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BENDING CREEP BEHAVIOUR OF OSB-WEBBED I-BEAM

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SYNOPSIS. Three months' duration creep test was carried out on the composite I-beam of a span of 4.5 m, loaded at third point along the beam. The beam consisted of two 38 × 58 mm flanges made of pine wood and 10 mm thick OSB/3 web. The results of the bending creep test were approximated using the creep equations of three-, four- and five-element viscoelastic models.

KEY WORDS: composite I-beam, creep, viscoelasticity, creep model, bending, pine wood, OSB

INTRODUCTION

Composite wood members, as prefabricated I-beams and box beams, were found in European building structures by the mid 1930s (McNatt 1980). The development of composite wood beams was intensified by increasing costs and decreasing availability of larger, solid-sawn wood structural members (McNatt and Superfesky 1983). First wood-based panel materials used as webs in composite I- or box beams were hardboard and plywood (Leichti et al. 1990). Later, as webs were also used particleboard, waferboard and – recently – oriented strand board (OSB). The primary material on flanges of composite wood beams was solid-sawn lumber. Recently, as an alternative material are used laminated veneer lumber (LVL) or parallel strand lumber (PSL), too. Since the early 1980s, studies at the Department of Engineering Mechanics and Thermal Techniques of the former Agriculture University of Poznań (at present: Poznań University of Life Sciences) have been conducted on the composite wood beams with hardboard webs. First, I-beams and box beams with nail-glued flange-web joints were examined (Ganowicz and Kwiatkowski 1985). Later, the conception of the tongue-and-groove flange-web joint was developed (Ganowicz et al. 1990), which proved to be very effective. The various problems connected with the design of wood composite I- and box beams were, in detail, discussed in a review by Leichti et AL. (1990). In Poland, studies on the load capacity and rigidity of wood composite beams with particleboard webs were conducted by CHMIEL (1970), with plywood webs – by WILCZYŃSKI and GOGOLIN (1996) and with hardboard webs – by GANOWICZ et AL. (1990). The wood composite I-beams with OSB webs were investigated by HIKIERT et AL. (2000). The short-term strength and rigidity of OSB-webbed I-beams were investigated by PLENZLER et AL. (2005) and by PLENZLER and SZYMOCHA (2008). MIELCZAREK and ŚLIWKA (2005) examined double-pitched composite box beams with hardboard webs and steel tension members. The composite beams with the corrugate plate webs were examined by LANGE and ORŁOWICZ (2004). Therefore, short-term strength and deflection performance of composite wood beams were repeatedly investigated. The effects of load and environmental histories on the deflection of such beams have been, however, the subject of very few investigations (LEICHTI et AL. 1990). MCNATT and SUPERFESKY (1983) reported the long-term behaviour of hardboard- and plywood-webbed I-beams loaded (up to 5 years) in one of three environments: uncontrolled interior, protected exterior, and controlled cyclic humidity. PLENZLER (1993) described the above 12-month bending test of hardboard-webbed I-beams loaded in the open air under roof and in the laboratory nearly constant conditions of air temperature and humidity. PLENZLER (1996 and 1999) also studied the problem of the stress redistribution on the cross-section of composite wood members made of wood and hardboard, under the constant load. LEICHTI and TANG (1986) studied the flexural creep behaviour of composite wood beams with plywood and waferboard webs. WISNIEWSKI et AL. (2000) reported the long-term behaviour of engineered I-joists and oriented strand board floor systems with OSB webs and skin and with LVL flanges. Results of the creep behaviour of composite I-beams made of wood and domestic OSB plates have been, up to now, unpublished.

The objectives of this work were to investigate the bending creep behaviour of the composite I-beam made of wood flanges and OSB web, and to discuss the merits of different rheological models for long-term prediction of its deflection.

MATERIALS AND METHODS

One composite I-beam of a total length of 4.6 m and 200 mm deep was constructed in a similar manner as reported earlier (PLENZLER et AL. 2005, PLENZLER and SZYMOCHA 2008). The beam was the same size as one type of "Kronopol I-beams" offered by a domestic manufacturer. The beam consisted of two 38 × 58 mm flanges made of pine wood (*Pinus sylvestris* L.) and 10 mm thick OSB/3 web (Fig. 1). The wood flanges were connected with the OSB web with the tongue-and-groove joint using the epoxy resin "Sikadur 20". To minimize variation in beam cross-section symmetry, pieces of flange material with the closest values of moduli of elasticity were chosen from a group of 9 pieces. The modulus of elasticity of each piece was obtained during the static bending test (Fig. 2). Because commercial OSB/3 panels (2500 × 1250 × 10 mm) were used, the web was made of three OSB/3 sheets joined by means of two OSB splice plates, glued on both sides of the web. The width of the splice plates (6 cm) was designed in accordance with the proposal of OZELTON and BAIRD (1976). Additionally, pine wood web stiffeners (38 by 24 mm) were glued on both sides of the web at reaction and concentrated load points to prevent the web from a buckling.

For the chosen cross-section of the composite I-beam (Fig. 1) were obtained the effective properties of a plane area: the area – $A_{ef} = 50.59$ cm^2, the moment of inertia – $J_{z,ef} = 3028.5$ cm^4 and the section modulus – $W_{z,ef} = 302.9$ cm^3. These values were calculated supposing that the moduli of elasticity of pine wood and OSB/3 panel are 12 000 MPa (PN-B--03150:2000) and 6300 MPa (WILCZYŃSKI and GOGOLIN 1999), respectively. Knowing, from the earlier work (PLENZLER and SZYMOCHA 2008), the value of 19.62 kN of the destructive force, $P_{\max}$, for similar composite I-beams, but with another section modulus ($W_{z,ef}$ = 433.3 cm^3) the destructive force of $P_{\max}$ = 13.72 kN was estimated for the proposed beam. The load level of 30% of this value was chosen for the bending creep test, because some authors reported that even at loads of 0.3 of the ultimate load in wood a cell-wall damage may

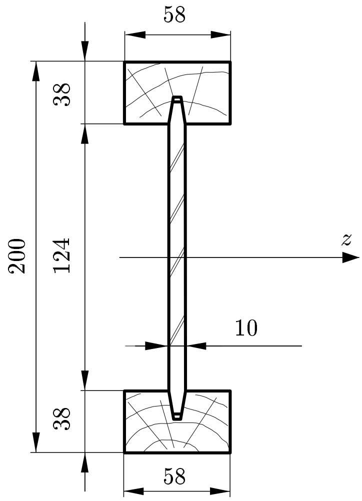

Fig. 1. Cross-section dimensions of the composite I-beam [mm]

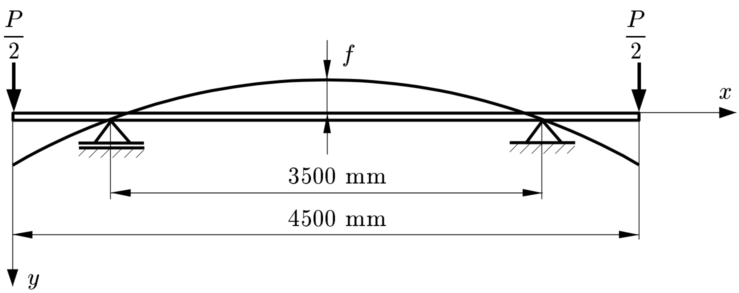

Fig. 2. Diagram of the flange load and deflection measurement

be expected (e.g. KITAHARA et AL. 1984). This phenomenon may be a reason of undesirable nonlinear creep behaviour of wood, while some linear viscoelastic models were chosen to the modelling of the creep deflection of the composite I-beam. Additionally, a load on this level should to produce normal stresses in wood flanges and OSB web somewhat lower than the computational values evaluated in accordance with the PN-B-03150 and PN-EN 12369-1 Standards.

The composite I-beam of an effective span L of 4.5 m was loaded at third point along the beam (Fig. 3) to obtain a wide (i.e. 1.5 m) zone of pure bending. The dead load of 410 kg cast iron bobs was applied to the beam quasi-statically, through the hydraulic jack, while the preload was of 28 kg. The test stand was equipped

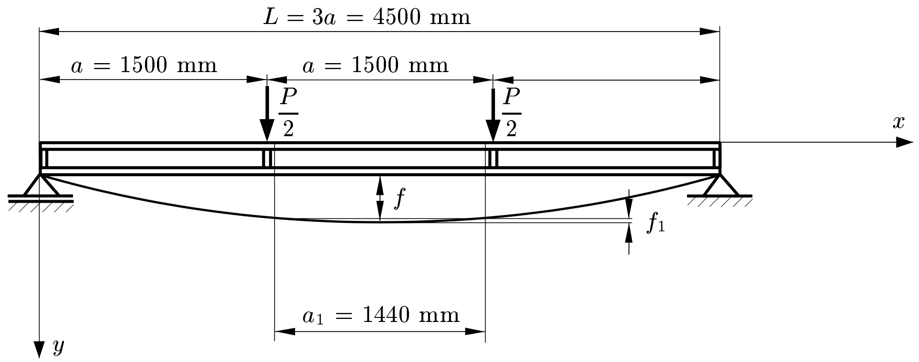

Fig. 3. Diagram of the composite I-beam load and deflections measurement

with two lateral supports with the spacing of 190 cm to avoid the lateral buckling of the beam. Three dial gauges with the accuracy of 0.01 mm were positioned at the zone of pure bending: one at the mid-span of the beam and two symmetrically, with the spacing of 144 cm.

RESULTS AND DISCUSSION

The results of static bending test showed that the average value of the bending modulus of elasticity (MOE) of pine wood predestined for the composite beam flanges amounted 16 226 MPa under the average moisture content of 8.8%. This value allow to classify used wood to structural lumber grade C 40, according to the Polish Standards PN-B-03150:2000 and PN-EN 1912:2000. Two pieces of wood material with the values of MOE about 16 818 MPa differing no more than 0.45% were selected for the flanges of the composite I-beam. Taking, as earlier the values of MOE of 6300 MPa for OSB web but 16 818 MPa for wooden flanges the effective properties of a plane area for the prepared composite beam were stated more precisely: $A_{ef} = 48.73$ cm^2, $J_{z,ef} = 3004.7$ cm^4 and $W_{z,ef} = 300.5$ cm^3. Therefore, under the presupposed level of load, maximum values of the normal stresses in the wooden flanges and the OSB web should amount $\sigma_{\max,\text{wood}} = \pm 10.73$ MPa and $\sigma_{\max,\text{OSB}} = \pm 2.50$ MPa, respectively. These are, certainly, only the initial values of the maximum stresses, because – as reported for instance by Plenzler (1996, 1999) – a stress redistribution effect in composite elements is expected due to different creep processes in both materials used. The instantaneous deflections: total ($f = 14.92$ mm) and in pure bending zone ($f_1 = 1.49$ mm) were evaluated from the formulas proposed for such beams by Plenzler and Szymocha (2008).

The results of three-months' creep test in the form of discrete values of the total (f) or "pure" (f_1) bending deflections were modelled with the creep equations of three chosen linear creep models:

– three-element standard model

$$y = y_0 + y_\infty \left(1 - e^{-\frac{t}{\tau}}\right) \tag{1}$$

– four-element Burger model

$$y = y_0 + y_\infty \left(1 - e^{-\frac{t}{\tau}}\right) + v_y t \tag{2}$$

– five-element exponential model

$$y = y_0 + y_{\infty 1} \left(1 - e^{-\frac{t}{\tau_1}}\right) + y_{\infty 2} \left(1 - e^{-\frac{t}{\tau_2}}\right) \tag{3}$$

where: y_0 – instantaneous deflection,
y_∞, $y_{\infty 1}$, $y_{\infty 2}$ – delayed deflections,
τ, τ_1, τ_2 – retardation times,
v_y – flow rate,
t – time.

The results of these approximations obtained by using Table Curve and Sigma Plot programs are summarized in Tables 1-3. From these tables, it is evident that the best fitting to the results of the three-months' creep test was obtained using the creep equation (3) of the five-element exponential model. The quality of the approximation with the creep equation (2) of the four-element Burger model was slightly worse. The worst fitting to the experimental results was obtained using the creep equation (1) of the three-element standard model. However, this model describes unsatisfactorily even the creep processes of both materials used for construction of the composite I-beam, i.e. wood (e.g. Socha 2002) and OSB (e.g. Plenzler and Miler 2009). From Table 1, it is evident that choosing the creep equation (1) of the standard model we receive the delayed viscoelastic deflections

Table 1. Creep test results fitted by 3-parameter equation (1)

Deflection	y_0 [mm]	y_∞ [mm]	τ [min]	r^2
Total, f	15.40	1.59	11 688.8	0.880
"Pure", f_1	1.71	0.12	2 069.5	0.878

Table 2. Creep test results fitted by 4-parameter equation (2)

Deflection	y_0 [mm]	y_∞ [mm]	τ [min]	v_y [mm/min]	r^2
Total, f	15.13	1.24	1 861.4	$7.04 \cdot 10^{-6}$	0.979
"Pure", f_1	1.69	0.12	337.1	$3.60 \cdot 10^{-7}$	0.935

Table 3. Creep test results fitted by 5-parameter equation (3)

Deflection	y_0 [mm]	$y_{\infty 1}$ [mm]	$y_{\infty 2}$ [mm]	τ_1 [min]	τ_2 [min]	r^2
Total, f	15.09	1.12	1.48	1 154.0	108 662.3	0.981
"Pure", f_1	1.69	0.10	0.05	208.7	34 805.6	0.954

(y_∞) only 9.4% and 6.6% of the ultimate total or "pure" deflections of the composite I-beam, respectively. However, in the case of the five-element exponential model the delayed viscoelastic deflections amounted 14.7 and 8.2% of the ultimate total and "pure" deflections, respectively. Figures 4-7 show creep charts of the composite I-beam both for total and in pure bending zone only deflections after approximations made with creep models (1), (2) or (3). Figure 8 shows the quality of the approximations with the use of the three-, four- and five-element creep models within the zone of delayed viscoelastic deformations only. It is evident that the approximation with the use of the five-element creep model is best both at the shortest and longest times. The measured instantaneous deflections of the composite beam: total (f = 14.65 mm) and "pure" (f_1 = 1.65 mm) turned to be smaller by 1.8% and greater by 10.7%, respectively, than the presupposed values of them. After a lapse of three months of the creep test the increase of deflection at the zone of pure bending (f_1) was already unnoticeable, while the total deflection (f) of the beam was still increasing. This phenomenon was caused, probably, by the creep of the OSB web and the wooden flanges at the supporting zones, due to the influence of the shear. A permanent support settlement, due to the compression of the wood perpendicularly to the grain is another, possible reason of this phenomenon. The average air temperature in the lab during the creep test was 19.6°C, while the average air relative humidity amounted 50.1%. The initial moisture content (MC) of the wooden flanges of 8.8% was obtained according to the PN-77-D-04100 Standard and for the OSB web it was 8.9%, according to the PN-EN 322 Standard. It may be that the moisture content of both material used was slightly increasing during the three-months' creep test, because the equilibrium moisture content of wood in the latter part of the experiment increased to 10.9%.

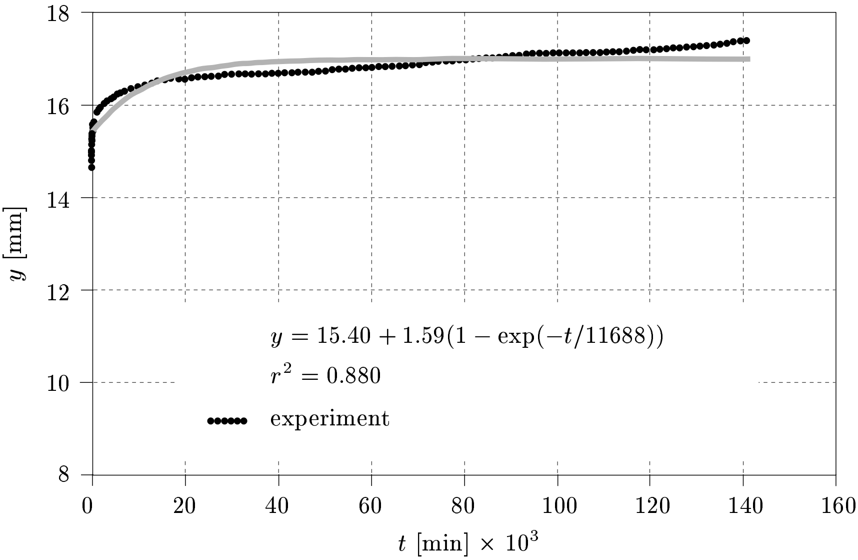

Fig. 4. Total deflection of composite I-beam – creep data fitted by 3-parameter equation (1)

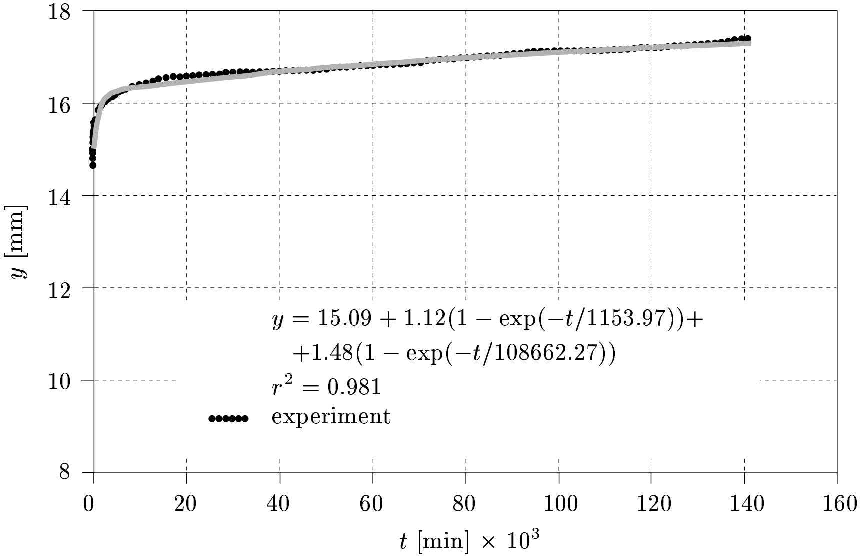

Fig. 5. Total deflection of composite I-beam – creep data fitted by 5-parameter equation (3)

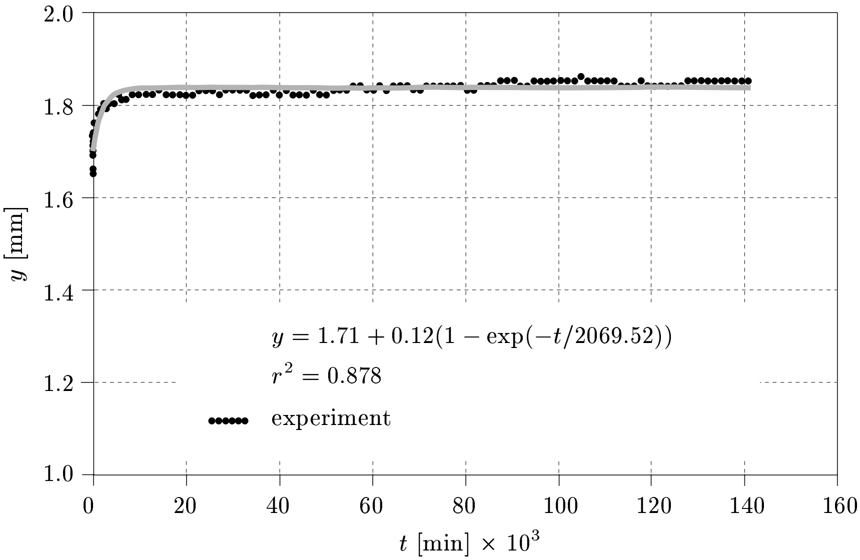

Fig. 6. "Pure" deflection of composite I-beam – creep data fitted by 3-parameter equation (1)

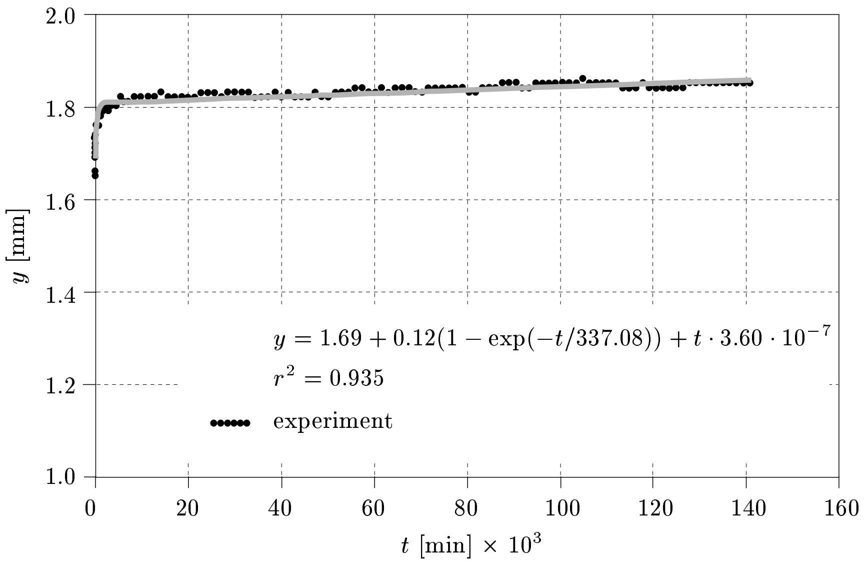

Fig. 7. "Pure" deflection of composite I-beam – creep data fitted by 4-parameter equation (2)

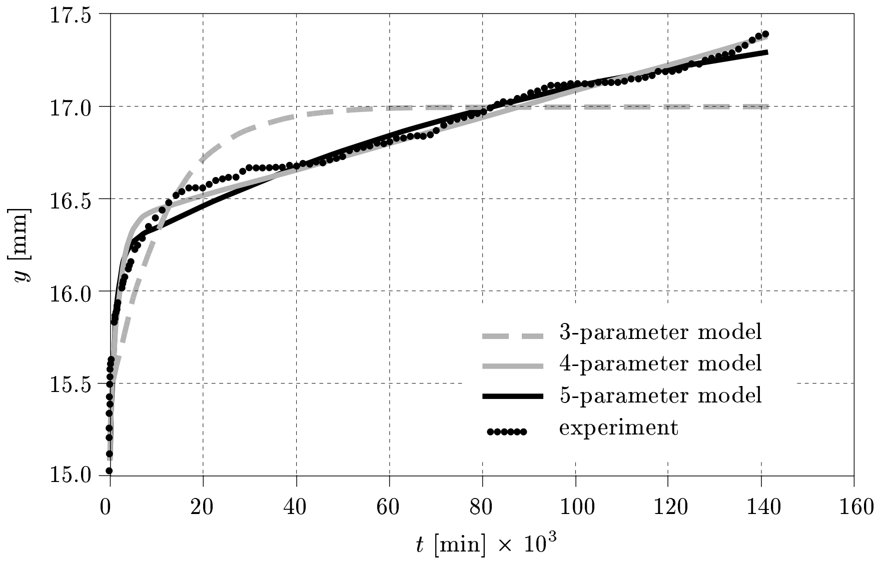

Fig. 8. Total deflection of composite I-beam – quality of fitting to the creep data by varied creep models within the zone of delayed, viscoelastic deformations

CONCLUSIONS

1. At the load level approximate to the standard value the composite I-beam with pine wood flanges and OSB/3 web creeps perceptible.
2. After the three-months' bending test the creep rate at the zone of pure bending dropped practically to zero, but the total deflection of the beam was still increasing slightly.
3. From among three linear viscoelastic models used to an approximation of the creep data the best fitting was obtained using the creep equation of the five-element exponential model and the worst in the case of the three-element standard model.
4. The measured after above three months' duration creep test delayed, viscoelastic deflections of the composite I-beam amounted 12.1% of the instantaneous deflection at the zone of pure bending and 18.6% of the instantaneous total deflection, respectively.

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