Construction and Building Materials 158 (2018) 236–242

Contents lists available at ScienceDirect

Construction and Building Materials

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

Laminated strand lumber (LSL) reinforced by GFRP; mechanical and physical properties

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HIGHLIGHTS

- The effect of GFRP and resin types on technical properties of LSL studied.
- Results confirmed that resin type and glass fiber have significant effects on the properties.
- The most beneficial effect of GFRP was on MOR, MOE, impact, shear and compression strengths respectively.
- Based on the results, bending strength, modulus of elasticity were improved by 123 and114%, respectively.
- GFRP layers led to alteration of fracture place from tension side to compression side.

ARTICLE INFO

Article history:
Received 14 March 2017
Received in revised form 25 September 2017
Accepted 26 September 2017

Keywords:
LSL
GFRP
UF
PMDI
Technical properties

ABSTRACT

The effect of glass fiber reinforced polymer (GFRP) on the technical properties of LSL made from poplar (*Populus deltoids* L.) employing pMDI and UF as binders was investigated. Technical properties such as modulus of rupture (MOR), Modulus of elasticity (MOE), shear strength (SS), compression strength parallel to the grains (CS //), impact strength (IS), water absorption (WA) and thickness swelling (TS) were determined. Results confirmed that resin type and GFRP have significant effects on the LSL properties. It was revealed that the most beneficial effect of GFRP is on MOR, MOE, IS, SS and CS respectively. The Highest properties were obtained by using pMDI as the resin and GFRP as the reinforcement, where properties such as MOR, MOE, IS, SS and CS were improved by 123, 114, 100, 94, and 90%, respectively, compared to control samples. Furthermore, GFRP incorporation led to alteration of fracture place from tension side to compression side. Depending on the treatment type, the WA and TS values of the LVLs improved between 23% to 68% and 19.5% to 78%, respectively.

1. Introduction

During the past decades, environmental awareness, land usage issues and diminishing timber resources have dramatically changed the timber supply outlook for the forest products industry. Furthermore, available lumbers are not as useful as they used to be because of small diameter or limited dimensions as well as low quality. On the other hands, owing to new applications and demands expected from forestry industry it seems no more they could fully satisfy the human being needs. In addition, solid wood usually has many drawbacks including anisotropy, low bending strength, weak biological durability, dimensional stability and fire resistance. The demand for engineered wood products (EWPs) such as glued laminated timber (glulam), laminated veneer lumber (LVL), parallel strand lumber (PSL), laminated strand lumber (LSL), oriented strand lumber (OSL), cross laminated timber (CLT) etc. has recently increased throughout the world. In EWPs, usually low-quality trees, small and thin logs and mill residues can be processed into value-added materials, and thereby the dependence on old growth forests and high quality logs could be decreased [1,2].

LSL is one of the high yield new EWPs used as structural composite lumber and its manufacturing process involves log conditioning, stranding, drying, blending, forming, pressing, and final processing. It is used almost in all fields of structural materials, especially in lintel, beam, ceiling, floor and rafter [3]. Development in EWPs typically prospers characteristics such as strength and stiffness, uniformity, consistency and manufacture of large dimension lumbers with structural applications.

Forests, the major sources of wood supply are declining at the alarming rate of 13.0 million ha each year in developing countries [4]. Consequently, plantation of fast growing woody species like

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https://doi.org/10.1016/j.conbuildmat.2017.09.172
0950-0618/

poplar, paulownia especially in wood short countries like Iran are gaining vast attention. As a raw material, Aspen or yellow-poplar is of very promising fast growing species for the manufacture of structural composite products owing to its low density (high compaction ratio), relatively easy cultivation and abundance all around the world [5–7].

GFRPs are a category of plastic composites that specifically uses glass fiber materials to mechanically improve the strength and stiffness of plastics. Applications of GFRP elements have grown steadily during the last decades, as they (commonly known as fiberglass structures) became extremely popular in different areas of the aerospace, automotive, marine, civil construction industries including ladders, platforms, handrail systems tank, pipe and pump supports and or as a reinforcers in EWPs [8]. Over the past few decades, many studies have been performed on studying the response of GFRP on structural materials such as concrete and wood based composites. Meekum [9] investigated the effect of glass fibers on tensile strength of LVL and found that core layer has no significant effect on the bending properties of LVL. In general, positioning the glass fibers closer to the surface layer improves panel's mechanical properties [10] as they tolerate the most tension and compression stresses as a result of locating at the outmost distance from neutral axis. Bal [11], investigated reinforcement of LVL with GFRP employing PF resin and reported some increases in mechanical and physical properties, especially in splitting strength upon incorporation of GFRP. Urea formaldehyde (UF) is the most common water based wood adhesive mainly due to its low price, high availability and colorless nature. On the other hands, Polymeric 4, 4′-diphenylmethane diisocyanate (pMDI) is a water resistance capable of bonding many materials including plastics, wood, metal etc. together and reacting directly. It has been reported that pMDI adhesives are capable of forming covalent urethane bonds with wood to enhance bond line durability [12]. Comparing the mechanical and physical properties of poplar LSLs glued with different glues can be useful in adaptation of optimum binder for intended uses.

Table 1
The characteristics of the resins.

Resin type	Solid content (%)	Density (gr/cm^3)	Viscosity (CP)	Gel time (s)	PH
UF	59	1.25	200	55	7.5
PMDI	99	1.273	300	–	–

Table 2
Specifications of the GFRP.

Modulus of elasticity (GPa)	Failure stress (GPa)	Ultimate strain (mm/mm)	Poisson's ratio	Density (Mg/m^3)
76	2	2.60	0.26	2.26

Literatures lacks comprehensive data on LSL fabrication using fast growing poplar reinforced with GFRP. Quality assurance of LSL must be ensured for proper satisfaction of the product usage as an engineering structural composite lumber in light of mechanical and physical properties. The objectives of this study were firstly to comprehensively investigate the suitability of low quality fast growing poplar species for producing LSL employing UF and pMDI adhesives and secondly, to determine the effects of GFRP on LSL panels mechanical and physical properties.

2. Materials and methods

2.1. Materials

Poplar (Populus deltoids L.) logs were provided from Kheirud educational and research forest, Mazandaran, Iran. UF resin was prepared of Tiran Chem Company, Iran. PMDI and chloride ammonium (as hardener; 1.5%) were supplied by Sigma-Aldrich, Germany. UF and pMDI resin at the level of 12% and 8% (based on oven dry weight) were used as adhesives in the panel production. Table 1 includes the properties of the resins. GFRP purchased from Diba Fiberglass Company, Iran with the specifications provided in Table 2.

2.2. LSL manufacturing process

The LSL panels were prepared in the laboratory, following the standard procedures complying with the industrial circumstance. In order to produce needed strands, with courtesy of Qazvin Iranchoob Company, strands were prepared from rotary-cut of poplar debarked wood veneers with nominal dimensions of 250 × 20 × 1 mm (L × W × T). The strands were dried at 103 °C temperature until 3% moisture content. In the next step, the dried veneers were cut into strands with 20 mm width by pneumatic veneer clipper, and into 250 mm length by band saw. The dried strands were blended with the resins in a rotating drum-type mixer with speed of 30 RPM fitted with a pneumatic spray gun. After gluing, strands mat formation (Fig. 1) were done in a mold (600 × 500 mm) and strands oriented along the length on a sheet which was covered with foil. The strands mat was placed in press for 15 min at temperature of 170 °C and under the pressure of 200 psi. The target specific gravity of the LSL panels was 0.8 gr/cm3. PSL boards after conditioning at 20 °C and 65% relative humidity to reach moisture content of about 12%, cut to final dimension of 550 × 450 × 30 mm.

To investigate the effect of resin types and GFRP layer on board properties, panels with different functional factors were determined. In this step, two glued GFRP layers manually were applied near the surfaces during the manufacturing of the LSL. The scheme of the GFRP location in the panels is shown in Fig. 1. The experimental design is shown in Table 3. For each treatments 5 boards,

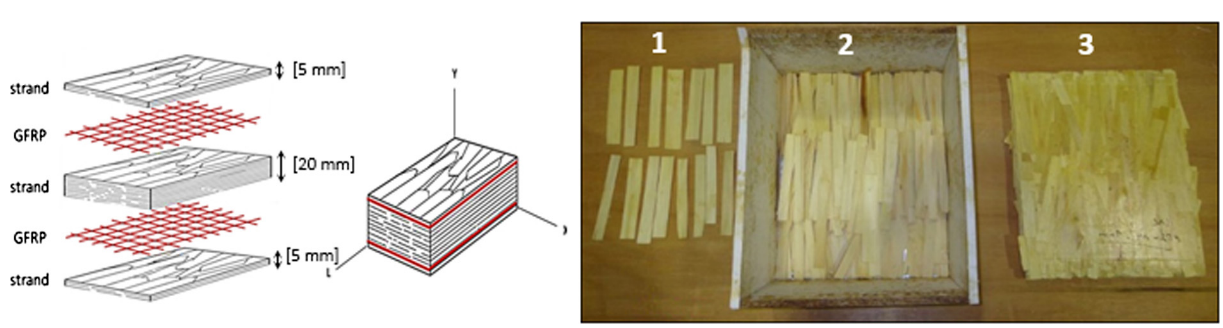

Fig. 1. Schematic and laboratory procedure of LSL production.