THE OPTIMAL DESIGN OF THE TESTING SPECIMENS FOR A MORE ACCURATE EVALUATION OF THE GLUES' MECHANICAL PROPERTIES

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Abstract
The main goal of the contribution consists in offering an improved method in the glues' mechanical behaviours estimation, involving also a new type of specimen. The described method can be used successfully not only in the wood industry, but also in several other industrial applications, where the adhesives' mechanical properties have to be determined as much as accurate possible. The authors elaborated the below-proposed method, based on their former, high-accuracy investigations by means of Holographic Interferometry, where were evaluated not only the time-dependent behaviours of the glues (evaluated by means of their displacements field), but also their residual behaviours, too. The original testing bench of the authors allows a wide range of stresses, out of which, this paper describes only the longitudinal shear one. The proposed testing specimen, analysed by means of FEM method, will eliminate totally the undesired bending effect, which produces the so-called peel stress. The authors express their hope that the proposed strategy will became an useful, objective and high-efficiency modality both for testing and choosing the most adequate glue (not only for wood-industry, but also for the general industrial purpose, too).

Key words: glue; mechanical properties; complex testing bench, new testing specimen; Holographic Interferometry.

INTRODUCTION
In the furniture industry the proper selection of the glue represents a very significant step in order to obtaining high-quality final products. The selected glue must have a high value of the permissible strength and good time dependent behaviour.
This last behaviour means that its nominal (rated) strength (predicted by producer) will be obtained after a relatively short time. So, the manufacturing process, using this type of glue, will take a reduced time and so, its efficiency becomes higher.

It is well-known that any of producers hadn't the intention to offer such important information, which is significant for the customers in order to be able to choose the proper sort of glue.

At this moment, in industrial praxis, the tests for glues' quality consist of a simply destroying a glued subassembly constituted from two symmetrical-disposed special parallelepiped-shape specimens (Fig. 1).
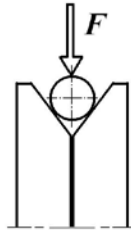

Fig. 1.
The actual glue test

There aren't any special requirements concerning the applied force magnitude or its dynamic. This force **F** is applied by means of a cylindrical steel part and the worker will evaluate the ratio between the whole, initial glued, surface and that one presenting clean part (only with glue, without any hint/trace of the conjugate wood-member).

In normal cases, this destroying test will produce two extreme kinds of surfaces: one is a clean surface (when the glue was very weak) and the other presenting at the whole surface visible hints/traces of the conjugate wood-member (in this case was used a very strong glue). In the common cases, one can find an intermediate situation, having only a percentage as clean part (of the surface).

The presented test isn't able to offer any useful information about the time-dependent behaviours of the glue, respectively about its residual displacements.

Consequently, in order to perform an efficient investigation for choosing the best/adequate solution (meaning the adequate glue), it is necessary a high accuracy, non-contact and also a full-field method, which also has to be repetitive.

Taking into consideration the above-mentioned requirements, the authors conceived other kind of specimens, having a double overlapping, respectively chose the Holographic Interferometry (**HI**) as investigation method (Száva *et al.* 2006).

HI presents several *advantages* in this respect; between others it has a very high-accuracy (with 10…. 15*nm*-accuracy) and is a non-contact investigation method, which can be practically applied without any restriction for a wide range of materials (homogenous, non-homogenous, isotropic, orthotropic or anisotropic ones).

Its *main disadvantages* consis in a very high-accuracy vibration insulation of the environment, respectively the limitation of the displacements' field magnitude, which has to be lower than $\lambda/4$, where λ represents the wavelength of the light (in the case of *HeNe* lasers /red light/ one has $\lambda = 632.8\ nm$. So, it is practically a laboratory method, less useful in investigations of the working processes.

In this sense, the authors performed several preliminary tests on two of widely used glues (Urelite and Polyvinyl-acetate) in the furniture industry, involving in these investigations their original testing bench (designed for **HI**), in order to validate both the adequateness of the proposed methodology and its usefulness in the glue testing. In their previous work (Száva *et al.* 2006) there are presented in detail both the theoretical and experimental approaches; in the following are only briefly summarised the main results in this sense.

A brief overview of the literature, concerning on the overlapping influence on the supplementary bending effect, which leads to the peel stress, offers the following main conclusions:

- *The single-lap adhesive bonding* produces a strong bending effect (Fig. 2), elaborated by Goland and Reissner in (Goland and Reissner 1944) and analyzed meticulously in reference (Lucas F.M. da Silva *et al,* 2009);
- In reference (Goland and Reissner 1944), Goland and Reissner calculated the shear and peel stresses in the adhesive layer, based on the determination of the loads at the ends of the overlap (Fig. 3);
- *The peel stress* is defined as the induced transverse direction normal stress through the thickness direction of the adhesive layer, due to the bonded parts' bending (mainly

as a cylindrical bended plate's one, applicable especially in the metal bonded parts); see references (Lucas F.M. da Silva *et al.* 2009; Volkersen 1938; Goland and Reissner 1944);

- A significant improvement concerning the specimens' type, consists of the double-lap adhesive bonding (Fig. 4), analyzed meticulously by Hart-Smith in references (Hart-Smith 1973,a; Hart-Smith 1973,b);
- Even in (Hart-Smith 1973,a; Hart-Smith 1973,b) it is analyzed the *double overlapping*, which served for the authors in their previous Holographic Interferometry-based investigations (Száva *et al.* 2006), there aren't any factual information concerning the bending effect, which leads to the peel stress; In this case, for a high-accuracy evaluation, the test results will not be able to separate the shear effect from the above mentioned bending one.

Consequently, in order 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 testing specimens; in fact, this represents the main goal of the authors in this contribution.
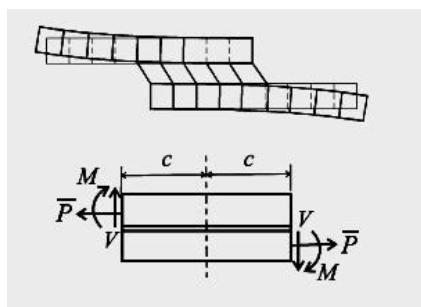

Fig. 2.
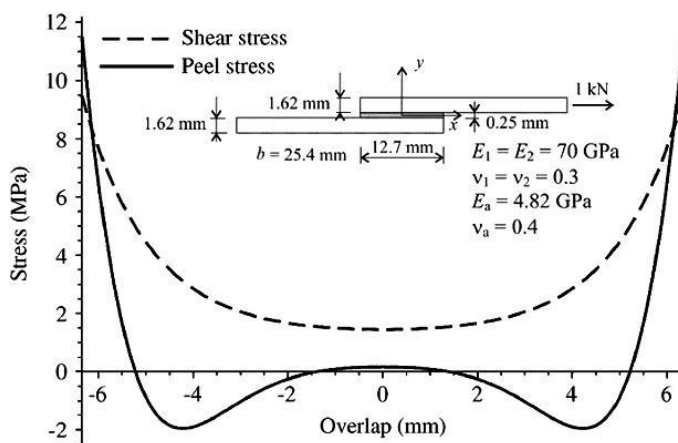**The Goland and Reissner's model (Goland and Reissner 1944)**

Fig. 3.
The adhesive shear and peel stress distributions, based on Goland and Reissner's researches for Aluminium alloy adherents and an epoxy adhesive (Goland and Reissner 1944)
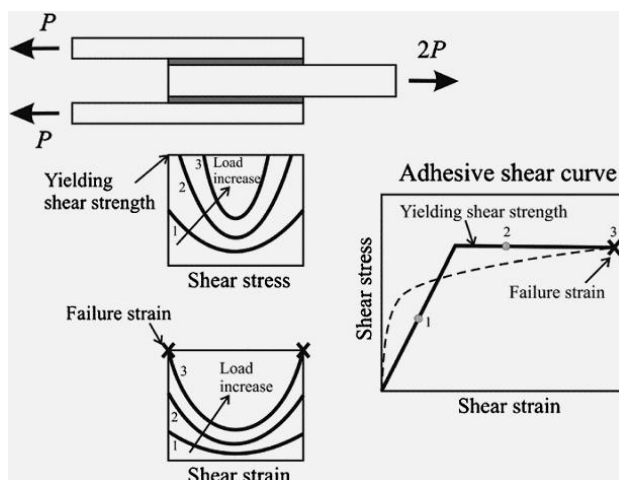

Fig. 4.
Schematic explanation of shear plastic deformation of the adhesive according to Hart-Smith (Hart-Smith 1973,b)

OBJECTIVES

The authors propose both a new experimental approach of the glues testing and a new, more adequate testing specimen, in order to eliminate the undesirable supplementary bending effect, which leads to the so-called peel stress.

Based on the numerical analysis' results, the proposed testing specimen will be more suitable and will present a more accurate evaluation of the glues' mechanical properties.

The briefly described testing bench, even initially was destined only to Holographic Interferometry, can be applied successfully also in two modern non-contact optical methods (ESPI/Shearography, respectively Video Image Correlation).
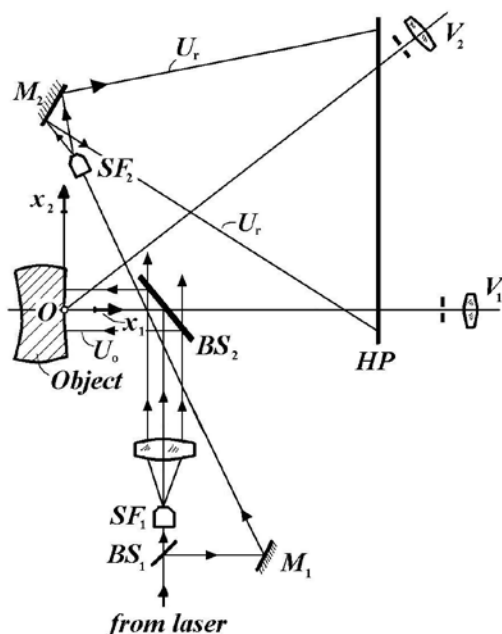
METHOD, MATERIALS AND EQUIPMENT

The involved method in this kind of experimental approach was the Holographic Interferometry (Jones and Wykes 1983; Vest 1979), where, in the general case, in order to establish all displacements' components in a point B, there are required minimum three independent viewing directions and corresponding evaluations. In order to obtain an easier approach, in reference (Jones and Wykes 1983) proposed a special optical feature (Fig. 5), where BS_2 and HP have to be large enough enabling three viewing directions V_1, V_2, V_3.
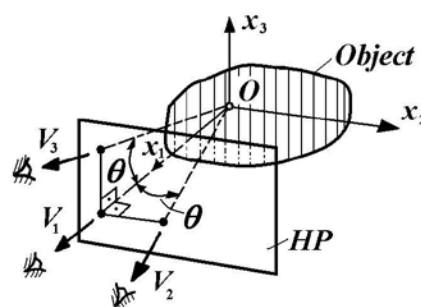
In (Száva *et al.* 2006) is presented an original Holographic testing bench for glue time dependent behaviours' evaluation of the authors (Fig. 6). In principle, this original stand allows testing different kind of glues to shearing, bending, tensile and torsion stresses, where the monitoring time starts from approximately 20 *minutes* after gluing (assembling); in this figure is presented only the shearing test-device.

The stand consists of a very rigid support *1*, where is fixed the tested wood specimen's subassembly *2* (Fig. 7), by means of a rigid cross piece *3*. The loading process is realised by means of a transverse *4*, witch transmits the acting force *F* to wood specimen using some very flexible nylon thread.

Practically, the acting force will be divided exactly into two equal parts. One can observe that there are two symmetrical placed/fixed wood members/specimens (the lower parts) and *in the first attempt* the glued surfaces (having each of them a surface A=35*30mm^2) *are practically stressed only to shear forces.*

a.

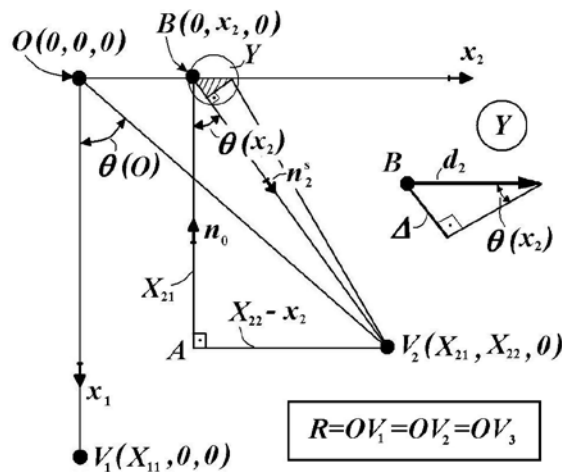V_1, V_2, V_3 – Viewing Directions
$x_2 O x_3$ – Object's Plan

b.

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c.
Fig. 5.
A practical arrangement for simplified calculus; a. the optical montage; b. the viewing positions; c. geometry for coefficients' calculus; BS$_2$ - beam-splitter; HP - holographic plate SF - spatial filter; M - mirror; U$_o$ - object beam; U$_r$ - reference beam; x$_1$ - the normal direction to the object's surface; x$_2$ x$_3$ - the object's plane; B - a given point of the object (Jones and Wykes 1983)
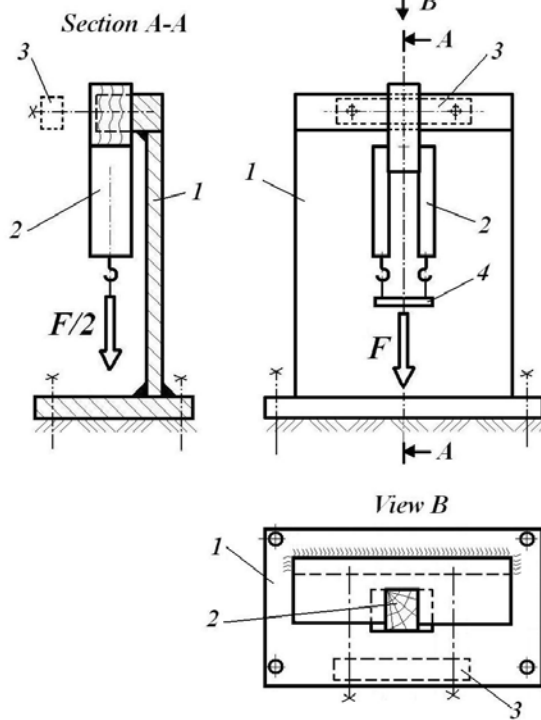
Fig. 6.
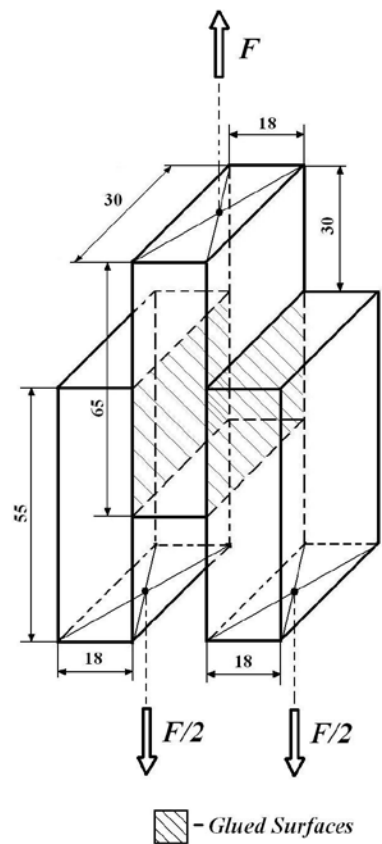*The schema of the Holographic testing bench (Száva et al. 2006)*

Fig. 7.
Wood-specimens subassembly (Száva et al. 2006)

One has to underline the fact, that the main goal of the authors, in the mentioned reference (Száva *et al.* 2006), consisted only in the time-dependent behaviour's evaluation, respectively in the residual displacements' monitoring the widely used glues in furniture industry (Urelite and Polyvinyl-acetate).

By a supplementary calculus, based on the above-mentioned simplified optical feature of the reference (Jones and Wykes 1983), the authors obtained for the in-plane rotation of the lower members from the testes specimen's subassembly roughly (2.0 … 2.4) *minutes*.

Even these values weren't high, nevertheless this fact suggested to the author to pay more attention to this detail, namely to look for another kind of testing specimen subassembly, where can be 100 % eliminated these undesired bending effect together with the mentioned angular displacement.

RESULTS AND DISCUSSION

Taking into the consideration the bending effect, which leads to the so-called peel stress, the authors re-evaluated the different kind of overlaps used in engineering practice.

The authors performed some comparative FEM simulations in ANSYS 14.0, of the briefly analyzed specimen types, in order to verify the predicted behaviours.

In this sense, the glue thickness was divided in 5 layers in order to take into consideration the adhesive stress modification through the thickness direction, mainly of the interface stresses.

In Fig. 8 and Fig. 9 the displacement fields through the thickness of the glue (in *z*-axis direction) for the single-lap joint and the double-lap joint's respectively are presented.
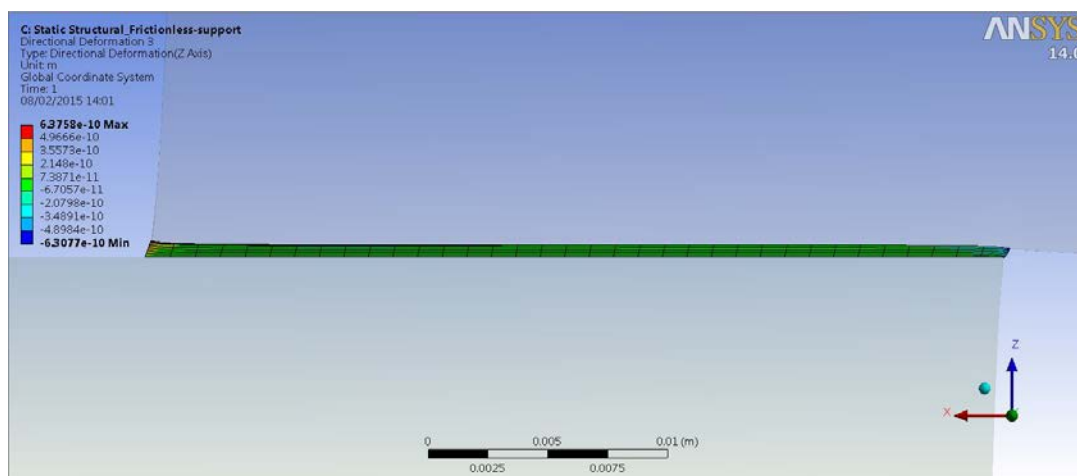

Fig. 8.
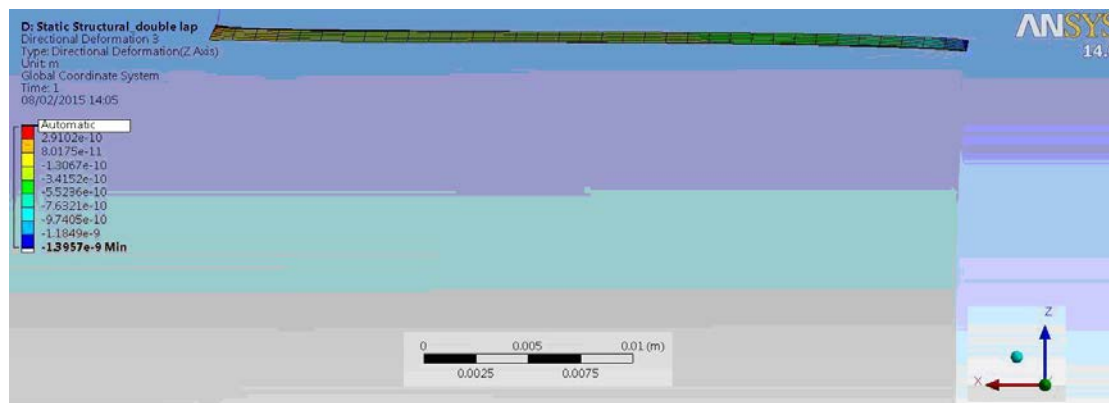*The single-lap joint's transversal displacement field*

Fig. 9.
The double-lap joint's transversal displacement field for a half of the joint

One can observe that the predicted transversal displacements exist in both of the cases.

Also, the authors' previous experimental investigations results by mean of Holographic Interferometry were confirmed.

In order to eliminate this bending effect, the authors propose a new testing specimen subassembly. Mainly, the idea of the new testing specimen consists of in superposing (by vertical rotation) of two sets of above-described specimens, finally obtaining the set presented in Fig. 10.
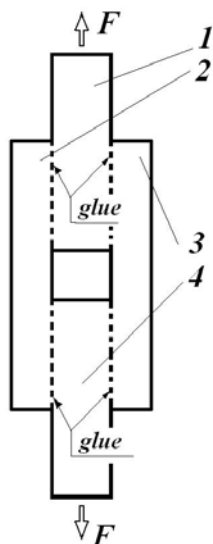

Fig. 10.
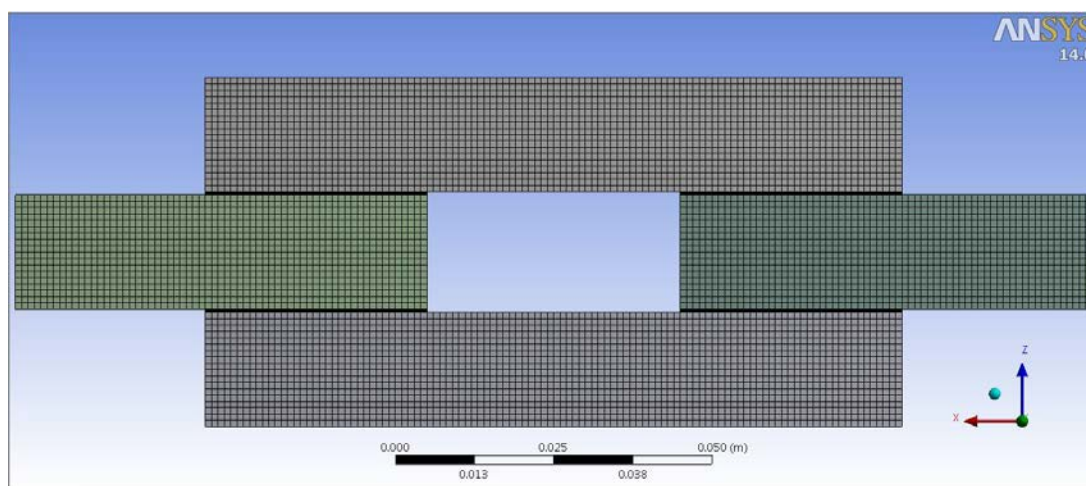*The proposed new testing specimen's subassembly*

Fig. 11.
The applied mesh for the new double-lap joint

In this case, one can suppose that the bending effect can be eliminated 100% and the shear effect will be easier to monitor. By numerical simulation in ANSYS 14.0, the authors obtained similar results. In Fig. 11 is shown the mesh of the specimen's subassembly and in Fig. 12: the transversal direction displacement field.
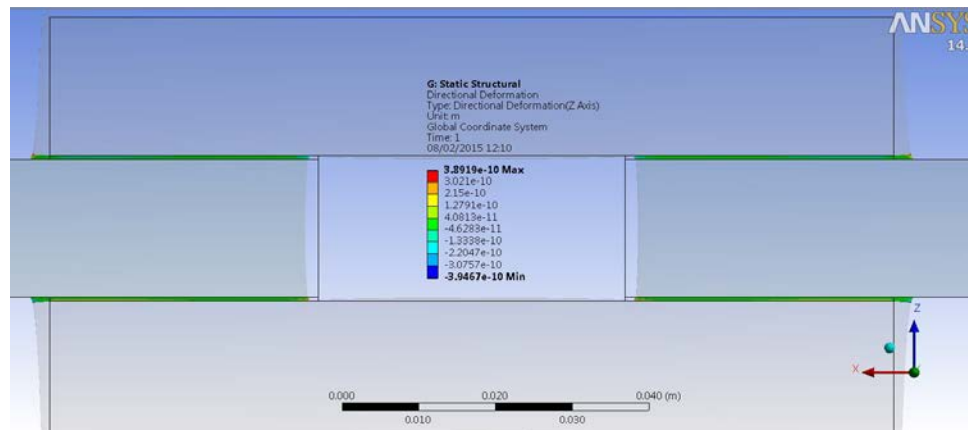
Fig. 12.
The proposed new double-lap joint's transversal displacement field

CONCLUSIONS

The proposed new specimens' set can be easily introduced in the mentioned original Holographic testing bench (Száva *et al.* 2006).

Taking into the consideration the fact, that in the last years the authors' team achieved both an ESPI/Shearography and Video Image Correlation optical systems, the proposed tests concerning on the glues' mechanical properties can be significantly improved.

It is well-known fact that the above-mentioned two optical systems together cover practically the whole range of the displacements field, starting form some *nanometre*s up to several *cm*s, the evaluation of the different kind of gluing subassemblies became easier possible with a very good accuracy.

Also, one has to mention the fact that using this new specimens' set a better statistical evaluation of the obtained values became possible, due to the fact that in this case each set will represent in fact two of the older ones.

Having four glued surfaces, the strain distribution (respectively the displacements ones) can be more easily evaluated by averaging the obtained values.

The further goal of the authors will be to perform several, statistical acceptable tests for different kind of glues, widely applied in Romanian furniture industry.

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