Construction and Building Materials 142 (2017) 499–505

Contents lists available at ScienceDirect

Construction and Building Materials

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

Withdrawal resistance of screws in structural composite lumber made of poplar (*Populus deltoides*)

Sadegh Maleki [a], Saeed Kazemi Najafi [a,*], Ghanbar Ebrahimi [b], Mohammad Ghofrani [c]

[a] Department of Wood and Paper Sciences, Faculty of Natural Resources, Tarbiat Modares University, Nour, Iran
[b] Department of Wood and Paper Sciences, Faculty of Natural Resources, University of Tehran, Karaj, Iran
[c] Department of Wood Industry, Department of Civil Engineering, University of Martyr Rajai, Tehran, Iran

HIGHLIGHTS

- Withdrawal resistance of screw in SCL was affected by screw type and characteristics.
- Different failure modes were observed in SCLs.
- The failure of screws timber joints is mainly due to shear stress.
- The larger diameter of screw, the higher withdrawal resistance.

ARTICLE INFO

Article history:
Received 17 November 2016
Received in revised form 10 February 2017
Accepted 7 March 2017
Available online 21 March 2017

Keywords:
Oriented strand lumber
Laminated veneer lumber
Poplar wood
Withdrawal resistance
Sheet metal screw
Drywall screw

ABSTRACT

Withdrawal resistance of screws on face, edge and end directions of oriented strand lumber (OSL), laminated veneer lumber (LVL) and plywood made out of poplar (*Populus deltoides*) were experimentally evaluated. Two types of screws, namely, drywall screw and sheet metal screw in two different diameters (4 and 5 mm) were evaluated. The results obtained were compared with those of solid poplar wood and the failure modes of specimens were visually examined. Test results showed that: (1) OSL joints were stronger than same joints constructed of LVL, plywood and poplar wood; (2) screw diameter positively influenced on withdrawal resistance, and its effects on withdrawal load were more influenced by root diameter of the screws and grain direction; (3) due to increased root diameter, sheet metal screw had significantly higher withdrawal resistance than drywall screw; (4) perpendicular to the grain direction (face and edge) were higher compared to the results for the parallel to the grain direction (end). However, there was no significant difference between OSL and poplar wood for maximum withdrawal resistance when the screw is either inserted in the edge or end-grain surface withdrawal directions; (5) the experimental results of failure modes included the plug shear failure around the screw of end direction, a rolling shear failure or tension axial stresses perpendicular to the grain of edge direction and splitting failure of the superficial fiber layer of the block of face direction.

1. Introduction

The timber industry has developed methods to produce structural composite lumber (SCL) using a variety of tree species that are relatively small and fast growing such as eucalyptus and poplar. SCL such as laminated veneer lumber (LVL), parallel strand lumber (PSL), laminated strand lumber (LSL) and oriented strand lumber (OSL) are manufactured from strands, veneers, and flakes then bonded by hot-pressing by using thermosetting resins. SCL technique has the potential to be used in structural applications such as construction, outdoor and indoor joinery, flooring and furniture industry and widely used as an alternative material for sawn timber [1–4].

It is believed that the connections play an important role in determining the overall performance of solid sawn lumber (SSL) and SCL; also failures occurring in timber structures are caused by connection related issues. For determining the ultimate-load and stability of SCL, connections are highly depended on transfer of lateral loads and on friction or mechanical interfaces for transfer of axial (withdrawal) loads, which are the typical and crucial factor [5]. Therefore, designers need to have thorough understanding

* Corresponding author.
E-mail address: skazemi@modares.ac.ir (S. Kazemi Najafi).

http://dx.doi.org/10.1016/j.conbuildmat.2017.03.039
0950-0618/© 2017 Elsevier Ltd. All rights reserved.

how to select an appropriate combination of members (type of material, size and geometry) and fasteners (nails, screws, dowels, and bolts). Screw is the most widely used fastening elements that are found of wood based structures made of oriented strand board (OSB) and plywood to SSL or SCL products. Due to their availability in different length, diameter and their high stiffness, screws are an efficient tool in reinforcement of timber structures as well. Thus far, extensive research has been undertaken on the evaluation of withdrawal resistance of screw joints such as timber and wood based products and is still going on.

Test results from various sources [6–8] demonstrated that the withdrawal strength of screws either parallel or perpendicular to the grain direction can be controlled by screw size and depth of penetration. Screws should also satisfy other criteria such as pre-drilling and thread contact area per unit length. The influence of a wide range of these parameters has been the subject of many research conducted during the past, these research aiming the development of design formulas for connections with screw. Theoretical analysis of screw joints has been conducted by several researchers [9,10]. Eckelman [11], proposed a shear strength parallel to the grain of wood is more suitable compared to its specific gravity to predict withdrawal resistance of wood screw. On the other hand, many experiments were also conducted to investigate the effect of particle geometry [12–17] and thread geometry on screw withdrawal strength by means of regression models [18–22]. According to [23,24] as well as [25], good correlation were observed between screw withdrawal strength and the density of solid wood. So the withdrawal strength would increase with an increase in the wood density. Test results reported in [26,27] show that the when pushing the screw into the timber, the main stresses located within the timber are in compression and tension strength perpendicular to the grain and around the thread, mainly shear stresses occur in the timber. Therefore, compression and tension strength perpendicular to the grain and the shear strength are the main parameters influencing the withdrawal strength. Therefore, some authors have concluded that the load-carrying capacity of screw connections, increase with increasing density of the specimens and pre-drilling can have a positive effect on the precision of screw positioning (depending on density of the timber e.g.), see e.g. [28,29]. On the other hand, experimental studies, presented in [30] and [31], indicate that face withdrawal resistances of screw were greater than the edge direction. Therefore, load-carrying capacity of screws under face direction are very stiff. The authors also have concluded that withdrawal resistances of screws increase as screw diameter and penetration depth.

During recent years, studies on bolted connections made of SCL such as LVL, LSL and PSL have been presented [32]. The test results confirmed that LSL has different failure patterns from most SCL and sawn lumber. Researchers have stated that LSL have superior mechanical performance to competing products, including high resistance to splitting and avoiding brittle failures. The mechanical properties of LSL and OSL made from poplar and paulownia wood (As fast growing species) was investigated [33]. The results showed that poplar panel had excellent performance, and withdrawal resistance of screw with OSL members was greater than LSL members.

As can be seen the previous survey, premature failure of timber structures under axial loading either parallel or perpendicular to the grain has primarily been blamed on poor screw installation resulting in reduced screw withdrawal strengths. Additionally, connections are being developed which will have screws installed into the end grain of the SCL, parallel to the glue lines and are subject to withdrawal loading [7]. In recognition of this fact, the review on the existing approaches and experimental results have shown that, up-to-date, most research efforts have been devoted on the determination of the proprietary testing on OSL, but on the contrary, available research results for withdrawal strength with different screw diameter and type of screw on face, edge and especially end-grain withdrawal directions in OSL member remains unknown. Hence in present study, the authors tried to investigate the withdrawal resistance of screws in OSL made of poplar wood. Additionally, the same parameters were studied in similar joints made on LVL, plywood and poplar sawn lumber used as a comparison member material.

2. Materials and method

2.1. Materials

Poplar (*Populus deltoides*) wood logs with a diameter 38–45 cm and with average density of 0.43 g/cm^3 were used to prepare OSL, LVL and SSL specimens. The LVL specimens were manufactured using the layers (2 mm thickness) which were obtained from the poplar wood by slicing method. The 18 mm thickness OSL specimens with density of 0.72 g/cm^{3}were made from 1 × 15 × 150 mm strands (thickness × width × length, respectively) which were cut from poplar layers. The strands were initially dried to an average MC of 3% and then were coated with UF resin (10% by dry weight of strands). The glued strands were formed to a mat and hot-pressed at a temperature of 160 °C and peak pressure of 50 kg/cm^2 for 10 min. The solid wood samples were also prepared from the similar poplar logs. To manufacture the LVL samples with 18 mm thickness, 9 layers were bonded with UF resin. The resin was spread in one side of the layers at the rate of 180 g/m^2. The nominal mean density of the samples was set at 0.58 g/cm^3. Then the OSL panels were manufactured using a hot press at temperature of 160 °C and peak pressure of 50 kg/cm^2 for 10 min. The poplar SSLs were also prepared from the similar poplar logs. The 11 layers commercial poplar plywood was prepared from a local manufacturer. Two different screws were used: sheet metal screws and drywall screw with coarse thread with nominal diameter4 and 5 mm (Fig. 1). The major specifications of the screws are given in Table 1.

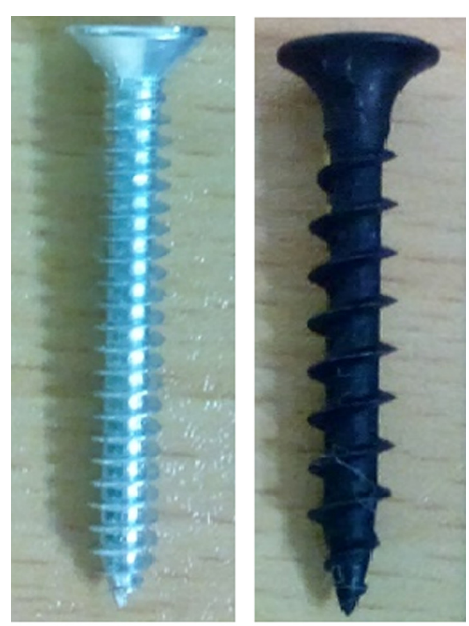

Fig. 1. Screws used in this study a) Sheet metal screw; b) Coarse thread drywall screw.