shear by tension loading. ASTM International, West Conshohocken, PA.
28. ***ASTM D1037-99, 2012: Standards test methods for evaluation properties of wood-base fiber and particle panel materials. ASTM International, West Conshohocken, PA.
29. ***ISO-3129, 2019: Wood – Sampling methods and general requirements for physical and mechanical testing of small clear wood specimens. International Organization for Standardization, Geneva, Switzerland.

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