WOOD RESEARCH
58 (2): 2013
285-294

SHEAR AND BENDING PROPERTIES OF STRUCTURAL ORIENTED STRAND BOARDS OSB/4

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(Received February 2012)

ABSTRACT

Some mechanical properties of Polish three-layered oriented strand boards of higher load capacity, OSB/4, of 12-mm thickness were examined. The shear modulus (G_{12}) was obtained from a plate twisting test made on square plate samples. The moduli of elasticity (E_1 and E_2) and bending strengths (R_{g1} and R_{g2}) were obtained from pure bending tests, with the load applied in a plane of the panel, on samples cut parallel or perpendicular to the longer OSB sheet edge, respectively. The shear modulus, G_{12}, turned to be somewhat higher than that of the OSB/3 plates and decidedly higher than that of plywood. The modulus of elasticity, E_1, turned to be 1.4 times higher as E_2 but similar to that of OSB/3 plates. The bending strength, R_{g1}, turned to be 1.28 times higher as R_{g2} and almost by 24 % higher than that of the OSB/3 plates 10 mm thick.

KEYWORDS: Oriented strand board, OSB, shear modulus, modulus of rigidity, modulus of elasticity, bending strength.

INTRODUCTION

Oriented strand board (OSB) is a relatively new kind of wood-based panel products, fabricated in Poland since 1997 (Hikiert 2001). Commonly, OSB plates are fabricated from slender wood strands glued with water-resistant resins (OSB/3 and OSB/4 grades) and formed of three crossing at right angle layers. According to the PN-EN 300 2007 Standard the OSB/4 plates (of higher load capacity) may be used as structural elements even under wet conditions. In fact, OSB is a symmetrical three-layer wood laminate built-up from almost orthotropic layers, i.e. it is a non-homogeneous material. However, the model of an orthotropic body is usually used to the description of an elastic behaviour not only of the individual layer of the OSB plate but of the whole plate, as well (Wilczyński and Gogolin 1999, Thomas 2003, Zhu et al. 2005, Ludwiczak-Niewiadomska 2008). The OSB plate used as a web of composite box- or I-beams is bent by the load applied in the plane of the panel then it is in two-dimensional stress state (plane stress).

An orthotropic material in a plane stress state has the following constitutive relationship (Ashton et al. 1969, Lee and Biblis 1977):

$$\begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & 0 \\ S_{21} & S_{22} & 0 \\ 0 & 0 & S_{66} \end{bmatrix} \cdot \begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{bmatrix} \tag{1}$$

where: ε_1, ε_2 - the normal strains in the principal axes (1, 2),
γ_{12} - the shear strain referred to the 1-2 axes,
σ_1, σ_2 - the normal stresses in the 1 and 2 directions,
τ_{12} - the shear stress in natural coordinate system (1-2),
S_{11}, S_{12}, S_{21}, S_{22}, S_{66} - components of the reduced compliance matrix.

The reduced compliance matrix [S] of the specially orthotropic material may be written using the elastic constants (German 1996), as:

$$[S] = \begin{bmatrix} S_{11} & S_{12} & 0 \\ S_{21} & S_{22} & 0 \\ 0 & 0 & S_{66} \end{bmatrix} = \begin{bmatrix} \frac{1}{E_1} & -\frac{\nu_{21}}{E_2} & 0 \\ -\frac{\nu_{12}}{E_1} & \frac{1}{E_2} & 0 \\ 0 & 0 & \frac{1}{G_{12}} \end{bmatrix} \tag{2}$$

where: E_1, E_2 - the Young's moduli in the 1 and 2 directions,
G_{12} - the shear modulus referred to the 1-2 axes,
ν_{12}, ν_{21} - the Poisson's ratios.

Only four of the five above mentioned elastic constants are independent because of the compliance matrix (S) symmetry: $\nu_{21}E_1 = \nu_{12}E_2$. In general the compliance matrix of the orthotropic body entering into the composition of the constitutive relationship in a case of three-dimensional stress state includes twelve non-zero components. These components may be expressed by terms of twelve elastic constants – nine of them are independent.

The elastic properties of commercially produced oriented OSB were investigated rather seldom. Wilczyński and Gogolin (1999) determined all the twelve elastic constants of commercial OSB/3 plate 18 mm thick. They measured deformations of specimens subjected to a compressive force using the electric resistance strain gauge technique. Szyperska and Nożyński (1999) determined the E_1 and E_2 moduli of the OSB/2, OSB/3 and OSB/4 plates 11 mm thick in static bending test in accordance with the PN-EN 310 1994 Standard, i.e. by the load applied perpendicularly to the OSB sheet. In consideration of the laminar structure of OSB plates the obtained E_1 and E_2 moduli are strictly apparent values (Thomas 2003). Additionally, as the three-point loading arrangement was used in this experiment the values of E_1 and E_2 were disturbed by the shear effect. Plenzler and Górecki (2002) determined the shear modulus G_{12} of commercial OSB/3 of 6- and 10-mm thickness by a test of plate twisting. Plenzler and Pałubicki (2006) obtained the modulus of elasticity and the bending strength of the OSB/4 plate 12 mm thick. The strip samples cut at 0, 22.5, 45, 67.5 and 90° with respect to the longer OSB sheet edge were tested in static bending by the load applied in the plane of the panel. Ludwiczak- Niewiadomska (2008) determined all the five components of reduced compliance matrix of oriented strand board OSB/3 of 12-mm thickness in tension static test. Deformations of the specimens were measured using the digital image analysis.

The objective of this work was to determine some elastic constants of OSB/4 plate (of higher-load capacity), especially the shear modulus G_{12} by a test of plate twisting and Young's moduli (E_1, E_2) in tests of pure strip bending by the load applied in the plane of the panel. Additionally the bending strengths (R_{g1} and R_{g2}) at the same static bending tests were determined.

MATERIAL AND METHODS

Two three-layered OSB/4 panels with dimensions of 2500 x 1250 x 12 mm produced by the factory of Kronopol-Żary, Poland were examined. The investigation material contains: wood of content 85 to 95 %, up to 15 % MUPF resins (melamine-urea-phenol-formaldehyde-resins), up to 5 % PU resins (polyurethane-resins), polyurea-plastics (0-5 %) and also paraffin wax (0.5 - 1 %). The oriented strand board was made of flat different wide strands (generally of pine wood – *Pinus sylvestris* L.) 100-120 mm long, and 0.6 mm thick. The sheets of OSB/4 were resawed into 102 samples of three types. Thirty four square plate samples 350 by 350, 12 mm thick were predestined for the plate twisting test (Fig. 1). Another 34 bending strip samples 600 by 33 mm were cut in such a manner that their longer edge (600 mm) was parallel to the longer sheet edge, i.e. along the major axis, 1 (Fig. 2). The last 34 bending strip samples were similar to above-mentioned ones but cut perpendicular to the longer OSB sheet edge, i.e. along the minor axis, 2.

The side-to-thickness ratio L/h of the square plate samples was equal to about 29 when, according to the ASTM D3044-94 2006 Standard, acceptable are values of this ratio from 25 to 40, for samples of wood-based panel products subjected to the plate twisting test. Plenzler and Górecki (2002) subjected OSB/3 of 6- and 10-mm thickness samples to the plate twisting tests assuming a value of this ratio of 30. A test of plate twisting was chosen to determine the shear modulus G_{12} of the OSB/4 plates because the panel shear test proposed in the PN-EN 789 1998 Standard requires a big test stand and a gluing of the sample with four wood or steel rails. Additionally, during such a panel shear test the load in the sample not only produces shear stresses but normal stresses as well. From among two ways of a realization of the plate twisting test (Biblis and Lee 1976, Lee and Biblis 1977) this one was chosen, when the deflection (δ) at the loading corner is measured (Fig. 1).

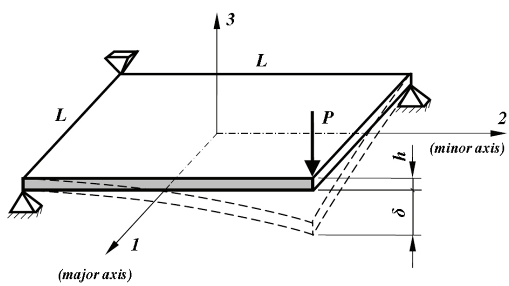

Fig. 1: Loading scheme for plate-twisting test.

For measuring deflections of square plate samples an unconventional loading apparatus with a weighing arm was used. The basic tests were preceded by a mechanical conditioning consisting of six times repeated loading from zero to 115 N und unloading. It was supposed to eliminate

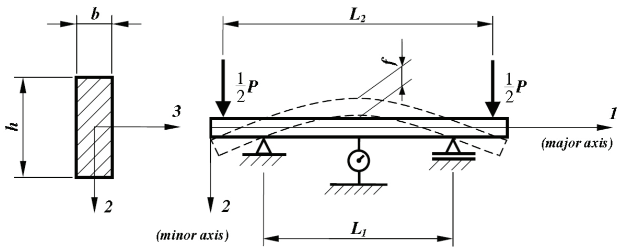

Fig. 2: Loading scheme at strip bending static tests for determining E_1 and R_{g1}.

an influence of the permanent set on deflections of the samples and, consequently, on calculated values of the shear modulus G_{12}, as well. Then each sample was loaded six times from 12.1 N (preload) to the maximum load of 100.7 N using steel disk weights and unloaded. Deflections (δ), at the loading corner of the sample, were measured by means of a dial gauge with 0.01-mm accuracy. These deflections were used for computing the shear modulus G_{12} by the following equation (Lee and Biblis 1977):

$$G_{12} = \frac{3PL^2}{\delta h^3} \tag{3}$$

where: P - the load applied at the corner of the square sample,
L - the length of the plate side,
h - the thickness of the plate,
δ - the deflection of the sample in the loading corner.

The PN-EN 13879 2004 Standard recommends test methods for determining some mechanical properties of commercial wood-based panel products in bending by the load applied in the plane parallel to the panel. Plate samples glued of many, vertically positioned strips cut out from the sheet are proposed in this Standard, i.e. a quite new wood-based panel product may be investigated. Therefore, we decided to investigate some mechanical properties of OSB/4 plates in bending on individual strip samples positioned vertically. The strip bending static test was realized in the same manner as reported by Plenzler and Pałubicki (2006), i.e. through a four point bending (Fig. 2).

The load was applied in the plane of the panel from the FPZ 100/1 testing machine with an unconventional equipment. One should be notice that employing the four point bending test with the load perpendicular to the panel sheet surface, as proposes the PN-EN 789 1998 Standard, only the "apparent" moduli E_1 and E_2 may be determined. The span size L_2 between two loading heads (Fig. 2) was 548 mm and the distance L_1 between the inner supports 415 mm. The samples were loaded in the plane of the panel, the size 33 mm was their depth and 12 mm (thickness of the OSB sheet) was their width. The basic bending tests were preceded by a mechanical conditioning consisting of three times repeated loading from zero (the weight of the upper part of the loading apparatus, as a preload, was not taken into account) to 380 N and unloading. Then each sample was loaded three times from zero to the maximum load of 300 N and rapidly unloaded. The loading phase lasted 60 ± 13 s, i.e. similarly as recommends the PN-EN 310 1994 Standard. Under the maximal load of 300 N the normal stress (σ) in outer fibres of the OSB samples reached the maximum value of ± 4.58 MPa, i.e. about 20 % of the expected OSB bending strength. Deflections (f) of the samples were measured at the center of the pure bending zone (Fig. 2) by means of a dial gauge with 0.01-mm accuracy. After the elastic tests were completed each sample was subjected to a destructive bending test at the same loading conditions, to obtain the bending strength R_g of the OSB/4 plates loaded in the plane of the panel. A loading phase in the destructive tests lasted 334 ± 89 s, similarly as recommends the PN-EN 789 1998 Standard (300 ± 120 s). The accuracy of a force measurement during the elastic and destructive tests amounted 2 and 10 N, respectively. The moduli of elasticity (E_1 and E_2) of the OSB/4 plates at bending in the plane of the panel were calculated by using the equation:

$$E_i = \frac{3}{8}\frac{P(L_2 - L_1)L_1^2}{bh^3 f} \tag{4}$$

where: i = 1 or 2,
P - the force,
L_1, L_2 - the span sizes between the outer supports and the loading heads, respectively,
b, h - the width and the depth of the sample, respectively,
f - the deflection measured in the middle of the sample span.

The strengths of the OSB/4 at bending in the plane of the panel (R_{g1} and R_{g2}) were calculated by using the equation:

$$R_{gi} = \frac{3}{2}\frac{P_{\max}(L_2 - L_1)}{bh^2} \tag{5}$$

where: P_{max} - the destructive force.

RESULTS AND DISCUSSION

The average values of shear moduli (G_{12}) of OSB/4 plates 12 mm thick obtained from the plate twisting test are listed in Tab. 1. These values are presented separately for samples collected from each of two OSB/4 sheets and jointly, for all samples.

The average values of moduli of elasticity obtained from the strip bending tests made on specimens cut with face grain parallel (E_1) and perpendicular (E_2) to the longer sheet edge are presented in Tab. 1, also. Results of bending strength tests on specimens cut with face grain parallel (R_{g1}) and perpendicular (R_{g2}) to the longer OSB sheet edge are presented in Tab. 2. The average values of OSB moisture content, obtained according to the PN-EN 322 1999 Standard after the tests were completed, are listed in Tab. 2, too – separately for each test (plate twisting or strip bending). In Tab. 2 are given also results of density measurements, made in accordance with the PN-EN 323 1999 Standard. The average air temperature in the lab during the plate twisting tests was 21°C, while the average air relative humidity amounted 37 %. During the bending tests the average air temperature and relative humidity amounted 25°C and 43 %, respectively.

Shear modulus

The average value of the shear modulus G_{12} of OSB/4 plates 12 mm thick determined by the plate twisting test amounted 2368 MPa and the difference between the G_{12} values obtained for each of two OSB/4 sheets (Tab. 1) turned out to be insignificant. This G_{12} value turned out to be decidedly higher than this determined by Ludwiczak-Niewiadomska (2008) for the OSB/3 plate

Tab. 1: Elastic properties of structural oriented strand boards OSB/4 of 12-mm thickness.

Sheet of OSB/4	Statistical estimators	Modulus of elasticity		Shear modulus G_{12} (MPa)
		E_1 (MPa)	E_2 (MPa)	
1	mean value ± s	6363.6 336.6	4160.7 212.8	2357.5 115.5
	ν (%)	5.3	5.1	4.9
	n	12	18	18
2	mean value ± s	5658.6 348.0	4245.8 455.7	2380.6 95.3
	ν (%)	6.2	10.7	4.0
	n	22	16	16
1 and 2	mean value ± s	5917.0 483.0	4203.0 352.0	2368.0 105.0
	ν (%)	8.2	8.4	4.4
	n	34	34	34

s – standard deviation, ν – coefficient of variation, n – sample size

Tab. 2: Bending strengths, density and moisture content of structural oriented strand boards OSB/4 of 12-mm thickness.

Sheet of OSB/4	Statistical estimators	Bending strength (modulus of rupture)		Density ρ (kg.m^{-3})	Average moisture content, MC (%)	
		R_{g1} (MPa)	R_{g2} (MPa)		Bending tests	Twisting test
1	mean value ± s	28.04 3.47	18.89 1.52	711.3 12.7	6.7	6.5
	ν (%)	12.4	8.0	1.8		
	n	12	18	18		
2	mean value ± s	22.47 2.43	19.39 2.65	719.0 14.3	6.9	6.8
	ν (%)	10.8	13.7	2.0		
	n	22	16	16		
1 and 2	mean value ± s	24.50 3.90	19.14 2.14	715.0 14.0	6.8	6.65
	ν (%)	15.9	11.2	2.0		
	n	34	34	34		

s – standard deviation, ν – coefficient of variation, n – sample size

12 mm thick by a tension test (G_{12} = 1391 MPa) and somewhat higher than this determined by Wilczyński and Gogolin (1999) for the OSB/3 plate 18 mm thick by a compression test

(G_{12} = 2070 MPa). The G_{12} moduli determined by Plenzler and Górecki (2002) in similar plate twisting tests carried out on OSB/3 plates of 6- and 10-mm thickness (2260 and 1996 MPa, respectively) were also somewhat lower than the obtained in the above described test carried out on OSB/4 plates. From this comparison, it is evident that the G_{12} value obtained for the OSB/4 plate 12 mm thick is higher not only than the G_{12} value of the OSB/3 plate with the same thickness but than the G_{12} values of OSB/3 plates of the thickness higher or lower than 12 mm, as well.

Moduli of elasticity

The average values of moduli of elasticity E_1 and E_2 of OSB/4 plates 12 mm thick, determined by the pure strip bending in a plane of the panel amounted 5917 and 4203 MPa, respectively. Some differences between the values of these moduli obtained for each of two OSB/4 sheets (Tab. 1) are observable, probably due to natural variability of the OSB properties, combined with the variables of a manufacturing process. The E_1 value obtained for the samples cut parallel to the longer OSB sheet edge turned out to be 1.4 times higher as the E_2 value, obtained for the samples cut perpendicular to this longer OSB sheet edge. Plenzler and Pałubicki (2006) obtained for similar OSB/4 plate 12 mm thick the values of E_1 and E_2 moduli at a level of 6323 and 5053 MPa, respectively, with the E_1/E_2 ratio of 1.25. The higher values E_1 and E_2 in that work were connected, probably, with lower moisture content (6 %) of the plate used. The moduli of elasticity values E_1 and E_2 obtained in this work and in the earlier work of Plenzler and Pałubicki (2006) for the OSB/4 plates turned out to be decidedly higher than those obtained by Ludwiczak-Niewiadomska (2008) in tension test for the OSB/3 plates of 12-mm thickness (4356 and 3053 MPa, respectively), while the E_1/E_2 ratio was equal to 1.43. The results of E_1 and E_2 moduli in this work are similar, however, to those obtained by Wilczyński and Gogolin (1999) in compression test on OSB/3 plates of 18-mm thickness (6300 and 4200 MPa, respectively), while the E_1/E_2 ratio was equal to 1.5. All of the above mentioned values of moduli of elasticity E_1 and E_2 of OSB/3 or OSB/4 plates are completely incomparable with values of the "apparent" moduli E_1 and E_2, obtained by strip bending tests with the load applied perpendicular to the panel sheet surface. The E_1/E_2 ratio for in this way obtained moduli may even be equal to 2.5 (Hikiert 2001).

Bending strength

The average values of the bending strengths R_{g1} and R_{g2} obtained in the same strip bending tests as the moduli of elasticity were equal to 24.50 and 19.14 MPa, respectively. The R_{g1} value, obtained on the samples cut parallel to the longer OSB sheet edge turned out to be 1.28 times higher as the R_{g2} value, obtained on the samples cut perpendicular to this longer OSB sheet edge. Some differences between the bending strength R_{g1} values obtained for each of two OSB/4 sheets (Tab. 2) are observable, while the bending strength R_{g2} values for both the sheets are comparable. The values of the bending strengths R_{g1} and R_{g2} obtained in this work are somewhat lower than those reported by Plenzler and Pałubicki (2006) for similar OSB/4 plates (27.43 and 20.14 MPa, respectively, with R_{g1}/R_{g2} ratio of 1.36), probably due to slightly higher (6.8 %) moisture content of material used in presented experiments. The bending strength R_{g1} obtained by Plenzler and Miler (2009) on similar OSB/4 plates with 7.1 % moisture content amounted 26.3 MPa, i.e. it was slightly higher. All of the above mentioned values of the bending strength R_{g1} obtained for OSB/4 plates on samples cut parallel to the longer sheet edge turned out to be distinctly higher than the reported by Pałubicki and Plenzler (2004) for OSB/3 plates of 10-mm thickness (19.8 MPa at moisture content of 6.4 %). One should notice that due to a laminar structure of OSB plates the bending strengths R_{g1} and R_{g2} obtained at a bending in the plane of the panel are completely incomparable with the strengths obtained at a bending with the load applied perpendicular to the panel sheet surface, according to the PN-EN 310 1994 Standard.

CONCLUSIONS

The design of wood composite box- or I-beams requires the knowledge of mechanical properties of all material used. The wood or LVL flanges are designed to carry almost whole bending moment, while the webs, made of wood-based panel materials are assumed to carry almost all shear forces. These wood-based materials, as plywood, waferboard, particleboard, hardboard or oriented strand board (OSB) should be therefore characterized by high shear modulus and shear strength. A value of the shear modulus G_{12} has an effect on the total deflection, i.e. on the stiffness of the composite beams and on their load capacity, as well.

The shear modulus G_{12} of the OSB/4 plates 12 mm thick turned to be somewhat higher than that of the OSB/3 plates but decidedly higher than that of plywood. The modulus of elasticity E_1 of these OSB/4 panels obtained on samples cut parallel to the longer OSB sheet edge turned out to be 1.4 times higher as the modulus of elasticity E_2 obtained on samples cut perpendicular to this longer sheet edge. The values of E_1 and E_2 moduli were rather similar to those obtained earlier for the OSB/3 plates. The bending strength R_{g1} obtained on samples cut parallel to the longer sheet edge turned out to be 1.28 times higher as the bending strength R_{g2} obtained on samples cut perpendicular to this longer sheet edge. Additionally, the bending strength R_{g1} of the OSB/4 plates of 12-mm thickness was almost 24 % higher than that of the OSB/3 plates 10 mm thick.

The results of the above mentioned investigation allow to suppose that the OSB/4 plates of 12-mm thickness are, as a cheaper replacement for high-quality structural grade plywood, a very good wood-based panel material, predestined to the use as the webs in composite box- or I-beams.

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