Annals of Warsaw University of Life Sciences – SGGW Forestry and Wood Technology No 71, 2010: 429-434 (Ann. WULS – SGGW, For. And Wood Technol. 71, 2010)

Density and shear strength as solid wood and glued laminated timber suitability criterion for window woodwork manufacturing

AGNIESZKA KUROWSKA*, PAWEŁ KOZAKIEWICZ**

* Department of Technology, Organization and Management in Wood Industry **Department of Wood Science and Wood Protection Faculty of Wood Technology, Warsaw University of Live Science - SGGW

Abstract: Significance of window woodwork has been increasing in value lately (production distinct increase) thus generating demand for raw material complemented by import of exotic wood, of most frequently new not very well known species. Suitability of glued laminated timber from selected species and types of tropical wood for manufacturing of window woodwork, on the basis of the determined density and shear strength in air-dry and wet condition has been defined in the present study. Taking the entire results into consideration it should be stated that density and moisture of wood used for manufacturing of glued laminated timber is the crucial factor of shear strength. The greater the wood density (with given moisture) the better shear strength. Presence of glue lines will not have negative impact upon noted shear strength along the grain (these are D4 class water resistant glue lines).

Keywords: density, shear strength, solid wood, glued laminated timber, glulam, glue line, window woodwork

INTRODUCTION

Solid wood and glued laminated timber (also called glulam) provided for opening woodwork must comply with several requirements as presented in several standards: EN 942:2008, EN 13307-1:2007 and EN 14220:2007 or EN 14221:2007. The requirements concern, among others, basic characteristic of the applied wood (appearance, admissible faults, natural durability, density and strength) dimension tolerance, wood surface quality, moisture, applied glues and characteristic of glue lines. The documents contain basic terminology and definitions of notions applied with this kind of products also.

Glued laminated timber used for manufacturing of window woodwork is, most frequently, the so-called "scantling" obtained by gluing of three planks thickness. The planks, after elimination of faults, are then joined along with mini dovetails. These are rather short elements in a ready product thus their shear strength is essential (element with slenderness ratio below 6 is most often destroyed by tangential stresses – causing longitudinal delamination and cracking).

As far as examination of wood and glue lines shear strength is concerned, there are several, not synchronized so far, standards (e.g. PN-D-04105:1979, PN-B-03156:1997, EN 408:2004). Different examination procedures recommended by the said standards (various quantities and shapes of specimen and ways of their loading) causing significantly different results. Unfortunately it is often the case that the choice of given procedure (standard) is not described or there is no such information in glued laminated timber characteristic.

MATERIALS AND METHODS

Glued, three layer laminated timber with section of 72x86 mm and length of 2100 mm, made of the following wood kinds and species: bintangor (*Calophyllum spp.*), durian (*Durio spp.*), eucalyptus (*Eucalyptus grandis* W. Hill ex. Maid.), kembang semangkok (*Scapium spp.*), dark red meranti (*Shorea spp.*), light red meranti (*Shorea spp.*) and pine (*Pinus sylvestris L.*) has been used for examination as a reference point – naming as per EN 13556:2005. The used glue (polyvinyl acetate, in short PVA or PVAc) gave D4 class water

resistant joints. From each of the three layer laminated timber, made of given wood kind or species, specimens comprising solid wood with respectively situated glue lines (in the plane of the future cutting) have been obtained. The following physical and mechanical properties of wood have been determined:

- moisture as per PN-77/D-04100,
- density as per PN-77/D-04101,
- shear strength of solid wood along the grains (from which glued laminated timber has been made) and strength of glue lines in air-dry condition (after 7 days of seasoning in normal climate, 20±2 °C and 65±5% relative humidity) and in wet condition (after 4 days of soaking in water) as indicated by PN-79/D-04105 standard. This method has been selected for examinations with regard to possibility of comparing the results (glue line strength - solid wood strength).

RESULTS

The wood applied in (window) opening woodwork should be sorted by density. Minimal density of deciduous wood in air-dry condition (moisture of 12%) should be 450 kg/m³ at least and 350 kg/m³ for coniferous wood respectively (EN-942:2008). For coniferous wood, the so called late wood is crucial as far as strength is concerned and therefore it s average density can be lower. Deciduous wood has more "balanced" structure of annual rings ("does not appear" on the so-called late wood zone) and thus higher minimal density is required.

Figure 1 shows examination results, i.e. determination of solid and glued laminated timber density with moisture showing $12\pm2\%$. It has been found that with reference to wood applied for glued laminated timber, bintangor (745 kg/m³) and dark red meranti (741 kg/m³) show the most average density, while light red meranti (435 kg/m³) shows the least average density.



□ solid wood Ø glued laminated timber

Fig. 1 Solid wood and glued laminated timber density

Apart from the a/m it has been found that in most cases (except glued bintangor and light red meranti wood) the density of glued wood is greater than the solid wood density. This is first of all because of significant dispersion of wood density within the glued element (glued laminated timber). It can be seen from the above data that the examined light red

meranti will not comply with the minimal density condition and the glued laminated timber made of it should not be applied in window woodwork.

As per data presented in literature, pine wood in air-dry condition, shows density in range of 330-520-890 kg/m³ (Krzysik 1974), bintangor wood: 450-650-720 kg/m³ (Wagenführ 2007), durian wood: 470-640-830 kg/m³ (Dahms 1995), eucalyptus wood: 550-650-720 kg/m³ (Wagenführ 2007), kembang semangkok: 470-520-670 kg/m³ (Dahms 1995), light red meranti: 380-500-580 kg/m³ (Kozakiewicz 2008).

Light red meranti is considered the material of bright red color and density not exceeding 580 kg/m³ in air-dry condition. For example, heavier wood, although obtained partly from same wood species, appears on the market as approved name of dark red meranti. The examined wood species, except bintangor and eucalyptus, showed density as per the data expressed in tables (literature). Bintangor had a little higher density (745 kg/m³) and eucalyptus wood – slightly lower density (447 kg/m³) as compared with the data presented in literature.

			Shear streng	gth [MPa]			
basic statistic measures	wood species						
	bintangor	durian	eucalyptus	kembang semangkok	dark red meranti	light red meranti	pine
solid wood							
after 7 days of seasoning in normal climate							
mean	10,82	7,70	5,63	6,50	6,75	6,87	7,84
SD	0,72	1,18	0,19	0,45	0,28	0,37	0,54
wood moisture $12 \pm 2\%$							
after 7 days of seasoning in normal climate and 4 days of soaking in water							
mean	7,49	6,41	4,33	4,65	5,05	4,86	4,54
SD	0,23	0,80	0,13	0,25	0,11	0,11	0,24
wood moisture $12 \pm 2\%$							
-	38	90	55	90	42	75	70
glued laminated timber							
after 7 days of seasoning in normal climate							
mean	12,57	8,09	10,04	11,13	11,32	4,91	8,51
SD	1,00	0,63	1,09	1,18	0,60	0,51	0,70
WFP	100	100	100	100	100	100	100
wood moisture $12 \pm 2\%$							
after 7 days of seasoning in normal climate and 4 days of soaking in water							
mean	7,55	7,31	5,08	6,06	7,49	3,52	3,31
SD	0,65	0,67	0,74	0,59	0,36	0,52	0,30
WFP	100	100		100	100	100	100
wood moisture $12 \pm 2\%$							
-	38	90	55	90	42	75	70

Tab. 1. Specification of results: determination of solid wood and glued laminated timber shear strength

Table 1 shows solid and glued laminated timber strength examination results, obtained in particular tests together with their basic statistic measures (SD – standard deviation), including WFP – mean apparent cohesive wood failure. The value of this coefficient has been determined by visual method with accuracy of 10%. As far as solid wood specimens in air-dry condition are concerned, the highest shear strength in dry condition, about 10.42 MPa was shown by bintangor wood, while the least value of 5.63 MPa was shown by eucalyptus wood. The remaining wood species showed approximate values of the feature noted for pine wood in the strength of the feature noted for pine wood.

(7.84 MPa). The shear strength in air dry condition measurement results obtained for particular solid wood species confirm the data as presented in literature. As per the data presented in literature, the shear strength of pine wood in air dry condition is 9.0-10.0 MPa (Krzysik 1957), for bintangor: 9.0-11.5-16.0 MPa (Kozakiewicz, Milewska 2009a), durian wood: 7.2-8.0 MPa (Kozakiewicz, Milewska 2009b), eucalyptus wood 5.3-7.8-9.6 MPa (Wagenführ 2007), kembang semangkok wood: 6.5-10.1-12.2 MPa (Kozakiewicz 2010), light red meranti: 6.3-6.9-7.3 MPa (Kozakiewicz 2008).

With reference to solid wood in wet condition (after 4 days soaking in cold water) the greatest strength in wet condition of 7.49 MPa was noted for bintangor, while the least value of 4.33 MPa was obtained for eucalyptus. The remaining species of wood showed the strength values close to pine wood strength, namely 4.54 MPa.

For specimens containing glue lines, the greatest shear strength - 12.57 MPa was noted for glued bintangor wood and the least value - 4.91 MPa was obtained for light red meranti. The remaining wood species (except durian) showed greater shear strength than glued pine wood (8.51 MPa). Similar dependence (with respect to exotic wood) was obtained for glued wood specimens, additionally subject to 4 days soaking in cold water. The above results confirm the dependence (fig. 1, tab. 1) that wood strength grows along with increase in density. The strength should be considered fully sufficient, remembering that the strength of sawn wood sorted by strength is required to be at the level of about 3 MPa.

It should be emphasized that for glued laminated timber - both in dry and wet test - the glue lines destruction at breaking loads occurred in solid wood layers. The percentage share of cutting in wood after dry test was included in range of 80-100%. Thus wood, not glue line, was found to be the weakest element of the tested joints. For wet test, the percentage share of cutting in wood was included in range of 0-20% for glued bintangor, eucalyptus, dark red meranti, light red meranti and pine; 0-50% for kembang semangkok and 50-100% for glued durian.

Satisfactory (correct) final effect in a form of durable, decorative and functional window is obtained by keeping up with the requirements, at each of the production stages: from selection of wood, throughout its processing into glued laminated timber, to end with appropriate use in ready product construction. The records of European standards, i.e. EN 14220:2007 in connection with EN 350-2:2000, EN 460: 1997 and EN 335-1: 2007 show that wood with higher natural durability, i.e. class 1, 2 and 3 is to be used for window (opening) woodwork with regard to biological hazard class 3.

According to EN 350-2 and L'Associacion Technique des Bois Tropiceaux CIRAD (http://tropix.cirad.fr) natural durability of pine heart wood is 3-4 (in a 5 degree scale, where 1 means very durable wood). The examined types and species of exotic wood show durability comparable with that of pine wood: eucalyptus and red light meranti: 3-4, kembang semangkok and bintangor: 3 and dark red meranti: 2-4. With regard to the above, wood protection should be applied when the wood is used for window woodwork. Regardless the species, the white wood zone (especially wide in pine wood) has lowest natural durability of class 5.

SUMMARY

Apart from light red meranti, all remaining species (eucalyptus – *Eucalyptus grandis* W. Hill ex Maid, dark red meranti – *Shorea spp*, durian – *Durio spp*, bintangor – *Calophyllum spp*, kembang semangkok – *Scapium spp*,) comply with the requirement of minimal density for deciduous wood applied in opening woodwork, i.e. 450 kg/m³, like pine wood (*Pinus sylvestris L.*) complies with the requirement for coniferous wood (350 kg/m³).

All the examined semi finished products (solid wood and glued laminated timber) showed respective high shear strength in both air-dry and wet condition. The crucial factor of

shear strength is density and moisture of wood used for manufacturing of glued laminated timber. The greater density of wood (for given moisture) the higher shear strength. Presence of glue lines does not have negative impact upon noted shear strength along the grain, provided that they are D4 water resistant class glue lines.

REFERENCES

- 1. DAHMS K.,G., 1995: Tropical Timber Atlas (Includes timbers exported from Japan). Part II – Asia, Australia. L'Association Technique Internationale des Bois Tropicaux (Commission VI).
- 2. EN 460:1997 Durability of wood and wood-based products. Natural durability of solid wood. Guide to the durability requirement
- 3. EN 350-2:2000 Durability of wood and wood-based products Natural durability of solid wood Part 2: Guide to natural durability and treatability of selected wood species of importance in Europe
- 4. EN 408:2004 Timber structures Structural timber and glued laminated timber Determination of some physical and mechanical properties
- 5. EN 13556:2005 Round and sawn timber. Terminology in the timber trade in Europe
- 6. EN 335-1:2007 Durability of wood and wood- based products Definition of use classes Part 1: General
- 7. EN 13307-1:2007 Timber blanks and semi-finished profiles for non-structural uses -Part 1: Requirements
- 8. EN 14220:2007 Timber and wood-based materials in external windows, external door leaves and external doorframes Requirements and specifications
- 9. EN 14221:2007 Timber and wood-based materials in internal windows, internal door leaves and internal doorframes Requirements and specifications
- 10. EN 942:2008 Timber in joinery General requirements
- KOZAKIEWICZ P., 2008: Meranti różowe (Shorea sp.) drewno egzotyczne z południowo-wschodniej Azji. Przemysł Drzewny nr 1 2008, s.33-36. Wydawnictwo Świat.
- KOZAKIEWICZ P., MILEWSKA A., 2009a: Gumiak (*Calophyllum sp.*) drewno egzotyczne z południowo-wschodniej Azji. Przemysł Drzewny nr 1, s.27-30. Wydawnictwo Świat.
- KOZAKIEWICZ P., MILEWSKA A., 2009b: Durian (Durio sp.) drewno egzotyczne z południowo-wschodniej Azji. Przemysł Drzewny nr 6, s.23-26. Wydawnictwo Świat.
- 14. KOZAKIEWICZ P., 2010: Kembang semangkok (*Scaphium sp.*) drewno egzotyczne z południowo-wschodniej Azji. Przemysł Drzewny nr 3 2010 Rok LXI, s.11-14. Wydawnictwo Świat.
- 15. KRZYSIK F., 1957: Nauka o drewnie. Państwowe Wydawnictwo Rolnicze i Leśne. Warszawa.
- 16. PN-77/D-04100 Drewno. Oznaczanie wilgotności
- 17. PN-77/D-04101 Drewno. Oznaczanie gęstości
- 18. PN-79/D-04105 Drewno Oznaczanie wytrzymałości na ścinanie wzdłuż włókien
- 19. PN-B-03156:1997 Konstrukcje drewniane Metody badań Nośność złączy klejonych
- 20. PN-D-04105:1979 Drewno. Oznaczanie wytrzymałości na ścinanie wzdłuż włókien
- 21. WAGENFÜHR R., 2007: Holzatlas.6., neu bearbeitete und erweitere Auflage. Mit zahlreichen Abbildungen. Fachbuchverlag Leipzig im Carl Hanser Verlag.
- 22. http://tropix.cirad.fr

Streszczenie: *Gęstość i wytrzymałość na ścinanie jako kryterium przydatności drewna litego i półfabrykatów klejonych do produkcji stolarki okiennej.* W ostatnich latach stolarka drewniana znów zyskuje na znaczeniu (wyraźny wzrost produkcji), co generuje zapotrzebowanie na surowiec uzupełniany importem drewna egzotycznego, często nowych, nie w pełni poznanych gatunków. W niniejszej pracy określono przydatność półfabrykatów z wybranych gatunków i rodzajów drewna tropikalnego do produkcji stolarki okiennej na podstawie oznaczonej gęstości i wytrzymałości na ścinanie w stanie powietrzno-suchym i w stanie mokrym. Biorąc pod uwagę całość wyników należy stwierdzić, że czynnikiem decydującym o wytrzymałości na ścinanie jest gęstość i wilgotność drewna użytego do wykonania półfabrykatów klejonych. Im większa gęstość drewna (przy danej wilgotności) tym wyższa wytrzymałość na ścinanie. Obecność spoin nie wpływa negatywnie na notowaną wytrzymałość na ścinanie wzdłuż włókien (są to spoiny wodoodporne klasy D4).

Corresponding authors:

Agnieszka Kurowska Department of Technology, Organization and Management in Wood Industry Faculty of Wood Technology, Warsaw University of Life Sciences – SGGW, ul. Nowoursynowska 159, 02-776 Warsaw, Poland e-mail:agnieszka kurowska@sggw.pl

Paweł Kozakiewicz Department of Wood Sciences and Wood Protection, Faculty of Wood Technology, Warsaw University of Life Sciences – SGGW, ul. Nowoursynowska 159, 02-776 Warsaw, Poland e-mail: pawel kozakiewicz@sggw.pl