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CONSIDERATIONS ON THE OPTIMAL TESTING OF THE GLUES USED IN WOOD-INDUSTRY

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Abstract: The authors, based on scrupulously analyzes of the literature, as well as on their former/previous experimental results, propose a new approach in the glue testing systems, mainly destined to the wood industry. The authors' previous experimental investigations, using both Moiré Fringe Method and Holographic Interferometry lead to some useful conclusions concerning on the test specimen's optimal shape as well as to its loading conditions. In this sense, the main goal of a common glue testing system consists of in establishing the permissible (admissible) shear strength of the glues. The most of the testing systems use test specimens and loading conditions, which produce undesired supplementary solicitations and consequently the so-called shear strength established in these conditions will be far (much less) from the real one. In order to eliminate these supplementary solicitations, such as bending, peeling (the so-called peel stress), etc., there is strongly need new type of test specimen and loading conditions, too. The author also performed meticulous numerical simulation, involving ANSYS 14.0 program, in order to put in evidence the mentioned undesired supplementary solicitations. Based on both the previous experimental results and on the numerical simulations' results, the authors propose (mainly for the wood-industry) a new test specimen and also a new approach, concerning on the testing bench. The proposed new test specimen will be analyzed involving ultramodern and high-accuracy optical systems, like Digital Image Correlation (DIC) and Electronic Speckle Pattern Interferometry (ESPI). In the forthcoming period, the authors propose performing several high-accuracy experimental investigations in order to establish as accurate as possible the magnitude of the shear strength of several widely-used glues in the wood industry.
Keywords: glue, wood industry, test specimen, testing bench, shear strength

1. INTRODUCTION

In the wood industry and especially in the furniture one, the proper selection of the glue leads to lower costs and higher-quality products. The selected glue has to possess both high value of the permissible shear strength and good time-dependent behaviours, too.

A good time-dependent behaviour of the glue means to obtain as quickly as possible its nominal strength (in the shortest time after the gluing). Consequently, the manufacturing time (corresponding to the squeezing of the assembled elements) will be reduced and also its manufacturing cost, too.

Unfortunately, any of the glue-producers companies has any intention to offer such important information and the wood engineer has to establish by own way these parameters. In this sense, there is important to select both the proper test specimen and the adequate experimental investigation method.

In the authors' opinion, based on over thirty years experimental practice, in order to obtain adequate efficiency of the investigations, only non-contact, full-field methods (as the optical ones, like Digital Image Correlation (DIC) and Electronic Speckle Pattern Interferometry (ESPI), or Holographic Interferometry (HI) can be involved in such high-accuracy tests.

There are several standards and corresponding test specimens, detailed between others in references [6, 16]. Their detailed advantages and limits are also analyzed in references [1, 2, 3, 6, 9, 12, 14].

Some special issues, offering different testing methods on special test specimens, with useful results are summarized in references [5, 6, 7, 9, 15], as well as numerical analyzes of the shear strength's load-bearing capacity [8].

Taking into the consideration the above-mentioned references and the authors' previous results [10, 11], in the following will be analyzed the main useful aspects of the test specimens and their loading conditions.

2. ANALYTICAL APPROACH OF THE TEST SPECIMENS

About the overlapping influence, in reference [6], there are sum up several useful aspects, based also on the previous investigations of Goland and Reissner [1], Volkersen [14], as well as of Hart-Smith [2, 3], from where one can mention the followings:

- The single-lap solutions (how will be analyzed both of them below) always leads strong supplementary bending effect, as well as the undesired peeling stress with high magnitudes at the ends of the overlaps;
- A significant improvement will offer the double-lap solution, by diminishing the above-mentioned effects, but not wholly eliminating;
- Also, by the authors' previous experimental investigations on such double-lapped test specimens, involving HI [10, 11], where putted in evidence several minutes small relative rotations of the components of the test specimens, which prove, together with the similar investigations of Müller [7] and Yong [15], performed with ESPI method;
- Some complex/multiple test specimens, involving up to ten (or more) elements, proposed by several authors, leads in the authors' opinion, some element of uncertainties, mainly in working/preparation accuracy of the components, in their assembling by gluing, as well as in identical loading conditions of them; these uncertainties can be put in evidence especially when there are involved in experiments full-field, high-accuracy noncontact methods, such HI, ESPI, as well as DIC;
- Due to the combination of these solicitations (shear with undesired bending and peeling), it will be very difficult to separate the shear effect from the mentioned undesired ones.

In conclusion, to put in evidence the pure shear effect (how is the adhesive responses to the shear effort), one has to look for other kinds of test specimens; which will be analyzed below.

In order to obtain a little bit clear approach of the solicitations, one can admit in the first attempt the hypothesis of the rigid elements of the test specimens (similarly with the Strength of Materials), excepting the glue layer, which will be considered hyper-elastic one.

Based on this hypothesis, the single-lapping test specimen, loaded axially with eccentrically-applied axial force, is analyzed in Figure 1. In this figure h_0 and h_1 represents the thickness of the wood-element, respectively of the glue-layer, with $h_0 \rangle\rangle h_1$.

In the Figure 1 are shown both the equilibrium of the glue-layer *3*, as well as the deformed glue-layer, based on the Goland and Reissner's approach [1]. Of course, the equilibrium of the wood parts *1* and *2*, will present equal magnitudes and opposite senses of the forces and moments with respect to the glue-layer's ones. One can observe that the bending moment $N \cdot h_0 / 2$, and correspondently the peeling effect, will be very significant.

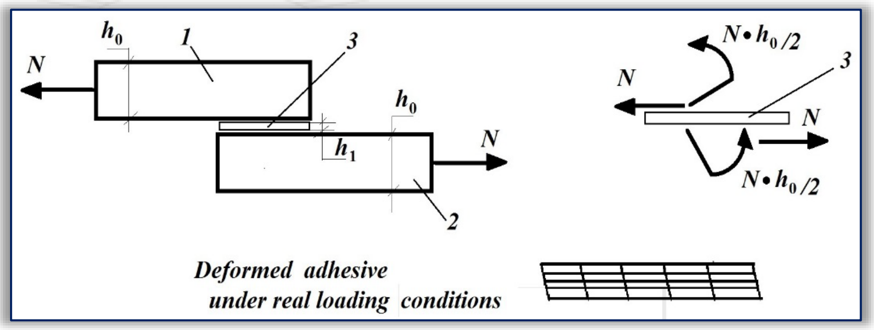

Figure1. The loading schema of the simple-lapping with eccentric axial loading

In this Figure 1, due to simplification, aren't shown neither the rotations of the wood-elements *1* and *2*, nor the corresponding deformation of the glue-layer *3*. Of course, the wood-parts deformations (due to their relatively high stiffness) aren't significant in comparison with the glue-layer's one.

Also, taking into the considerations some well-known assumptions from Strength of Materials, the presented deformation of the glue-layer, mentioned in reference [1], is a consequence of the presence of the shear forces (which can't be included in the applied equilibrium, based on the above-mentioned rigid body assumption).

In Figure 2 is offered the improved solution for the simply-lapping assembling, where the bending moment $N \cdot h_1 / 2$, and correspondently the peeling effect, will be less significant with respect to the former solution. By analyzing carefully this schema, one can conclude that here the loading is almost perfect axially, having only a small amount of bending moment (and peeling effect).

One of the specimen's disadvantages consists of its relatively difficult manufacturing (to offer plan-parallel surfaces for the wood-parts with identical thicknesses).

In several cases there are glued two identical wood-elements at the fixing level, in order to obtain the foreseen $\approx 2 \cdot h_0$ thickness; it is also widely applied in the testing of the thin elements (such as the veneers and sheets of bamboo) assembling (by gluing).

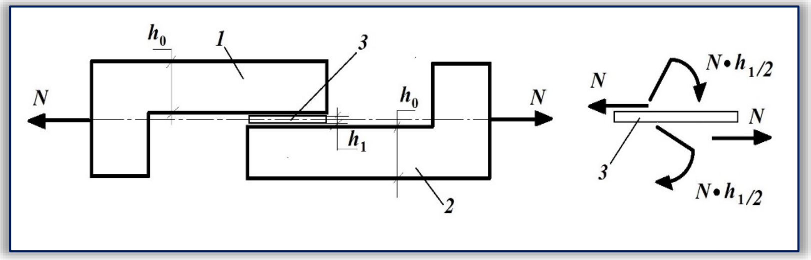

Figure 2. The loading schema of the improved simply-lapping with approximately perfect axial loading

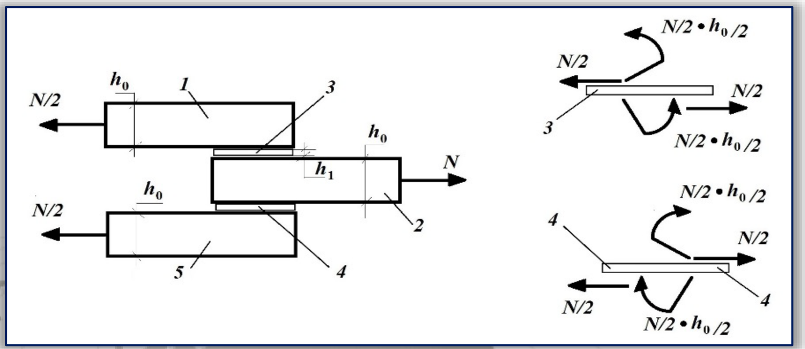

Figure 3. The loading schema of the first kind of double overlapping test specimen

In order to obtain a supplementary improvement of the test specimen (with respect to the simply overlapping, shown in Figure 1), one was conceived the double-lapping (or double overlapping) solution (Figure 3).

This solution is widely applied due to its simplicity and its relative good axial loading. In this case, the bending moment $N \cdot h_0 / 4$, and correspondently the peeling effect, will be less significant with respect to the mentioned simply overlapping one. The relatively small eccentricity of the applied load leads to small bending effect.

This kind of test specimen was used by the authors in their previous investigations by means of HI and how was mentioned before, they monitored only small peeling effect and small relative rotations of the wood-elements *1-2*, respectively *2-5* [10, 11].

In order to eliminate also these relatively small rotations and peeling effects, the authors propose the second kind of double overlapping test specimen (Figure 4).

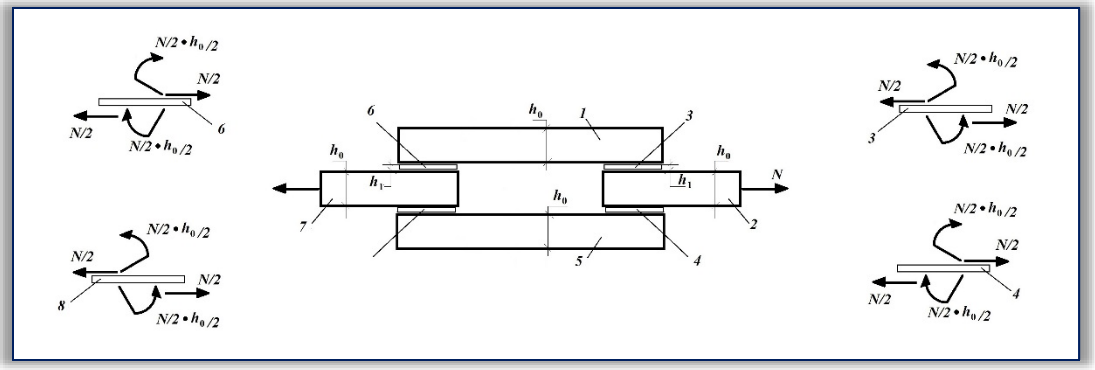

Figure 4. The proposed variants of the double overlapping

By a carefully analysis of the elements' equilibriums, one can conclude that the bending moments and the corresponding peeling effects are wholly eliminated due to the fact that the lateral wood elements *1* and *5* have relatively high stiffness.

One other advantage of this kind of test specimen consists of offering four glue-layers, instead of two from this former double overlapping one. These higher numbers of the glue-layers assure a higher precision approach of the glue testing, mainly by the above-mentioned optical, non-contact methods, where for each of the analyzed glue-layer one will obtain individual values (e.g. shear strength, residual displacements, etc.).

These individual values can be combined (e.g.: by calculating of their mean value or establishing other statistic parameter) and finally, for the same (identical) testing conditions, the researcher will obtain a more realistic approach of the requested parameters.

3. NUMERICAL APPROACH OF THE TEST SPECIMENS

The authors performed meticulous numerical simulation, by Finite Elements Method, involving ANSYS 14.0 code, in order to put in evidence the mentioned undesired supplementary solicitations.

By combining these results with the previously obtained experimental data, became possible to prove the efficiency of this improved double overlapping test specimens' efficiency, mainly for the wood-industry, but also for other adhesive-testing problems, too.

In these numerical simulations the main goal was to put in evidence the transversal displacements, which leads the so-called peeling effect.

In order to take into the consideration the variation of the adhesive stress-state through the thickness direction (mainly of the interface stresses ones), the glue thickness was divided in five layers.

In the following will be presented and comparatively analyzed the transversal displacements' fields of the glue-layers (in z-axis direction).

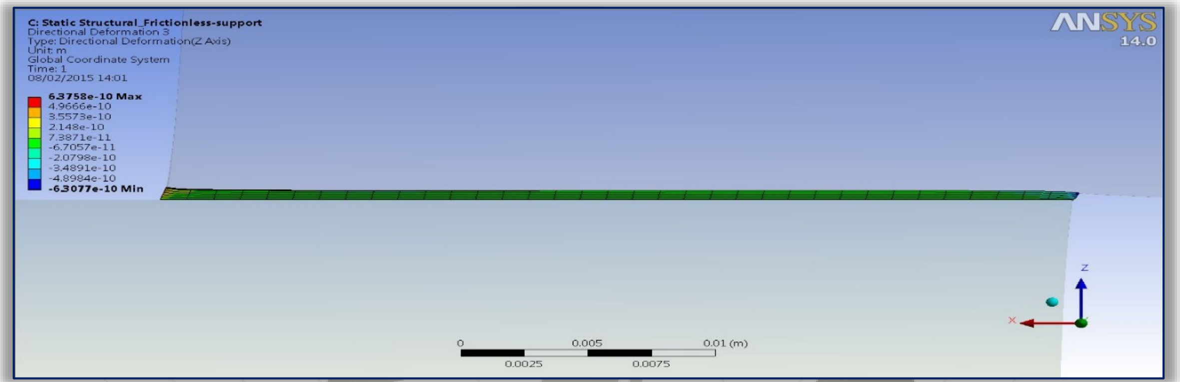

Figure 5. The transversal displacements' field of the first simple-lapping tests specimen (detail of the glue-layer)

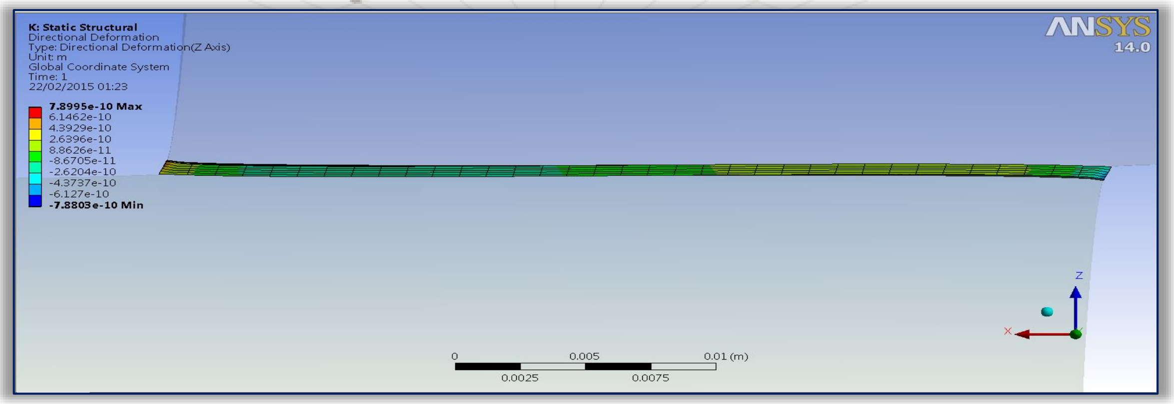

Figure 6. The transversal displacements' field of the improved simple-lapping tests specimen (detail of the glue-layer)

In Figure 5 is presented the field of the transversal displacements for the first simple-lapping tests specimen, respectively in Figure 6: the corresponding values for the improved simply-lapping (analyzed in Figure 2). One can observe that in both cases exist the transversal displacement field even with different magnitudes. In this sense, one can mention that the authors of the references [7, 15] prove by high-accuracy experimental investigations (applying ESPI method) that the simply overlapping produces significant bending and peeling and consequently this kind of test specimen will offer truth-less (untrue) shear strength for the glue.

In Figure 7 is offered the transversal displacements' field of the first kind double-lapping test specimen (half of the joint), analyzed in Figure 3. In this case, also one can observe the existence of the peeling-effect.

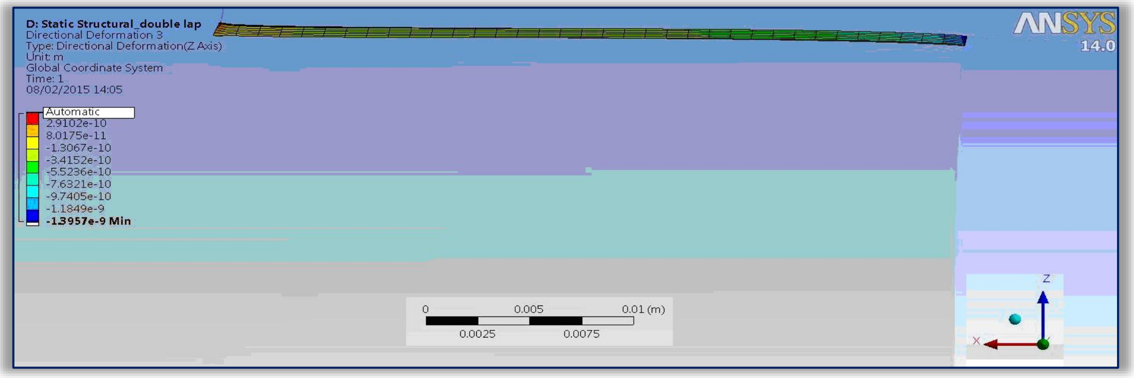

Figure 7. The transversal displacements' field of the first kind double-lapping test specimen (half of the joint)

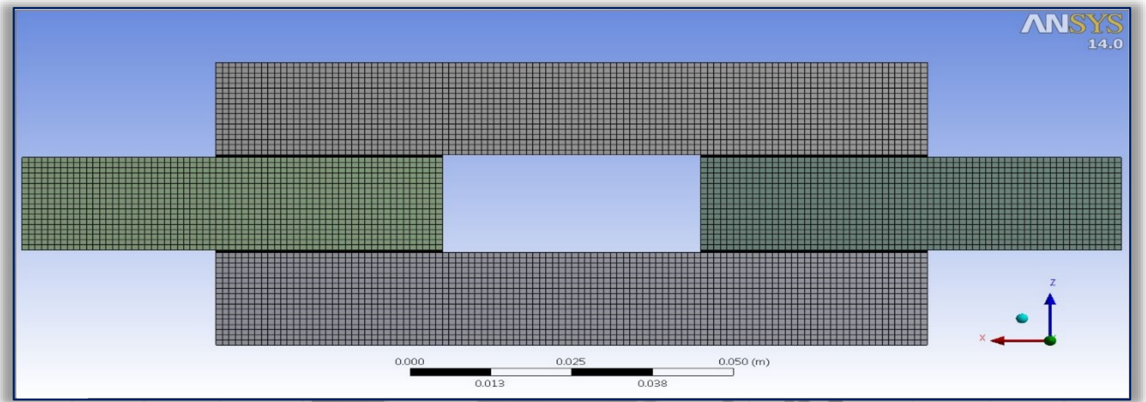

Figure 8. The mesh of the proposed double-lapping test specimen

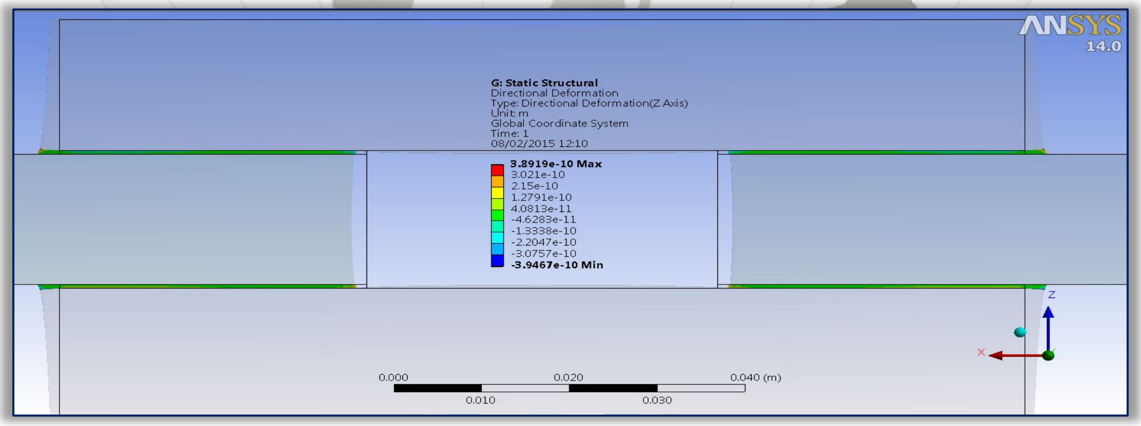

Figure 9. The transversal displacements' field for the proposed double-lapping test specimen

Figure 8 offers the mesh of the second kind of double-lapping test specimen, and finally, in Figure 9: the transversal displacements' field (which practically is lacking) due to the high stiffness of the lateral wood elements.

Consequently the bending and the peeling effect are wholly eliminated and by experimental measurements one can obtain the pure shear strength as well as its influence (effect) on the glued-assembly's time-dependent behaviours.

4. CONCLUSIONS

The above-presented/proposed test specimen, one can apply both in wood industry and in other industrial problems, where the assembling is solved by gluing.

The authors express their hope that this approach will offer high-accuracy and easy testing conditions for shear strength evaluation, accordingly to the longitudinal shear loading.

In the authors' opinion, the obtained experimental results also will be useful for the optimal choosing of the glue (to select the most proper glue destined for the predicted purpose).

In the authors' opinion, by involving in these experimental investigations high-accuracy optical methods (either Digital Correlation or Electronic Speckle Pattern Interferometry) one can obtain not only the real/true shear strength, but became possible to evaluate the time-dependent behaviours of the glue as well as their residual behaviours, too.

This new test specimen (due to its four identically loaded glue-layers) leads a simultaneously monitoring of all layers.

Consequently, by means of these experiments one can obtain not only the real shear strength but also a better statistical evaluation of the experimental data.

In the next period the authors intend to perform several meticulous-cared tests on different widely-used glues in wood industry.

References

[1.] Goland M, Reissner E. (1944) J Appl Mech 66:A17.

[2.] Hart-Smith LJ. (1973) NASA Contract Report, NASA CR-112235.

[3.] Hart-Smith LJ. (1973) NASA contract report, NASA CR-112236.

[4.] Jones,R., Wykes,C., (1983) Holographic and Speckle Interferometry, A discussion of the theory, practice and application of the techniques, Cambridge University Press, Cambridge.

[5.] Le, E.A., Nairm, J.A., Measuring Interfacial Stiffness of Adhesively-Bonded Wood, Wood Science and Technology, vol. 48, 2014, pp. 237-248.

[6.] Lucas F.M. da Silva et al,. (2009) Analytical Models of Adhesively Bonded Joints- Part I: Literature Survey, International Journal of Adhesion and Adhesives, 29, 319-330.

[7.] Müller, U., Sretenovic, Viceconti, A., Gindl, W., Direct Measurement of Strain Distribution Along a Wood Bond Line, Part 1: Shear Strain Concentration in a Lap Joint Specimen by Mean of Electronic Spekle Pattern Interferometry, Holzforschung, Vol. 59. pp. 300-306, 2005.

[8.] Serrano, E., A Numerical Study of The Shear-Strength-Predicting Capabilities of Test Specimens for Wood-Adhesive Bonds, Elsevier, International Journal of Adhesion and Adhesives, 24 (2004), pp. 23-35.

[9.] Stoeckel, F., Konnerth, J., Gindl-Altmutter, W., Mechanical properties of adhesives for bonding wood - A Review, International Journal of Adhesion and Adhesives, Vol. 45, Sept. 2013, pp. 32-41, Elsevier.

[10.] Száva, I. et al., New Testing Device for Time-dependent Glue Behaviour Analysis by Means of Holographic Interferometry, The 5th International Symposium, Wood Structures and Properties '06, Organised by Technical University in Zvolen, September 3-6, 2006, Sliac-Silenica, Slovakia, Edited by Arbora Publishers, Zvolen, Slovakia, ISBN 80-968869-4-3, pp. 409-412.

[11.] Száva, I. et al., The Optimal Design of The Testing Specimens for a More Accurate Evaluation of The Glues' Mechanical Properties, Pro Ligno, Vol. 11. nr.2/2015, pp 260-267, ISSN-L- 1841-4737.

[12.] Uysal, B., Kurt, S., Yildirim, M.N., Boding Strength of Wood Materials Bonded with Different Adhesive After Aging Test, Construction and Building Materials, 24 (2010) 2628–2632, Elsevier.

[13.] Vest, Ch. M., (1979) Holographic Interferometry, John Wiley & Sons, New York.

[14.] Volkersen O. (1938) Luftfahrtforschung,15:41.

[15.] Yong, Ch., Mingjie Guan, M., Shear Strain Distribution of Bonding Interface in Ductile PF Bonded 2-Ply Bamboo Sheet by The Method of Electronic Laser Speckle Interferometry, Proceedings of the 55th International Convention of Society of Wood Science and Technology August 27-31, 2012 - Beijing, CHINA BAF-6 pp. 1-8.

[16.] *** - Glued Laminated Timber-Shear Test of Glue Lines, British Standard, BS EN 392-1995.

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