Comparative analysis on laboratory bearing tests for beams made of OSB3 and of solid timber

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Abstract. Current times impose the usage of less raw building and more recycled materials. Wood is a material that can be recycled and processed in the factory in order to create new materials. Due to its mechanical characteristics, OSB3 has been chosen to create glued beams, which are hybrid elements with a configuration similar to GLULAM. This paper presents an analysis of the results obtained in four points bending tests on real scale beams made of solid wood and of glued OSB3 lamellae. The current research intends to compare solid wood beams with OSB3 glued beams, from failure load and elastic behaviour points of view.

1. Introduction
The construction sector is currently one of the largest waste generators, but the environmental impact could be diminished with the help of the circular economy principles [1, 2].

To reduce the usage of raw building materials, it is necessary to develop new recycled ones. One of these raw materials is wood; a renewable resource that often comes from sustainable managed forests. It is highly sustainable to recycle wood that can be recovered from old furniture, formwork waste, pallets, packaging railways or bridges. Wood can also be recycled from raw products that cannot be used as they are in construction: branches, old chopped trees, trees with very small diameters. All these products can be processed in the mill in order to make wood chips, shavings and sawdust that are used to manufacture new recycled building materials [3].

Therefore, what if recycled materials, such as OSB – Oriented Strand Board could be used for structural elements? The current study is aimed to answer this question and focus on OSB3 material, which was chosen due to its bearing capacity and to the fact that it can be used outdoors, in humid environments. OSB3 lamellae were used to create glued beams, with a structure similar to GLULAM, which resulted in hybrid structural elements.

2. Production of OSB3 glued beams
The solid timber beams were made of fir, a softwood species.

The wood used to manufacture OSB3 is around 70% pine and spruce, the rest of 30% are species like: beech, birch, lime tree and willow. This ratio of softwood and hardwood species, in addition to the surface-to-core ratio and the pressing parameters determine the quality and characteristics of the final products. Other components of OSB3 are glue, water and paraffin wax emulsion [4, 5].

The hybrid structural elements have a lamellar structure and were manufactured from six OSB3 lamellae, each with a thickness of approximately 24 mm, glued with polyurethane adhesive for wood. To obtain high quality hybrid structural elements, a strict technological process was respected in the factory. For the OSB3 lamellae to have the same characteristics, the OSB3 was chosen from the same batch.

After delivery, the OSB3 lamellae were kept inside the factory for at least 24 hours for acclimatization. For the polyurethane adhesive to properly adhere to the OSB3 material, the OSB3 lamellae had their surface polished and individually calibrated. The calibration was executed by the Calibration and polishing machine, using a rubber lane with 100 granulation.
To manufacture a beam of 140 x 140 mm cross-section, six OSB3 lamellae were glued together using polyurethane adhesive. For this process, a Polyurethane Spray machine applied the polyurethane adhesive on the entire width and length of the first five OSB3 lamellae. The polyurethane adhesive was applied only on top of the first five OSB3 lamellae, the sixth lamella adhering to the fifth one. This assemble was then placed in the wood pressing machine. The applied pressure on the cross-section of the OSB glued element reached 64 bars, for a period of 60 minutes. To ensure the perfect conditions for this process, the temperature was between 10 – 25°C.

After the beams were removed from the wood press, they were stored for 8 hours. After 24 hours, the faces of the hybrid structural elements were finished using the Machine that processes on 4 sides. The dimensions for the resulted hybrid structural elements were of approximately 140 x 140 x 3000 mm (Figures 1 and 2).

3. Four-point bending tests on timber and OSB glued beams

3.1. Test specimens

To determine the static bending strength of timber and OSB3 glued beams, laboratory tests were carried out in accord to standards SR EN 14080 (july 2013) and EN 408:1995. The timber beams and the OSB3 glued beams were tested at the Faculty of Civil Engineering and Building Services, “Gheorghe Asachi” Technical University of Iasi. Experimental tests were made using the equipment of Zwick/Roell Material Testing Machine BP1-F1000SN.M11 [6, 7, 8, 9, 10].

Three solid timber beams and seven OSB3 glued beams were tested [11]. The first three OSB3 glued beams, GLO1, GLO2 and GLO3 were tested with the load, F, acting perpendicular on lamellae, Figure 3-a, and the other four beams, GLO4, GLO5, GLO6 and GLO7 were tested parallel to lamellae, Figure 3-b.

All beams had a prism shape, and their exact dimensions are presented in tables 1 and 2.
3.2. Testing procedure
The beams were subjected to four-point bending, hence the elements were simply supported on two pin supports of 150 mm width and the load was applied on two points, symmetrically placed at a distance $a = L/3 = 900$ mm from the supports, where $L$ is the beam span, Figure 4 [8, 9]. The load was applied continuously with constant test speed of 0.08 mm/sec.

![Figure 4. Laboratory test equipment and beam sample.](image)

3.3. Test results
Total failure was reached for all tested beams. The failing modes are depicted in Figures 5 and 6, for solid timber beams and OSB3 glued beams.

![Figure 5. Failure mode of solid timber beams.](image)
Figure 6. Failure of OSB3 glued beam, 
a. tested perpendicular on lamellae, b. tested parallel to lamellae.

Observing the figure above, it can be stated that failure occurred and remained in the tensile area for solid timber beams and for OSB3 glued beams, with the load applied perpendicular on lamellae. For the OSB3 glued beams tested parallel to lamellae, failure occurred on the entire width of the beams, thus splitting the element in two parts.

The load-displacement curves for all beams are depicted in Figures 7, 8 and 9.

Figure 7. Load – displacement curves for solid timber beams.

As it can be observed for solid timber beams, their flexural behaviour is mostly elastic, up to a load of 40000 N, and then the beams start presenting plastic deformation, up to their failure at an average of 50025.56 N, with a displacement of 58.89 mm.
Figure 8. Load – displacement curves for OSB3 glued beams tested perpendicular on lamellae.

The OSB3 glued beams subjected to bending perpendicular to lamellae presented an elastic behaviour up to failure, which occurred at a load of 12800.66 N, with an average displacement of 45.37 mm, Figure 8. The different behaviour between GLO2 and the other beams can be explained due to the manufacturing procedure, thickness and uniformity of the adhesive layers.

The OSB3 glued beams subjected to bending parallel to lamellae also presented an elastic behaviour up to failure at a load of 11895.19 N with an average displacement of 37.24 mm, Figure 9.

The obtained results after testing the beams are presented in tables 1 and 2.

Table 1. Tests results for solid timber beams

| Timber beam | b [mm] | h [mm] | L [mm] | $F_{\text{timber max}}$ [N] | $w_{\text{timber max}}$ [mm] |
|-------------|--------|--------|--------|-----------------------------|-----------------------------|
| GL1         | 148    | 148    | 2700   | 51978.20                    | 60.477                      |
| GL2         | 148    | 150    | 2700   | 45974.06                    | 57.90                       |
| GL3         | 149    | 148    | 2700   | 52124.43                    | 58.31                       |
| Mean        |        |        |        | 50025.56                    | 58.890                      |

Table 2. Test results for OSB3 glued beams

| Tested Perpendicular on lamellae | OSB3 glued beam | b [mm] | h [mm] | L [mm] | $F_{\text{OSB3 max}}$ [N] | $w_{\text{OSB3 max}}$ [mm] |
|---------------------------------|-----------------|--------|--------|--------|-----------------------------|-----------------------------|
| Perpendicular on lamellae      | GLO1            | 138    | 143    | 2700   | 13490.61                    | 46.400                      |
|                                 | GLO2            | 139    | 143    | 2700   | 11392.82                    | 42.890                      |
|                                 | GLO3            | 138    | 145    | 2700   | 13518.50                    | 46.809                      |
| Mean                            |                 |        |        |        | 12800.66                    | 45.380                      |
| Parallel to lamellae            | GLO4            | 139    | 143    | 2700   | 11788.63                    | 35.320                      |
|                                 | GLO5            | 138    | 143    | 2700   | 12160.46                    | 39.520                      |
|                                 | GLO6            | 139    | 143    | 2700   | 10663.68                    | 33.870                      |
|                                 | GLO7            | 138    | 148    | 2700   | 12968.00                    | 40.250                      |
| Mean                            |                 |        |        |        | 11895.19                    | 37.240                      |
where: \( b \) is the width of beam; \( h \) is the height of beam cross-section; \( L \) is the length of beam; \( F_{\text{timber}}^{\text{max}} \) is the failure load of timber beam [N]; \( w_{\text{max, timber}} \) is the maximum displacement of timber beam, [mm], corresponding to the failure load; \( F_{\text{OSB3}}^{\text{max}} \) is the failure load of OSB3 glued beam, [N]; \( w_{\text{max, OSB3}} \) is the maximum displacement of OSB3 glued beam, [mm], corresponding to the failure load.

Analyzing the overall results, it can be stated that the OSB3 glued beams present similar values for failure load and displacements, and these values are around 24.7% of the failure load of solid timber beams. Meanwhile, the displacements of OSB3 glued beams are approximately 70.13% of the ones of solid timber beams. This indicates that, OSB3 glued beams in the presented configurations can be subjected to lower loads to attain deformations close to solid timber beams. Furthermore, looking at the load-displacement curves in Figure 10, for a load of 12347.925 N (which is the average failure load of OSB3 glued beams), the displacement for solid timber beams is approximately 10 mm. Comparing this displacement to the one of OSB3 glued beams of 41.3 mm, it results that OSB3 glued beams present deformations 413% times greater than solid beams.

The curve shape of GLO4 beam is slightly different than the other, and this can be explained by certain irregularities in the manufacturing procedure, as the thickness or uniformity of the adhesive layers.

4. Evaluation of bending modulus of elasticity

The elasticity modulus of each beam was computed, \( E_{m,g} \), using equation (1), according to NP 408-2004 [6]:

\[
E_{m,g} = \frac{L^3(F_2 - F_1)}{bh^2(w_2 - w_1)} \left[ \frac{\left(\frac{3a}{4L}\right) - \left(\frac{a}{L}\right)^3}{3a} \right] \tag{1}
\]

where: \( b \) is the beam width, [mm]; \( h \) is the beam height, [mm]; \( L \) is the distance between supports, meaning 2700 [mm]; \( F_1 \) is the load value of approximately 0.1\( F_{\text{max}} \), [N]; \( F_2 \) is the load value of approximately 0.4\( F_{\text{max}} \) [N]; \( w_1 \) is the displacement corresponding to load \( F_1 \), [mm]; \( w_2 \) is the displacement corresponding to load \( F_2 \), in mm; \( a \) is the distance between a loading position and the nearest support in a bending test, in this case 900 [mm].

Tables 3 and 4 present the results obtained for the bending elasticity modulus computation for each set of beams: solid timber beams, OSB3 glued beams subjected to bending perpendicular on lamellae and parallel to lamellae.
Table 3. Evaluation of elasticity modulus for solid timber beams

| Timber beam | $F_{\text{max}}^{\text{timber}}$ [N] | $F_1$ [N] | $F_2$ [N] | $w_1$ [mm] | $w_2$ [mm] | $E_{\text{timber}}$ $g$ [MPa] |
|-------------|---------------------------------|----------|----------|----------|----------|-----------------|
| GL1         | 54416.00                        | 4330.80  | 14740.60 | 3.90     | 12.69    | 10350.90        |
| GL2         | 42674.10                        | 7921.00  | 15558.50 | 7.84     | 14.74    | 9287.93         |
| GL3         | 50124.40                        | 11080.80 | 21777.10 | 11.04    | 21.10    | 9227.49         |

Mean $E_{\text{timber}}$ $g$ = 9622.09

The mean modulus of elasticity for solid timber beams is 9622.09 MPa, which corresponds to a strength class of C18, which is widely used for structural elements [10].

Table 4. Test results for OSB3 glued beams

| Tested | OSB3 glued beam | $F_{\text{max}}^{\text{OSB3}}$ [N] | $F_1$ [N] | $F_2$ [N] | $w_1$ [mm] | $w_2$ [mm] | $E_{\text{OSB3}}$ $g$, $\perp$ [MPa] |
|--------|-----------------|---------------------------------|----------|----------|----------|----------|----------------------------------|
| Perpendicular on lamellae | GLO1 | 13490.61 | 1273.47 | 5071.23 | 3.14 | 16.0 | 3076.87 |
|        | GLO2 | 11392.82 | 2440.35 | 5717.43 | 7.55 | 18.8 | 3004.38 |
|        | GLO3 | 12877.98 | 2014.43 | 5975.24 | 7.51 | 19.9 | 3193.12 |
| Mean   | $E_{\text{OSB3}, \perp}$ | = 3091.46 |

| Tested | OSB3 glued beam | $F_{\text{max}}^{\text{OSB3}}$ [N] | $F_1$ [N] | $F_2$ [N] | $w_1$ [mm] | $w_2$ [mm] | $E_{\text{OSB3}}$ $g$, $II$ [MPa] |
|--------|-----------------|---------------------------------|----------|----------|----------|----------|-----------------|
| Parallel to lamellae | GLO4 | 11788.63 | 1639.72 | 6641.34 | 2.1 | 16.7 | 3528.43 |
|        | GLO5 | 12160.46 | 1432.47 | 4759.70 | 3.34 | 14.7 | 3490.24 |
|        | GLO6 | 10663.68 | 2046.15 | 4294.50 | 3.38 | 10.3 | 3523.65 |
|        | GLO7 | 12968.00 | 1045.58 | 1880.55 | 2.48 | 4.86 | 3782.67 |
| Mean   | $E_{\text{OSB3}, \perp}$ | = 3581.25 |

The average modulus of elasticity for OSB3 glued beams is 3091.46 MPa, for beams tested perpendicular on lamellae, and is 3581.25 MPa for beams tested parallel to lamellae. These values are about 3 times smaller than solid timber of strength class C18, which presents a standardised longitudinal modulus of elasticity of 9000 MPa [10].

5. OSB3 glued beams vs. timber beams of strength class C18

After analyzing the laboratory tests results, it has become clear that the tested OSB3 glued beams have low bearing capacity, as compared to solid timber beams of similar dimensions. Therefore, the OSB3 glued beams bearing capacity must be improved to match the solid timber beams resistance and rigidity characteristics for a case of strength class C18.

The maximum instantaneous deflection, $f_{\text{max,inst}}$, of a beam subjected to two concentrated loads equal to $F_{\text{max}}/2$, can be calculated according to equation (2), where $E_m$ is the longitudinal modulus of elasticity, [MPa], and $I_y$ is the moment of inertia of the cross-section, $b \cdot h^3/12$, in [mm$^4$] [7].

$$f_{\text{max,inst}} = \frac{23}{648} \cdot \frac{F_{\text{max}}^2}{E_m I_y}$$

(2)

For OSB3 glued beams subjected to bending perpendicular on lamellae, the easiest method to improve the flexural behaviour is to increase the number of OSB3 lamellae, hence increasing the height of the glued beams.

The maximum instantaneous deflection was evaluated using equation (2), with $F_{\text{max}}=F_{\text{max}}^{\text{timber}}$, and $E_m=E_{\text{OSB3}, \perp}$, for various numbers of OSB3 lamellae, and the results are presented in table 5. The beam width is constant, of 138.33mm, which is the average between GLO1, GLO2 and GLO3.

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Table 5. Evaluation of OSB3 glued beams displacement for various numbers of lamellae, for bending perpendicular on lamellae

| Lamellae width, [mm] | Number of lamellae | Beam height, [mm] | Beam width, [mm] | Deflection, [mm] |
|----------------------|--------------------|-------------------|------------------|-----------------|
| 6                    | 144                | 164.20            |
| 7                    | 168                | 103.40            |
| 24                   | 8                  | 192               | 138.33           | 69.28           |
| 9                    | 216                | 48.66             |
| 10                   | 240                | 35.47             |

Analysing Table 5, it can be observed that, for a load equal to the failure force of solid timber beams and the OSB3 longitudinal modulus of elasticity, the increase of lamellae number can provide a considerable reduction of deflection. For nine lamellae, the deflection for the OSB3 glued beams is smaller with 17.4% than that of solid timber beams, which is of 58.89 mm.

Therefore, increasing the number of lamellae to nine, resulting in a cross-section of 138.33 x 216 mm, the OSB3 glued beams present smaller deflections than solid timber beams of 148 x 149 mm cross-section of strength class C18.

For OSB3 glued beams subjected to bending parallel to lamellae, the increase of height can be done by choosing OSB3 lamellae with larger widths; some variations are presented in Table 6.

The deflection was computed using equation (2) with $F_{max} = F_{max}^{\text{timber}}$ and $E_m = E_{m,OSB3,II}$ and $b=138.5$[mm], which is the average between GLO4, GLO5, GLO6 and GLO7. For a height of OSB3 glued beams of 216 mm, the maximum deflection is 41.95 mm, which is 28.77% smaller than that of solid timber beams of class C18. The exact same maximum deflection of 58.89 mm as solid timber beams is met for OSB3 glued beams of 192.9 mm height.

Similar methods for improving flexural behaviour of OSB3 glued beams were detailed in their analytical study, where the focus was on the bearing capacity of hybrid structural elements such as columns and beams made of OSB3 lamellae [2].

Table 6. Evaluation of OSB3 glued beams displacement for various lamellae widths, for bending parallel to lamellae

| Beam height, [mm] | Beam width, [mm] | Deflection, [mm] |
|-------------------|------------------|-----------------|
| 144.0             | 141.58           |
| 168.0             | 89.16            |
| 192.0             | 59.73            |
| 192.9             | 58.89            |
| 216.0             | 41.90            |
| 240.0             | 41.95            |

6. Conclusions

The presented laboratory experiments evaluated the flexural behaviour of solid timber beams and OSB3 glued beams subjected to four-point bending, in an attempt to find new ways to use recycled wood products to replace standard structural elements.

Comparing the results of the timber beams with those of OSB3 glued beams, the modulus of elasticity for the glued beams is $\approx 33.47\%$ lower than the solid timber beams. In addition, the failure load of OSB3 glued beams is $\approx 24.7\%$ of the load of solid timber beams.

These results indicate that the cross-sections of OSB3 glued beams must be increased in order to produce structural elements with a flexural behaviour similar to solid timber beam. For OSB3 glued beams subjected to bending perpendicular to lamellae, by increasing the number of OSB3 lamellae from 6 to 9, the deflection of the glued beams became smaller with 17.4% than that of solid timber of strength...
class C18. Similarly, smaller deflections can be achieved for bending parallel to lamellae, by using OSB3 boards wider than 192.9 mm, resulting in OSB3 glued beams with bigger heights.

Other solutions that can improve the strength and rigidity characteristics for OSB3 glued beams experimented in the present study, can be the hybrid composition, in which there is a mixture of lamellae, most of them made of OSB3 and one or more to be made of materials with superior strength and rigidity. Examples include the use of flat lamellae made of fibre-reinforced polymeric composites placed in the tension area of the beam cross-section. In addition there are solutions with reinforcement made of independent bars made of steel or long-fibre-reinforced polymeric composites [12].

The experiments performed in the laboratory of the Faculty of Civil Engineering and Building Services from the "Gheorghe Asachi" Technical University of Iasi highlighted a new field for the use of OSB type products. Climate change and environmental degradation are an existential threat to Europe and the world. The studied elements can be the solution to this threat, being part of the development of a modern economy, competitive and efficient in terms of resource use.

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