Construction and Building Materials 68 (2014) 120–126

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Some physical and mechanical properties of reinforced laminated veneer lumber

Bekir Cihad Bal *

Department of Forest Industry Engineering, Faculty of Forestry, Kahramanmaraş Sütçü İmam University, 46100 Kahramanmaraş, Turkey

HIGHLIGHTS

- Impact bending strength and specific impact bending strength values of reinforced LVL were greater than those of LVL.
- Impact bending strength and the percentage increase were greater in the flatwise direction than in the edgewise direction.
- The shear strength of reinforced LVL was significantly greater than that of LVL.
- Some physical properties of reinforced LVL were more favorable than those of LVL.

ARTICLE INFO

Article history:
Received 17 February 2014
Received in revised form 21 June 2014
Accepted 25 June 2014

Keywords:
Glass fiber
Impact bending
Shear strength
Laminated veneer lumber
Physical properties

ABSTRACT

In this study, poplar laminated veneer lumber (LVL) was produced using phenol formaldehyde adhesive, and reinforced LVL (RLVL) was produced by inserting woven glass fibers between the veneer sheets. Some tests were conducted to analyze the effects of the reinforcement on the properties of the LVL. Some physical properties, such as density, moisture content, and swelling were determined, as were the mechanical properties of impact bending, specific impact bending, and shear strength. The test results indicated that density, impact bending, and shear strength increased. Conversely, tangential swelling, volumetric swelling, moisture content, and specific impact bending decreased. Increased dimensional stability of wood-based materials is a preferred property for many applications due to the increased service life. In addition, the increases in impact bending and shear strength, especially in the connection points and load-bearing points in structural applications, were the most important results of the study.

1. Introduction

The demand for wood-based materials has increased in many countries in recent years. In some applications, wood-based materials are preferred over other engineering materials, such as concrete, plastics, iron, and steel [1]. Some of the reasons that wood-based materials are preferred are that wood is a renewable material, its density levels range from low to high, and it can be used in many different surface shapes. Also, it can be processed easily, it has good shock resistance, and it has a high strength-to-weight ratio [2]. Despite these excellent properties, its mechanical properties are low, and this is especially true for low-density woods.

Solid wood has some undesirable characteristics, such as cracks, knots, growth stress, and limited length. Laminated veneer lumber (LVL) is preferred for many applications, such as beams, headers, joists, rafters, scaffold planks, and truss chords, due to its superior properties that eliminate some of the shortcomings of wood mentioned above [3]. LVL is manufactured using low-density tree species, such as Douglas fir, southern pine, spruce, and poplar. LVL produced from these tree species has low mechanical properties. Reinforcement of laminated wood composites allows the structural use of woods that have mechanically inferior properties. So, researchers have focused on the development of techniques that can be used to reinforce these types of materials. The historical development of reinforced wood and wood-based composites was reviewed by Laufenberg et al. [4] and Bulleit [5]. According to their reviews, such reinforcement was done initially by Wangaard [6] and Biblis [7], who used epoxy resin and fiberglass in their studies. In addition, Laufenberg [4] studied the economic feasibility of producing LVL that was reinforced by synthetic fibers. In addition, in 2000, Cooke [8] patented his invention related to reinforced laminated veneer lumber, and his design included an engineered fabric that was placed between veneer sheets to provide added reinforcement, allowing the use of lower-grade veneer sheets for structural applications.

* Tel.: +90 344 280 18 11; fax: +90 344 280 17 12.
E-mail address: bcbal@hotmail.com

http://dx.doi.org/10.1016/j.conbuildmat.2014.06.042
0950-0618/

There were several studies that followed, including Rowlands et al. [9] who studied reinforcing wood composites with glass, Kevlar(R), and graphite using 10 different adhesives. Their findings indicated that epoxy adhesives were superb for glass, Kevlar(R), graphite, and glass fiber, and the laminated products were technically and economically superior to wood. Yanagawa et al. [10] studied LVL produced using sugi wood reinforced with glass-fiber net, and the results showed that the mechanical properties increased as the number of layers of nets increased. Hallström and Grenestedt [11] conducted experiments with laminated timber beams reinforced with glass-fiber composites and noted that the reinforcement prevented cracks in the wood. Li et al. [12] showed that wood beams reinforced with carbon fibers had enhanced flexural performance. Ribeiro et al. [13] studied glued-laminated wood beams of maritime pine wood with glass fibers and pultruded lamellas, but the results indicated that there was very little increase in the modulus of rupture (MOR) values of beams reinforced with fiberglass. Basterra et al. [14] conducted experiments with duo beams reinforced with flax fibers, glass fibers, and carbon fibers using epoxy resin, and they reported that there were no significant increases in the mechanical properties of the beams reinforced with flax fiber and glass fiber. Borri et al. [15] conducted experiments to assess the flexural properties of timber beams that were reinforced with natural materials, such as hemp, flax, basalt, and bamboo fibers, and the results showed significant increases in the load-carrying capacity and deflection ductility of beams that had been considered to have poor mechanical properties. In addition, Alam et al. [16] reported the results of laboratory experiments to assess repair strategies using some reinforcing materials for timber beams that had been fractured in bending to simulate structural damage. Smedley et al. [17] studied the repair of historic timber structures using bonded-in pultruded carbon fiber plates as a practical application.

In addition, Bal [18] tested reinforced poplar LVL with woven glass fibers using phenol formaldehyde and reported some increase in the mechanical properties, but there were some decreases in specific mechanical properties. However, in these previous studies, some important physical properties were not assessed, i.e., impact bending, shear strength, and wood–water relationships. Thus, the following aspects of LVL and RLVL were included in this study:

- Impact bending strength (IBS) and specific impact bending strength (SIBS) of LVL and RLVL were determined in the flatwise and edgewise directions.
- The shear strengths (SS) of LVL and RLVL were determined in the direction that was parallel to grain and perpendicular to the glue line.
- Some physical properties of LVL and RLVL were determined, e.g., tangential swelling (TS), radial swelling (RS), volumetric swelling (VS), density (D), and water absorption (WA).

2. Materials and methods

2.1. Veneer preparation

Rotary-peeled veneers were obtained from poplar logs and dried in a plywood factory until the moisture content was 7 ± 1%. The veneers were classified visually based on observable defects, such as cracks and knots. Only grade 1 veneers were visually selected according to TS 4893 [19]. Veneer sheets were cut into sizes of 600 × 600 × 3 mm (length × width × thickness). Each veneer sheet was numbered and cut in half, so that the new dimensions were 600 × 300 × 3 mm, as shown in Fig. 1. Thus, two groups of identical veneer sheets were available for testing. These veneer sheets were used to produce LVL boards using phenol formaldehyde adhesives. One group was used to produce LVL, and the other group was used to produce RLVL (Fig. 1B and C). This was done to provide homogeneity of the groups between the LVL and the RLVL.

2.2. Woven glass fiber

For this study, woven glass fiber was obtained from Fibroteks Dokuma San. ve Tic. A.Ş. Kocaeli-Turkey. The weight of the woven glass fiber was 800 g/m^2, and it was woven using the 'plain-weave' type of weaving. Such glass fiber is made from single-end rovings, the weft and warp of its strand count are 2400, and the coupling agent is silane.

2.3. Adhesive

Commercial phenol formaldehyde adhesive (PF) was obtained from the Gentaş Kimya Company in Turkey. The PF adhesive was used in pure form; no additives or fillers were used. The adhesive was applied to the surface of the veneer with a roller glue applicator. The properties of the PF adhesive at 20 °C are listed below:

- Specific gravity = 1.12 g/cm^3.
- Solid content = 47 ± 1%.
- pH = 8.4–8.8.
- Viscosity = 350–450 Cp.

2.4. Manufacturing LVL

The LVL was manufactured in a laboratory. The amount of adhesive used for the veneer was approximately 200 g/m^2. The adhesive were spread manually on the loose side of the veneers. Approximately 400 g of adhesive per square meter of glass fiber surface were applied with a gluing machine because of the roughness of the surface of the E-glass woven glass fiber (WGF). After gluing, six veneer sheets (nominal sizes of 600 × 300 × 3 mm) were laid with the directions of the fiber parallel to each other after the gluing process. The WGF sheets were placed between the wood veneer sheets in each glue line. Five WGF sheets were placed for each RLVL board.

Then, without any initial pressing, the panels were pressed in the laboratory using a hot press. The pressure applied by the press for the LVL and RLVL boards was 8 kg/cm^2. The duration of the press and the temperature were 20 min and 140 °C, respectively. Five LVL boards and five RLVL boards were produced for each of the two groups. After pressing, the billets were stored for a week for exact curing. After curing, 30-mm edges were cut off of the panels. Then, test samples were prepared from the LVL and RLVL billets, as shown in Fig. 1D.

2.5. Tests

2.5.1. Mechanical properties

Experiments were conducted to determine the SS and IBS according to TS 3459 [20] and TS 2477 [21] based on the Turkish standards, and Fig. 2A and B show the schema of the SS and IBS test samples. Fig. 2A shows the dimensions of the SS test samples. The loading rate was 10 mm/min during the SS tests. Thirty samples were prepared for the SS tests. The IBS tests of the LVL and RLVL samples were performed in flatwise and edgewise directions. The dimensions of the IBS test samples were a × 20 × 300 mm (height × width × length), and the span was 240 mm. Forty-four IBS samples were prepared for both the LVL tests and the RLVL tests. Of the 44 samples, 22 were tested in the flatwise position, and 22 were tested in the edgewise position. Prior to the tests, the samples were conditioned in a cabinet at 20 ± 3 °C and 65 ± 5% relative humidity until they reached a constant weight. At the end of the conditioning period, thickness (a) of LVL was 17 mm, and thickness (a) of RLVL was 19 mm.

The tests were performed on a pendulum impact bending machine. In addition, specific impact bending (SIB) was calculated to account for the effect of density. Twenty-two flatwise and 22 edgewise test samples were prepared for each of the two groups. Before the tests, the dimensions and weights of the samples were determined to a precision of 0.01 mm, and 0.01 g, respectively. The dimensions and weights of the samples were used for calculating the densities of the test samples. IBS and SIBS were calculated using Eqs. (1) and (2), respectively.

$$\mathrm{IBS} = Q/(a \times b) \tag{1}$$

where IBS is impact bending strength (kg m/cm^2), Q is absorbing energy (kg m), a is the width of sample (cm), and b is the thickness of the sample (cm).

$$\mathrm{SIBS} = \mathrm{IBS}/D_{12}, \tag{2}$$

where SIBS is the specific impact bending strength (m^2), and D_{12} is the air-dried density (g/cm^3) at a moisture content of 12%.

2.5.2. Physical properties

Air-dried density (D) was determined based on TS 2472 [22], and the percentage of linear swelling (radial and tangential) and volumetric swelling were determined according to TS 4084 [23] and TS 4086 [24], respectively. The dimensions of the samples used to measure density and to conduct the swelling tests were a × 20 × 30 mm (thickness, width, length), as shown in Fig. 2C. Twenty-two samples were prepared for the LVL tests, and 22 samples were prepared for the RLVL tests. The samples were dried in an oven at 103 ± 2 °C until their weights were constant. The dimensions and weights of the samples were measured to calculate linear