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Glulam beam made from hydrothermally treated poplar wood with reduced moisture induced stresses

Ghaneh Mirzaei [a], Behbood Mohebby [a,*], Ghanbar Ebrahimi [b]

[a] Department of Wood and Paper Sciences, Tarbiat Modares University, P.O. Box 46414-356, Noor, Iran
[b] Department of Wood and Paper Sciences, Tehran University, Karaj, Iran

HIGHLIGHTS

- Hydrothermally modified wood could be used for engineered wood products; such as glulam beams.
- Application of modified wood could reduce moisture induced stress and moisture gradients in glulam beams.
- Moisture induced stresses are correlated with wood moisture contents in glulam beams.

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ABSTRACT

Moisture induced stresses were studied in glulam beams, which were made from hydrothermally treated poplar (*Populus deltoides*) wood in the current research work to understand whether the hydrothermal wood modification can reduce those stresses or not. Wood blocks with dimensions of 6 (R) × 10 (T) × 73 (L) cm^3 were cut and hydrothermally treated in a stainless steel reactor at temperatures of 140 and 160 °C for a holding time of 30 min. The treated wood blocks were dried to achieve moisture content of 12%. Afterwards, the glulam beams (4-ply) were manufactured by using polyurethane (PUR) adhesive. In order to evaluate cross sectional moisture induced stresses (MISes) and bending properties of glulam beams; wood density, equilibrium moisture content (EMC) of wood, 4-point bending of the glulam beams (according to ASTM D 198-02), 3-point bending of the treated and untreated wood (according to ASTM D 143-09) and the moisture induced stresses in cross section of the glulam beams were determined. The results showed that the hydrothermal treatment reduced the cross sectional moisture induced stresses as well as relevant moisture gradients and also it caused increase of the bending strength as well as stiffness of the treated wood and the glulam beams.

1. Introduction

Glued laminated timbers (glulam beams) are engineering materials that are generally designed for applications where they will be highly stressed under designed loads [1,2]. The moisture gradients are occurred in the wood element due to variation of the relative humidity (RH) in outdoor applications. Physical and mechanical properties of the manufactured products from the glulam beams are affected by the moisture gradients which are responsible for the internal stresses perpendicular to grain in the wood [2,3]. Moisture induced stresses (MISs) due to the moisture gradients are sometimes so significant, which can exceed the tensile strength of timbers perpendicular to grain [3]. Developing risk of the cracks in wood elements is a result of overcoming this strength, which is usually responsible for safety risks as well as serviceability problem of the timber members in the wood products [3,4]. In the timber members, the annual growth ring patterns are also affect the modulus of elasticity (MOE) of the beams. The high the MOE is obtained in the middle part of the beams where the radial direction is dominating the wood cross section. This will affect the stress distribution [5]. The tension capacity of the wood is also affected by the moisture-induced stresses to a great extent at perpendicular to the grain direction. Therefore, this phenomenon should also be taken into account during designing the structural elements in which this strength (tension perpendicular to grain) is of a great importance; e.g. for the curved and the notched glulam beams, the joints, and also vicinity of the holes [3].

Application of the treated/modified wood in manufacturing of the glulam beams might reduce the moisture gradients in the beams. There are some reports which are indicating the effects of the wood preservation/modification on the glulam beam properties.

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* Corresponding author.
E-mail address: mohebbyb@modares.ac.ir (B. Mohebby).

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Mechanical properties were studied in glulam beams made from ACQ preservative-treated hardwood lumbers. The results revealed that the static- and dynamic-MOE of the beams were decreased by retention increase of the ACQ preservative. However, no delaminating was determined when the beams were soaked and boiled in water [6]. There is another research report which is about structural glued laminated timber (glulam) beams and finger-jointed boards made from the thermally modified wood [7]. Bending strength as well as stiffness of the glulam beams made out of the thermally modified beech wood were also studied and the results revealed that the thermal treatment of wood increases stiffness of the glulam beams, however, there was a reduction in the bending strength of the beam [8]. Mechanical wood modification is another process that can provide increase of wood density by densification technique. Densified wood was also used to manufacture glulam beams according to the literatures [9]. Results of such research works revealed that stiffness and load bearing capacity of the manufactured glulam beams are improved due to increase of wood density during densification process. Hydrothermal treatment is also a type of wood modification process that reduces moisture absorption of wood [10]. Therefore, it could be expected that manufacturing of the glulam beams from hydrothermally treated wood might reduce moisture induced stresses in cross section of the glulam beams and increase their bending strength. Since, the moisture induced stresses as well as bending properties of the glulam beams are important properties for structural designing that should be calculated in detailed designing of the timber construction [11]. Therefore, the main objective of the current research work is to investigate the moisture induced stresses (especially) and bending properties of the glulam beams made out of the hydrothermally treated poplar wood (*Populus deltoides*) to understand capability of hydrothermal wood modification in reducing the stresses due to the moisture absorption.

2. Material and methods

2.1. Materials

2.1.1. Wood

The wood logs were cut from two 23-year old poplar trees (*Populus deltoids* Bartr. Ex Marsh) grown at KoluDeh Forest Research Institute (Northern Iran, 36°33′14″N52°18′19″E). Flatsawn wood blocks were prepared in dimensions of 6 (R) × 10 (T) × 73 (L) cm^3 after debarking the logs.

2.1.2. Hydrothermal treatment

The blocks were placed in a stainless steel cylinder (half filled with water) and then they were treated hydrothermally at temperatures of 140 and 160 °C for a holding time of 30 min in stainless steel cylinder. Afterwards, the treated wood blocks were initially air seasoned and then dried in a semi-pilot scale vacuum dryer at 50 °C to achieve moisture content of 12% prior to preparation of the sample glulam beams.

2.1.3. Adhesive

The polyurethane adhesive was used in current research work to mount the laminations with the following specifications as shown in Table 1.

2.2. Manufacture of glulam beams

The treated and untreated wood blocks were conditioned (RH: 52 ± 2%, T: 20 ± 3 °C) to achieve uniform moisture contents in the blocks. Pre-laminations with dimensions of 2.3 (R) × 7.4 (T) × 71 (L) cm^3 were initially trimmed by a finger joint machine at both ends and then they were matched and mounted by using the PUR adhesive under a pressure of 0.6 MPa for 24 h and then, the laminations were conditioned according to ASTM D 4933-99 [12] with sodium dichromate (saturated salt) at 20 °C in glass chambers. The laminations were then planned and finished to prepare fresh surfaces prior to bonding. Afterwards, the polyurethane adhesive was applied on surfaces of the laminations as 200 g/m^2 (for mixture of adhesive as well as the hardener). The laminations were laid up to assemble sample glulam beams and then pressed for 24 h in a cold press under a pressure of 1 MPa. Finally, 68 glulam beams (4-ply) were manufactured with dimensions of 7.6 (H) × 7 (B) × 130 (L) cm^3. The beams were conditioned in controlled glass chambers containing sodium dichromate (t: 60 days, RH: 52 ± 2%, T: 20 ± 3 °C).

2.3. Experiments

2.3.1. Density and EMC

Density and equilibrium moisture content (EMC) for both treated and untreated wood blocks were determined according to ASTM D 2395-93 [13] and ASTM D 4442-92 [14], respectively. Nine specimens (replications) were used to evaluate each parameters (density and equilibrium moisture content) for each type of the treatment level.

2.3.2. Bending test

The 4-point bending test was performed according to ASTM D 198-02 [15] using a computer-controlled Instron testing machine. Displacement increments were applied by a rate of 3.2 mm/min. Modulus of elasticity (MOE) and rupture (MOR) of the beams were calculated according to equations 1 & 2. It should also be noticed that the 3-point bending test was performed for clear cut untreated ant treated wood specimens according to ASTM D 143-09 [16] and the MOE and the MOR were also calculated according to Eqs. (3) & (4). Five specimens (replications) were used to evaluate the bending testes for each type of the treatment level.

$$MOE = \frac{P\prime a}{4bh^3c}(3L^2 - 4a^2) \tag{1}$$

$$MOR = \frac{3Pa}{bh^2} \tag{2}$$

$$MOE = \frac{p_{pl}L^3}{4bh^3d_{pl}} \tag{3}$$

$$MOR = \frac{3PL}{bh^2} \tag{4}$$

Where MOE is static bending modulus of the elasticity (MPa), MOR is modulus of rupture (MPa), P' is load at proportional limit (N), P is maximum transverse load on beam (N), a is distance from reaction beam to nearest load point (mm), L is span of the beam (mm), b and

Table 1
Specification of PUR adhesive.

Adhesive type	Color	Hardener	Density (g/cm^3)	Pot life (min at 20 °C)	Solid content (%)	Application temperature (°C)	Thermal resistance
Polyurethane	Cream	MDI	1.3	25	100	5–40	Good