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BENDING STRENGTH PROPERTIES OF SCARF JOINTED EUROPEAN SPRUCE WOOD (*Picea excelsa*)

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ABSTRACT

The aim of this work was to study the strength properties of small dimension scarf joint European spruce *(Picea excelsa)* for the manufacture of laminated wood for restoration purposes. Particularly, it was examined the bending strength (modulus of rupture) of scarf jointed laboratory specimens that were connected across the grain. Ten different cutting angles (90^o, 135^o, 140^o, 150^o, 160^o, 170^o, 172^o, 174^o, 176^o και 180^o) and two glues (a polyvinyl acetate based D2 type and a polyurethane D4 type) were investigated. From the results, it can be concluded that European spruce can be utilized with end to end scarf joints for the production of laminated wood. End grain connections at 90^o up to 160^o inclined planes did not show adequate strength. The cutting angle of 170^o seems to be the most resistant scarf jointed with the use of the PVA glue. Correspondingly for the polyurethane glue, the best cutting angle was that of 174^o.

Keywords: scarf joint, European spruce, laminated wood, bending strength -modulus of rupture.

1. Introduction

The marketable timber quantities of softwoods in Greece we estimated to be at 77.349.481 m^3 (56,01 % of the total marketable Greek wood quantities). The quantities of European spruce are close to 856.395 m^3 (0,62 % of the total quantity) [1]. European spruce and other softwoods are mainly used in construction applications. The increased demand for softwoods in Greece is covered by imports [2].

Various types of laminated wood jointed end to end grain have been developed. The main types are butt, scarf and finger joint (Fig. 1) [3, 4]. Butt joints show low mechanical strngth [5, 6]. Generally when the jointed surface is perpendicular to the grain direction, the laminated timber ehibits low mechanical strength properties [7, 8].

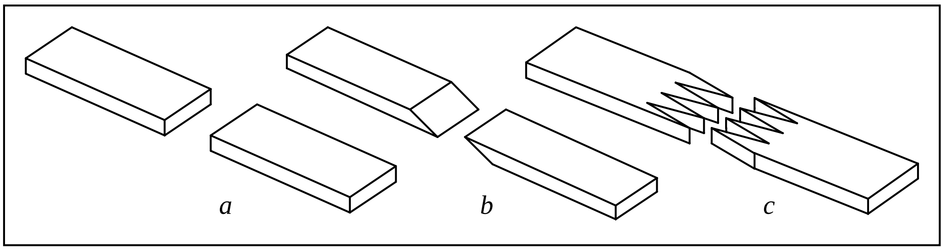

Fig. 1. Various types of end jointed wood: a: butt joint, b: scarf joint, and c: finger joint.

Laminated wood with glued edges with inclined planes has better mechanical properties, but there are some problems with its industrial production [9, 10]. The same happens also in the case of jointed particleboards [11]. Beyond of these problems, scarf joints in wood can be an easy way for a craftsman to connect two pieces of wood along grain in order to achieve a desired length. The construction of the inclined planes can be done easily with portable sawing machines. Scarf joints in wood are used widely for building restorations and shipbuilding [12].

Scarf joints in wood with slopes 1:10 or 1:12 showed to have up to 90 % strength correspondingly to the solid wood. The increase of the slope up to 1:20 increased the strength properties of laminated wood (95 % correspondingly to the solid wood) [13, 14].

Laminated spruce wood has been used for window production [15]. The results showed that spruce wood can be used with finger joint connections with excellent results. Also finger jointed connections of spruce wood have been investigated with acoustic methods [16].

The aim of this work was to study the strength properties (modulus of rupture) of European spruce for scarf jointed connections, using two commercial glues.

2. Experimental procedure

For the experimental work, air dried European spruce *(Picea excelsa)* having 13 % moisture content, a density of 0.40 gr/cm^3 and dimensions 30 x 30 x 400 mm was used. Defects were removed according to EN 385/2001. The material was conditioned at 20^{o}C temperature and 65 % relative humidity until the weight of wood was stabilized. Afterwards, the specimens were cut in the middle of their length with a table saw at various cutting angles, namely: 90^o, 135^o, 140^o, 150^o, 160^o, 170^o, 172^o, 174^o, 176^o and 180^o (Fig. 2).

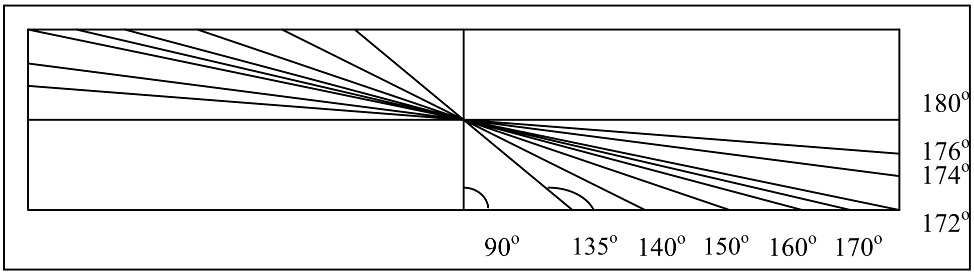

Fig. 2. Jointing cutting angles.

Two commercial glues were used: a polyvinyl acetate - PVA D2 type glue for interior use and an one-component polyurethane D4 type glue for exterior use). The above types were applied by brush in one side of the joints. The applied end pressure accomplished with a manually operated press and lasted 20 min for the polyurethane glued specimens and 60 min for PVA glues specimens. The scarf jointed specimens were conditioned in the normal conditions as above and were cut to final dimensions 20 mm x 20 mm x 360 mm. Bending strength (modulus of rupture – MOR) of the scarf-jointed specimens was measured according to ISO 10983/1999 and DIN 52186/1978. For each cutting angle, the influence of the cutting orientation (horizontal and vertical) with regard to the direction of the load and orientation of the growing rings, was examined (Fig. 3). In each case, 15 specimens were tested according to EN 385/2001.

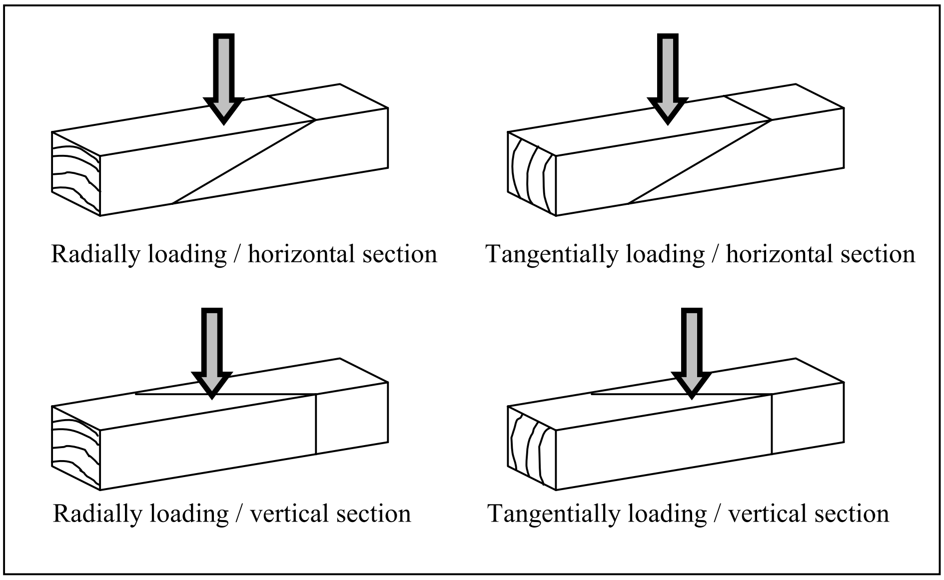

Fig. 3. Section orientation and loading direction in specimens.

3. Results and discussion

The results of modulus of rupture of all the materials tested are shown in Table 1.

Table 1. Bending strength - MOR of the longitudinally glued at various jointing cutting angles European spruce with scarf joints.

Jointing cutting angle (^{o})	Radially loading				Tangentially loading			
	Horizontal section		Vertical section		Horizontal section		Vertical section	
	PVA	Polyure-thane	PVA	Polyure-thane	PVA	Polyure-thane	PVA	Polyure-thane
90	13.25 (2.69)	12.19 (2.92)	13.25 (2.69)	12.19 (2.92)	15.70 (1.63)	10.44 (0.94)	15.70 (1.63)	10.44 (0.94)
135	15.78 (1.40)	16.82 (2.00)	19.29 (2.78)	16.06 (3.24)	21.14 (1.49)	16.97 (4.00)	20.48 (0.70)	15.07 (2.21)
140	16.59 (1.60)	17.74 (5.53)	16.79 (2.59)	17.48 (2.62)	14.93 (1.72)	13.75 (2.56)	17.01 (3.25)	15.53 (3.49)
150	23.80 (4.15)	19.12 (1.67)	23.94 (0.59)	20.17 (5.25)	27.66 (1.55)	21.26 (2.27)	22.94 (1.97)	22.72 (3.02)
160	45.44 (5.28)	32.36 (3.76)	46.25 (5.89)	29.54 (4.23)	38.52 (3.77)	23.95 (5.69)	32.10 (1.08)	26.85 (5.05)
170	58.03 (1.26)	56.30 (4.22)	65.61 (4.08)	56.02 (4.53)	67.84 (3.11)	65.49 (4.77)	63.16 (4.87)	53.61 (4.26)
172	52.10 (2.76)	52.18 (3.30)	54.42 (4.51)	43.86 (3.14)	48.18 (3.55)	51.15 (3.97)	50.70 (2.34)	52.27 (3.74)
174	56.51 (4.68)	60.28 (5.87)	58.90 (3.10)	60.82 (2.10)	56.54 (2.75)	49.55 (4.07)	52.96 (5.60)	54.61 (5.78)
176	57.90 (3.20)	58.06 (3.92)	59.60 (2.30)	55.22 (3.05)	55.90 (5.98)	52.52 (1.86)	46.13 (2.84)	50.01 (4.55)
180	47.41 (1.90)	46.98 (1.15)	60.25 (4.82)	60.76 (4.90)	57.70 (3.69)	56.66 (1.21)	50.82 (4.49)	47.68 (4.12)
Control	59.03 (4.39)				56.58 (4.84)			

* *Mean values of 15 samples and standard deviation in parenthesis.*

As it can be seen in Table 1, bending strength – MOR of the tested specimens fluctuated from 12.19 up to 67.84 N/mm^2. These values correspond to 20.65 and 119.90 % of the mean values of the solid wood (57.80 N/mm^2).

The increase of the cutting angle from 90^o (butt joint) up to 160^o generally increases MOR values, but these remain very low correspondingly to the solid wood. The higher values of the glued specimens in this range (46.25 N/mm^2) corresponds to 78.35 % of the solid wood. The above results indicate that jointed european spruce along grain with inclined planes from 90 up to 160^o, are not suitable for constructive purposes.

The increase of the cutting angle from 160 to 170^o increases significantly bending strength – MOR values (from 27.71 up to 173.44 %). Bending strength – MOR of the specimens with cutting angle 170^o fluctuated from 56.02 N/mm^2 (for the specimens glued with polyurethane glue in radial loading and vertical section) up to 67.84 N/mm^2 (for the specimens glued with PVA glue in tangential loading and horizontal section). This angle seems to be ideal for the most resistant in modulus of rupture connections glued with PVA glue.

Further increase of the cutting angle up to 180^o, generally decreases modulus of rupture values of the specimens, but these values still remain high. Specifically, specimens glued with PVA glue show lower modulus of rupture values than the specimens of with 170^o inclined planes. In the case of the specimens glued with polyurethane glue the same effect exists for the specimens in tangential loading and horizontal section. In all the other cases the higher modulus of rupture values exist in the specimens with 174^o inclined planes.

Modulus of rupture values affected more or less by the section orientation of the specimens (horizontal, vertical). The influence is higher in the case of the glued with PVA glue specimens in radial orientation, where specimens with vertical orientation are more resistant than the specimens with horizontal.

Modulus of rupture values affected more or less by the type of loading (tangential, radial). Generally the specimens that are charged radially seem to be more resistant in modulus of rupture than the specimens that were charged tangentially. The above effect is more intense in the case of the specimens in vertical section, where specimens with radial loading are more restistant than specimens with tangential.

4. Conclusions

Based on this study, the following conclusions could be drawn for european spruce:

- Bending strength – MOR of the tested specimens fluctuated from 12.19 up to 67.84 N/mm^2 (20.65 and 119.90 %, correspondingly to the solid wood).
- Specimens with cutting angles between 90^o and 160^o exhibit low values in modulus of rupture and are prohibitive for constructive purposes. Increases resistance exists when the inclined planes of the specimens is at least 170^o.
- Commercial PVA and polyurethane glues could be used for making scarf joints. The best cutting angle for the inclined planes is 170^o when is used PVA glue and 174^o when is used polyurethane.
- Modulus of rupture of the glued specimens affected more or less by the section orientation and the type of loading. Generally, specimens in radial loading and vertical section, seem to be more resistant than the specimens in tangential loading and horizontal section.

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