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The possibility to use a side-timber in glulam beams manufacturing for structural applications

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Abstract: *The possibility to use a side-timber in glulam beams manufacturing for structural applications*. The aim of presented study was to determine the mechanical properties of three-layered glued structural beams manufactured with the use of side-timber pieces as an outer layers and the fragmented main yield as an inner layer. Four types of beams were pressed and tested in terms of four-point bending strength and modulus of elasticity. Variants differed from each other in the direction of the fibers in the inner layer and in the presence of adhesive layer between the fragmented wood. Studies have shown that the bending strength of the beams depended on the calculation method. Moreover, no significant effect of the inner layer arranging method on the bending strength of the beams was found. The values of modulus of elasticity (MOE) were low. The presented study is a starting point for further investigations concerning the possible way of the rational application of fragmented timber pieces and the side-timber for structural applications.

Keywords: glulam beams, structural elements, pine timber, knots

INTRODUCTION

For centuries wood has been a natural construction material for buildings. Its common occurrence is strongly influenced by the following features such as lightness, simplicity in fabrication, reusability and environmental compatibility (Issa and Kmeid 2004). The wood in construction is usually present in the form of engineered wood products (EWP). The glued laminated timber, parallel strand lumber, laminated strand lumber, laminated veneer lumber and many others can be listed among the examples of commonly applied structural composites (Lam 2001, Riberio et al. 2009). Due to the high-quality raw material shortages there are many ongoing studies aimed to obtain a full quality product from the material that was not suitable for specific uses due to its insufficient quality or size (Borysiuk and Kowaluk 2007, Chen et al. 2016, Mirski et al. 2020a). In order to reinforce the wooden beams the composite materials in various forms of bars, bands, tapes, meshes, strings etc. are commonly applied. The already performed experiments concerned the use of e.g.: fiber reinforced polymers (FRP), carbon fiber-reinforced polymers (CFRP), basalt-fiber reinforced polymers (BFRP) or glass fiber-reinforced polymers (GFRP) and aramid fiber-reinforced polymers (AFRP) (Mirski et al. 2021). In addition to synthetic polymers, the materials of natural origin such as jute, bamboo or flax are also studied as a reinforcing methods (Borri et al. 2013, Mahmoud et al. 2020, Valdes et al. 2020).

In order to improve the usefulness of timber in the construction industry it is necessary to provide the components with as low number of defects as possible (Mirski et al. 2020b). The most common defect type in pine timber are the knots. They are bases of limbs imbedded in the trunk and their form depends on many factors such as species, conditions, age of tree etc. The effect of knots occurrence on wood strength properties depends on the location, type, size, number, soundness etc. According to Takeda and Hashizume (1999) knots strongly affect the tensile strength and physical properties of wood. Moreover, their presence considerable reduce the modulus of rupture especially when they are located in the tension zone (Kollman and Cote 1968). The reduction of beam's strength is particularly noticeable when they occur in the tension zone and less visible in case of their presence in the compression zone. Moreover, besides the strength properties of wood, knots can cause problems during sawing, planning, gluing, finishing, drying which can also affect the properties of manufactured beams (As et al. 2006).

Taking into account the adverse effect of the knots occurrence the timber can be manipulated with the cutting planes assumed in such way to eliminate their presence. The presented study was aimed to examine the properties of three-layered beams manufactured with the use of side-timber pieces as an outer layers and the fragmented main yield as an inner layer. The fibers direction of pieces included in the inner layer differed depending on variant and it was perpendicular or parallel to the side-timber's fibers direction.

MATERIALS AND METHODS

The research material which the analysis were conducted on was pine timber. The main yield originated from the Forest Division Olesno (50°52'30"N 18°25'00"E). No complete timber origin records were available for side boards. The details about a method of log sawing and establishing both the main yield and the side timber in the log cross-section were previously discussed by Mirski et al. (2021). The main yield pieces were characterized by the dimensions of 137 mm × 39.5 mm × 3485 mm (width × thickness × length). The side boards were of the same width and length but varied in thickness from 23 to 25 mm. The thickness was reduced during the trimming on a thickness planer to 38 mm and 22 mm in case of main yield and side boards, respectively.

In first step the visual assessment of side boards was done in order to make sure that no rotten and edge knots were located on their surfaces. Then the modulus of elasticity and density of side boards were determined based on the deflection caused by a load of 61.8 N. Main yield having a visible defects were manipulated in order to obtain defect-free pieces with the dimensions of 137 mm × 137 mm. The surfaces of the outer layers were glued with melamine-urea-formaldehyde adhesive (MUF1247) mixed with commercially dedicated hardener (2526). The formulation consisted of 15 g of hardener per 100 g of resin as recommended by the supplier Akzo Nobel (Amsterdam, Netherlands). The resin was applied in the amount of 200-220 g/m^2 and the mixture was applied by a roller coating machine which was self-constructed in order to perform the investigations. In two variants the pieces located in the inner layer were additionally glued with each other and the adhesive was applied using a brush. Twelve beams were pressed at the same time with the pressure of 0.48 MPa for 20 hours using the industrial press with hydraulic cylinders dedicated for the structural elements production (FOST, Czersk, PL). The pressing parameters were adjusted to be the same as in the case of the beams manufactured in the horizontal system (Mirski et al. 2020a). The schemes of manufactured beams are presented in Figure 1.

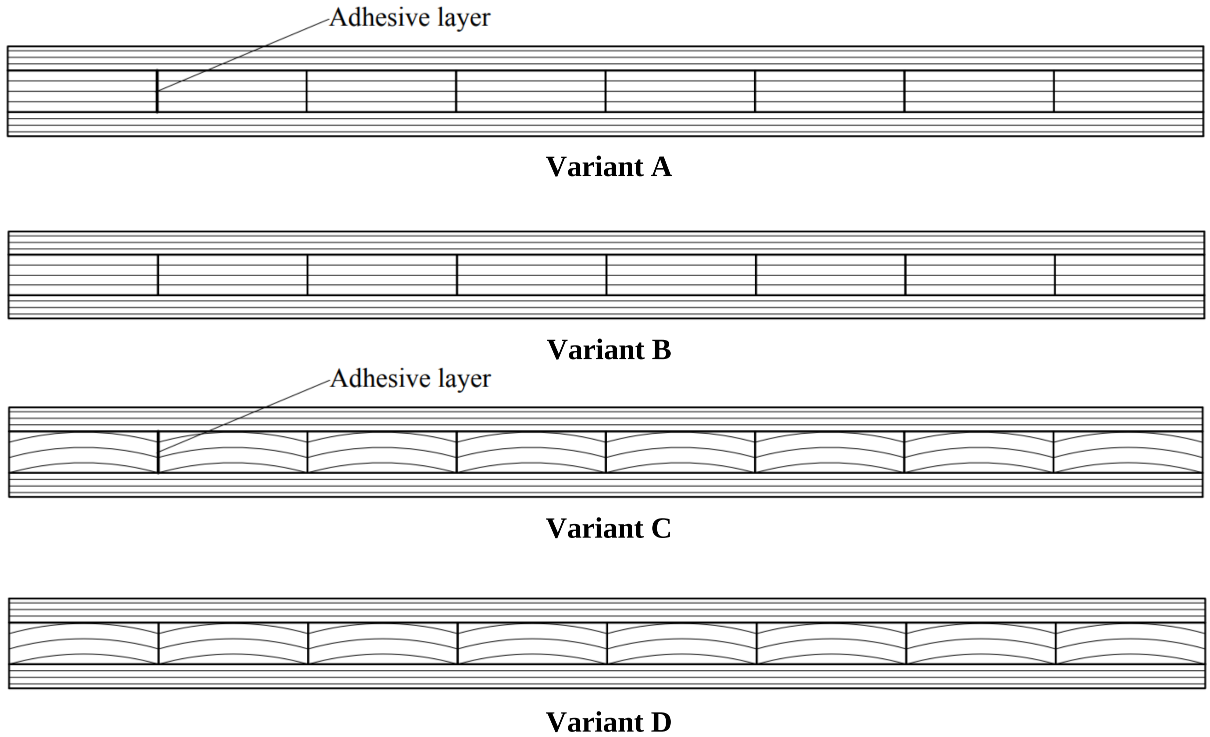

Figure 1. The schemes presenting variants of manufactured glulam beams (straight lines mean the longitudinal direction and curved lines mean the cross-section of timber)

After the pressing, the beams with the average dimensions of 3480 mm × 137 mm × 85 mm were conditioned in laboratory for storing the beams for four weeks at the temperature of 21±2°C and relative humidity of 55-65% similarly as in the case of Mirski et al. (2020a) experiments. 12 beams were manufactured in each variant and their properties were assessed in 4-point bending strength test which was performed in accordance with the diagram presented in Figure 2.

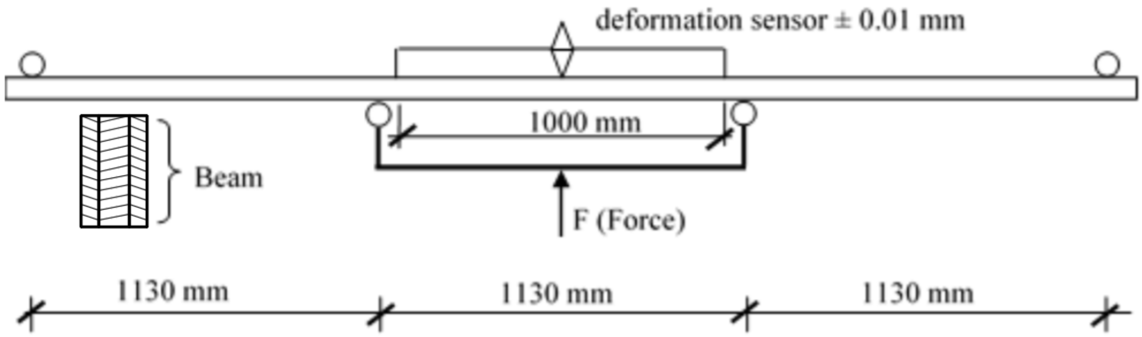

Figure 2. The scheme of four-point bending test for manufactured beams

The stand was equipped with: hydraulic pump (50 Mg, Hi-Force, Daventry, UK), hydraulic cylinder (50 Mg, Hi-Force, Daventry, UK), oil flow rate regulator (Hi-Force, Daventry, UK), deformation sensor (KTC-600-P, Variohm Eurosensor Towcester, UK) and force sensor (CL 16 tm 500 kN, ZEPWN, Marki, PL). The beams were tested in such way that the force worked perpendicularly to the pressing direction. Both the appearance of the test stand and the beam placement are shown in Figure 3. The results of performed investigations were analyzed using the Statistica 13.0 package.

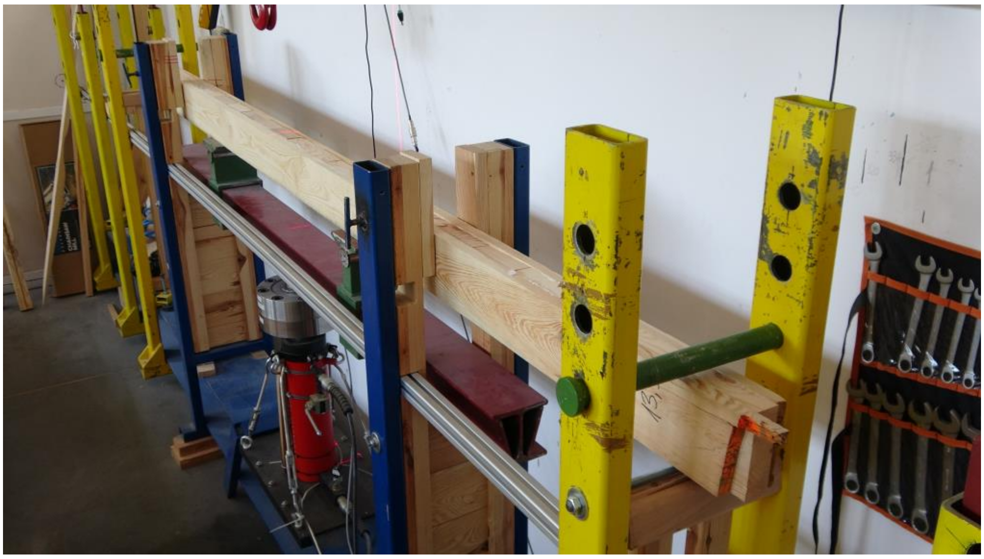

Figure 3. The beam's placement and the stand which was used to perform the investigations

RESULTS AND DISCUSSION

One of the important factors strongly influencing the values of the determined modulus of elasticity or static bending strength of the beams or other wooden material is the moisture content (MC) of tested element. It is generally accepted that these two mechanical properties are depended on moisture content and therefore the obtained results (for given MC) should be converted into the values with the moisture content of 12% in most cases. One of the most commonly used equations for this conversion is the Bauschinger equation. As can be seen from the values presented in Figure 4, the average moisture content of the tested beams ranged from 8.9 to 9.8%. Thus, it was approximately 3% lower than the equivalent moisture content (EMC) of 20°C and relative humidity of 65%. According to the Bauschinger equation, the estimated properties may be about 10% - 12% higher if they were not assessed at the MC of 12%. There were no statistically significant differences in the average moisture content of individual beam types, as well as in accordance with EN 384 (2016) + A1 (2018) there is no need to convert strength values to the moisture content of 12%. Moreover, the change in modulus of elasticity did not exceed 3% and because of all that, the conversion of MC was abandoned when analyzing the results.

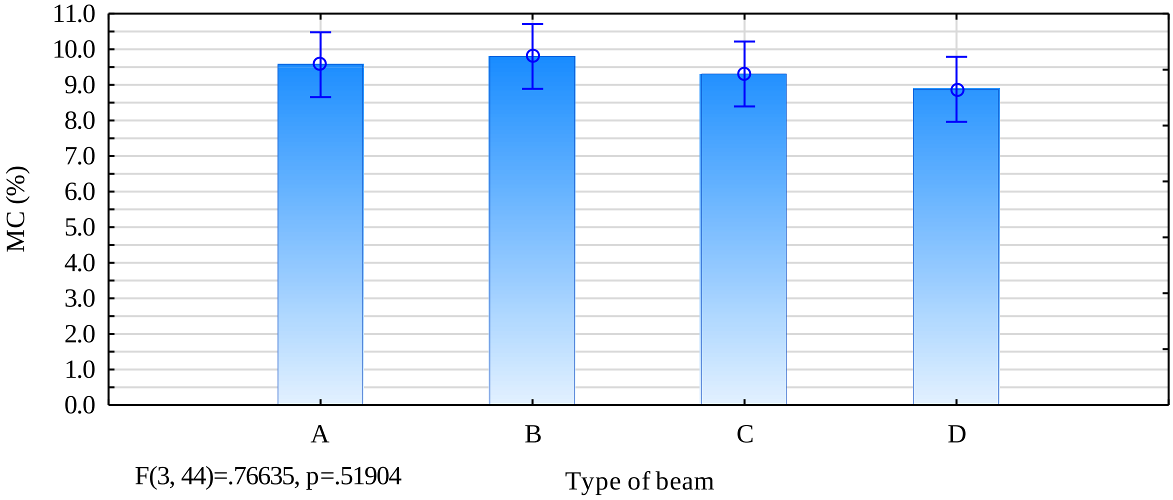

Figure 4. Moisture content of the beams

The average static bending strength of the manufactured beams ranged from 22.7 N/mm^2 to 25.9 N/mm^2. Thus, there is no reason to reject the null hypothesis that the average strength is equal, regardless of how the beams were designed. Both the arrangement of the timber pieces and the presence of an adhesive layer between them did not affect the results. The strength of the beams produced this way was not high, it was much lower in comparison with the glued laminated beams described by Mirski et al. (2020a). The strength of glued laminated beams made of the timber from main yield was about 45 kN/mm^2 and did not significantly depended on the MOE of the timber from which the beams were manufactured. In the discussed publication, the average MOE of the designed beams was 11.7 kN/mm^2 for GL24c beams and 12.8 kN/mm^2 for GL28c beams. In case of the beams featuring the fragmented pieces the MOE of the side timber was 11.1 kN/mm^2, 12.3 kN/mm^2, 12.9 kN/mm^2 and 12.6 kN/mm^2 for variant A, B, C, D, respectively.

Figure 5 presents the results of bending strength investigated in four-point bending test. Regardless of the variant, the strength properties reached a similar level.

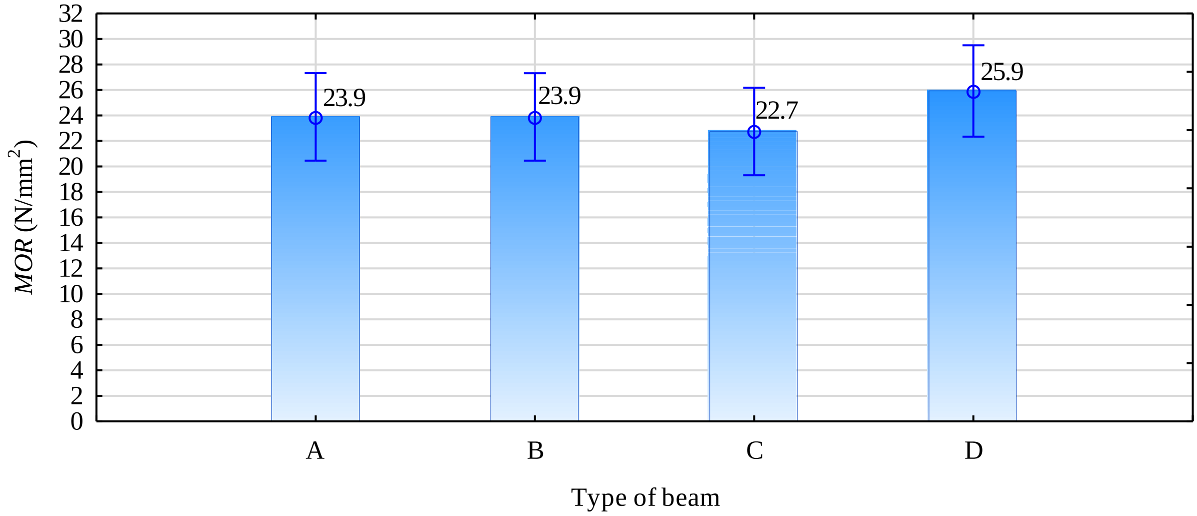

Figure 5. The results of four-point bending strength test

The pieces located between the side timber can be treated as spacer elements rather than as main elements. Therefore, the system can be considered as the combined structure comprising three elements characterized by different modulus of elasticity. Since these are fragmented pieces it seems that the modulus of elasticity having a value of zero can be assigned. So according to equation 1, they should not be taken into account when determining the strength and the moment of inertia of the cross-section:

$$E = V_{t1} \times E_{t1} + V_k \times E_k + V_{t2} \times E_{t2} \quad (1)$$

where:
V – volume fraction of given phase,
E – Young modulus of given phase,
t – side timber,
k – fragmented pieces.

Following this assumption, the equation 2 takes the form of equation 3:

$$W = \frac{(b_t + b_k) \cdot h^2}{6} \tag{2}$$

$$W = \frac{(b_t) \cdot h^2}{6} \tag{3}$$

where:
W – cross-sectional strength index,
b – width of cross-section,
h – height of cross-section.

When calculating the strength of the designed beams with the use of equation 3, it turns out that the average values reached the range from 44.5 N/mm^2 to 47.9 N/mm^2 (Figure 6).

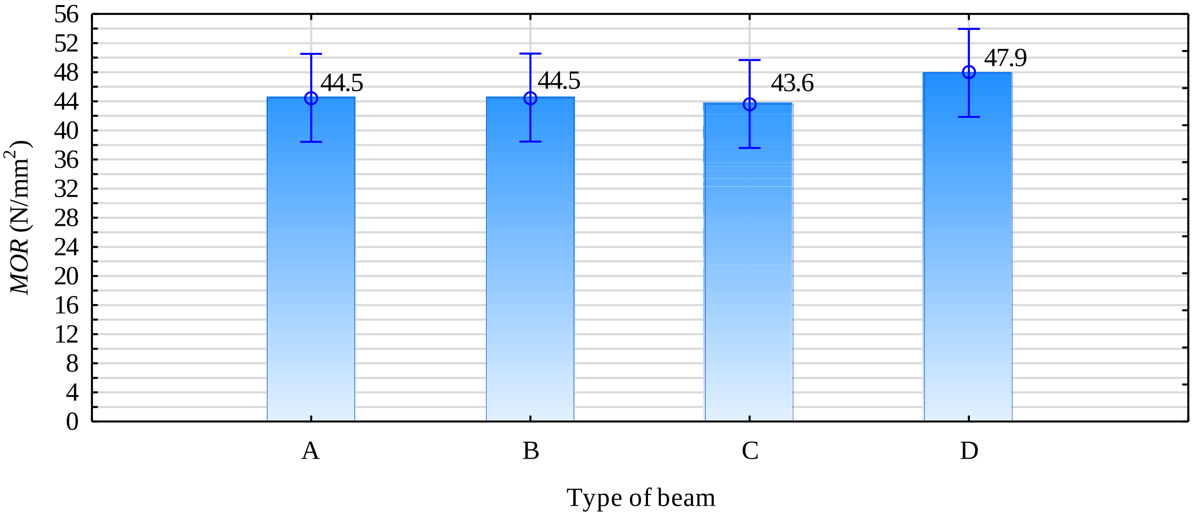

Figure 6. The results of four-point bending strength test calculated using the equation 3

Thus, the beams manufactured this way were characterized by the strength similar to the properties of the beams presented in the work of Mirski et al. (2020a), where the timber from main yield was used and the boards were arranged in a horizontal system. At this stage of the research it is not possible to demonstrate a positive effect of the fragmented wood on the strength of the beams manufactured this way. The wider beams allow better and easier assembly of the structural elements based on them. In relation to the strength of the control side timber, which were selected to have a similar MOE, the increase in strength was very significant, as it amounts to as much as 40% (the average strength of the side timber is presented in Figure 7). As stated earlier, at this stage of the research it is difficult to assess whether there may be a positive effect of the pieces located in the inner layer or if a more notable increase would be obtained by gluing only two side-timber pieces.

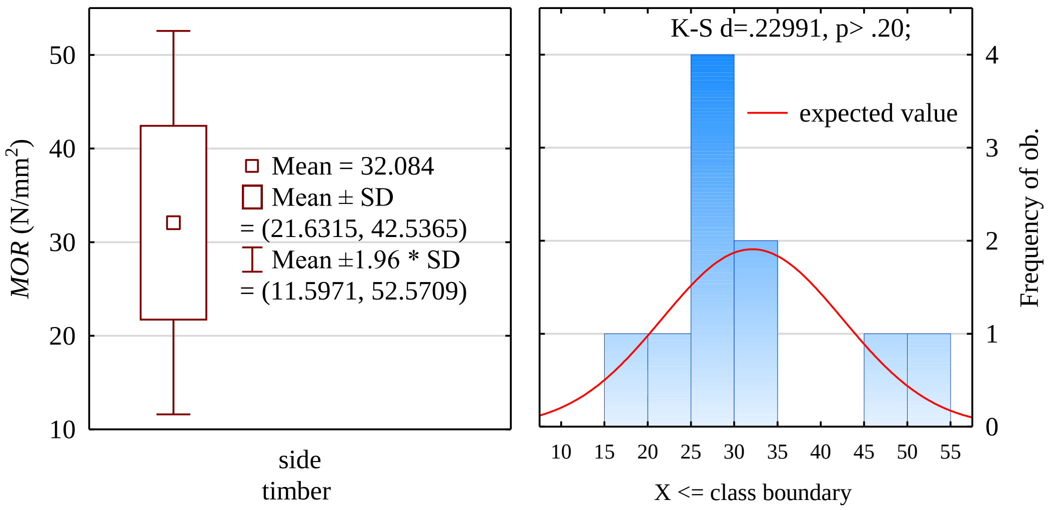

Figure 7. The bending strength of side timber pieces (on the left) and the histogram of bending strength (on the right)

As can be seen in Figure 8, the manufactured beams were characterized by a very low values of MOE. Except for variant labeled as C, for which the average MOE was over 11 kN/mm^2 (class GL24c), in other cases it was significantly lower than the values characterizing the side timber used in the experiment. It is hard to indicate why such low values of MOE were obtained for the remaining types of beams. One of the reasons may be a method error. This method will be closely evaluated and probably will be reconsidered while performing further investigations. The modulus of elasticity was determined based on the deflection which was measured with the single sensor. Data collected from the testing machine were converted using an Excel spreadsheet. Because of that, the sensor error is difficult to capture directly when investigating the MOE.

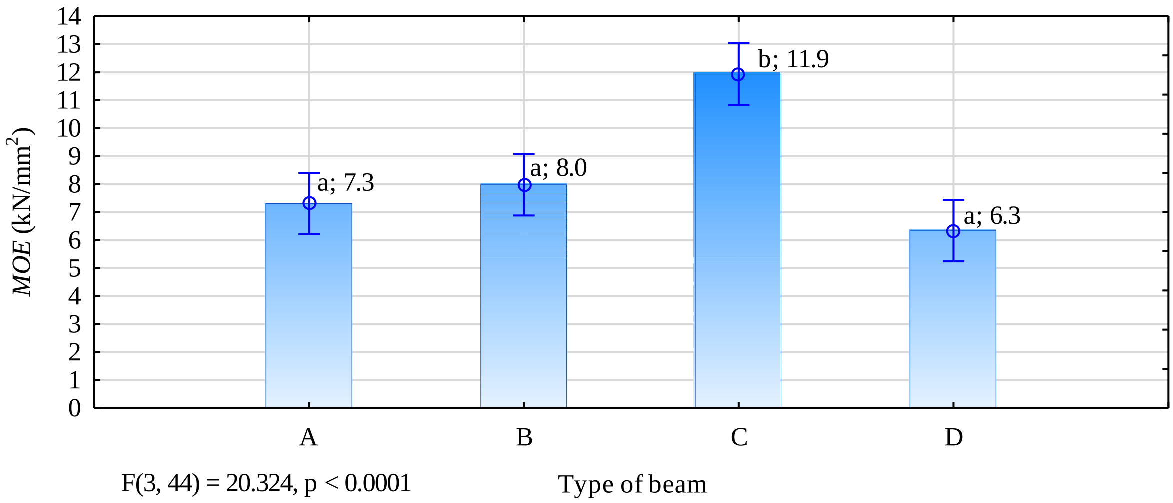

Figure 8. Modulus of elasticity of the manufactured beams

CONCLUSIONS

The study attempted to investigate the possibility of use the fragmented wood and the side-timber pieces in the production of glued beams. Very short sections of timber which are not rationally used by a finger jointing because they are characterized by small dimensions were used as the inner layer of the structural beams in similar way to the battens used in the compressed beams. Based on the conducted research a following observations were made:

- the bending strength of the beams calculated without taking into account the inner layer ranged from 44 N/mm^2 to 48 N/mm^2,
- the strength of the beams manufactured this way was 40% higher than the pieces od side-timber itself, which probably resulted from the reduction of the impact of defects by gluing,
- no significant effect of the inner layer arranging method on the bending strength of the beams was found,
- the highest modulus of elasticity of 11.6 kN/mm2 was noted for variant C, which assumed the arrangement of fragmented wood perpendicularly to the fibers of the side-timber and the adhesive layer between the pieces,
- perhaps a better application of this type of fragmented wood would be to use them as an axially compressed and not bent elements. In this case the volume of applied wood will be used even better.

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Streszczenie: *Możliwość wykorzystania tarcicy bocznej do produkcji klejonych belek konstrukcyjnych.* Celem przeprowadzonych badań było określenie właściwości mechanicznych trójwarstwowych, klejonych belek konstrukcyjnych wytworzonych z wykorzystaniem tarcicy bocznej oraz tarcicy głównej w postaci odpadów kawałkowych jako warstwy wewnętrznej. Wytworzono i przebadano cztery typy belek aby określić ich wytrzymałość na zginanie w próbie zginania czteropunktowego oraz moduł sprężystości. Warianty różniły się pomiędzy sobą kierunkiem przebiegu włókien w warstwie wewnętrznej oraz występowaniem spoiny pomiędzy fragmentami drewna w warstwie środkowej. Badania wykazały, iż wytrzymałość na zginanie wahała się od 44 N/mm^2 do 48 N/mm^2. Ponadto nie stwierdzono aby sposób ułożenia warstwy wewnętrznej miał istotny wpływ na właściwości mechaniczne wytworzonych elementów konstrukcyjnych. Wartości modułu sprężystości były niskie (w najkorzystniejszym wariancie 11,6 kN/mm^2). Prezentowane badania są punktem wyjścia do dalszych poszukiwań racjonalnego sposobu wykorzystania odpadów kawałkowych drewna powstających np. w procesie manipulacji wad oraz tarcicy bocznej w zastosowaniach konstrukcyjnych.

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