Construction and Building Materials 158 (2018) 149–163

Contents lists available at ScienceDirect

Construction and Building Materials

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

Experimental investigation of flexural behavior of glulam beams reinforced with different bonding surface materials

Murat Uzel [a], Abdullah Togay [b], Özgür Anil [c,*], Cevdet Söğütlü [d]

[a] Hacettepe Ankara Chm. of Industry 1st Organized Indst. Zone Voc. School, Ankara, Turkey
[b] Gazi University, Department of Industrial Design, Ankara, Turkey
[c] Gazi University, Civil Engineering Department, Ankara, Turkey
[d] Gazi University, Faculty of Technology, Department of Wood Products Industrial Engineering, Ankara, Turkey

HIGHLIGHTS

- Flexural behaviors of glue laminated timber beams.
- Number of laminations, types of adhesive materials and reinforcement nets used in the lamination surfaces.
- Use of reinforcement nets at the lamination surfaces increased the ultimate load capacities.
- Finite element simulations of some test specimens were performed.

ARTICLE INFO

Article history:
Received 1 July 2017
Received in revised form 29 September 2017
Accepted 5 October 2017

Keywords:
Glulam beam
Bonding
Strengthening
Bending
Bond strengthening
ANSYS

ABSTRACT

In this study, flexuralbehaviors of glue laminated timber beams manufactured from Pinussylvestristree were investigated by comparing the results with those of massive timber beams. The main variables considered in the study were number of laminations, types of adhesive materials and reinforcement nets used in the lamination surfaces. In scope of the experimental study, glue laminated beams with 5 and 3 lamination layers were manufactured with 90 x 90 mm beam sections. In the lamination process epoxy and polyurethane glue were used. Morever, in order to improve the bond strength at the lamination surface, aluminium, fiberglass and steel wire nets were used at the lamination surfaces. Load–displacement responses, ultimate capacities, ductility ratios, initial stiffness, energy dissipation capacities and failure mechanisms of glue laminated beams were compared with those of massive beams. It was observed that the general bending responses of glue laminated beams were better than those of massive beams. In addition to that the use of reinforcement nets at the lamination surfaces increased the ultimate load capacities of the tested beams. The highest ultimate load capacities were oberved from the tests of glue laminated beams manufactured using five laminated layers and retrofitted with polyurethane glue using steel wire reinforcement nets, in the direction normal to the lamination surface. Finally, the finite element simulations of some test specimens were performed to observe the accuracy of finite element technology in the estimation of ultimate capacities of glue laminated timber beams.

1. Introduction

Timber is a material with high thermal and acoustic insulation properties with varying colors and fiber structures. It has been used for centuries due to its high strength/weight ratio as well as its aesthetic properties, easy processing, fiber structure, excellent thermal and sound insulation and better durability properties compared to other materials used as building materials [11]. It also has many positive environmental features including low buried energy, low carbon impact and sustainability [5]. Owing to these features, timber is a material used in the construction of beams, columns, roof trusses, poles, construction systems such as piles, slab elements, railway bases, and to give shape to concrete [11].

In North America, timber was used as the main structural material in most of the houses and commercial buildings before the 20th century. The abundance of timber resources is the foundation for most of the homes, commercial buildings, bridges and electricity poles. Today, houses and light commercial and industrial buildings are built using modern timber structural materials [14].

* Corresponding author.
E-mail address: oanil@gazi.edu.tr (Ö. Anil).

https://doi.org/10.1016/j.conbuildmat.2017.10.033
0950-0618/

Conversion factors

1 mm	0.039 in
1 mm^2	0.00152 in^2
1 kN	0.2248 kips
1 MPa	145 psi

Symbols

a	Distance between to support and loading, shear span length
h	Beam height
ρ_k	Charectheristic Density
ρ_{12}	Density
β_r	contraction coefficient
β_t	contraction coefficient
β_v	contraction coefficient
$E_{0,mean}$	Mean modulus of elasticity for perpendicular loading
$f_{m,k}$	Charectheristic bending strength
$f_{t,0,k}$	Charectheristic tension strength
$f_{c,0,k}$	Charectheristic compression strength
G_{mean}	Mean shear modulus for perpendicular loading

Wooden materials are still widely used today in settlement, commercial and industrial buildings, as well as in various constructions such as scaffoldings, bridges, retaining walls and power transmission towers. For example, in the United States, 90% of homes are timber [15].

In practice, the maximum possible span of the structural timber beams is limited to 5.0–7.0 m since the maximum size of the timber harvested from the logs is 300 mm depending on the tree species and the growing area. Before timber engineering products emerge, wooden trusses have been widely used to cross above the wide spans that are often required in the construction of roofs and bridges. Wooden trusses produced from timber are still the most common solutions for roofing in small houses. Wooden roof trusses are often used for spans up to 12.0 m, but can also be designed for openings up to 30.0–40.0 m [23].

Today, instead of using wood material directly, the use of wood based composite materials is preferred. Structural composite timber has been developed to reduce the consumption of forest resources and to meet the increasing demand for high quality timber. Structural composite timber is being used as a replacement for raw timber in the manufacture of engineering wood products such as prefabricated wooden I-beams and in other various applications to benefit from higher engineering design values than those offered by the raw timber [20]. Structural systems based on flat and sloping glue laminates have been developed for roofs with spans up to 100.0 m. Today, many other wood based products such as Laminated Veneered Lumber (LVL) and Parallel Strip Lumber (PSL) are used for large-scale timber constructions. Similarly, these products are suitable for larger spans, such as flat glued laminate timber elements [23]. Glue laminated timber started to be used in the late 1800 s. It was used extensively during and after World War II. Use of glue laminated beams (glulam beam) increase both in buildings and bridges. Structures cannot be erected using only saw timber proved the practical and successful aspects of glued laminated beams [21]. Wooden structures have also grown in size with the development of technology and the use of wooden building elements increased in different application fields such as bridges, sports facilities and industrial facilities besides the structures. The most important parameter affecting the load bearing capacity and general behavior of the timber laminated beams is the adherence of the laminated elements with each other. Several researches have been performed on this subject [19,22,4]. For larger spans, the design of laminated timber beams by reinforcing them with various composite materials has gain importance. The investigations have shown that researches on reinforcing timber laminated beams with composite materials such as CFRP are available in the literature [12,7,17,18]. In addition, there are studies in which steel elements are supported by wooden elements [24] or strengthened by prestressing [9,2,3,25].

In this study, it was aimed to use reinforcement elements produced from aluminum, fiberglass and steel materials in order to strengthen the bond between the two laminates of the beams to increase their performance under the effect of reversed cyclic loads such as seismic loads. From the literature review, it is observed that the externally bonded steel elements, CFRP elements and steel prestressing elements used for the strengthening of timber laminated beams. However, there are no studies in the literature on the use of retrofitting elements (fiber, aluminum, steel etc.) produced from various materials used to increase the bond between timber layers. For this reason, an experimental study was planned to investigate the effects of such bonding elements on the flexural behavior of glue laminated timber beams, which will increase the bond strength in the adhesion zone. The variables considered in the experimental study are: (i) the thickness, and (ii) number of laminates used in timber beams, (iii) the type of adhesive to be used on the bonding surface, (iv) the type of nets used to increase the bond strength on the bonding surface, (v) and the flexural load applied to the timber beams (i.e., perpendicular or parallel to the lamination surface). In order to examine the effects of the considered variables on the flexural behavior, timber beams were produced and tested under the effect of four point bending load. The ultimate load capacities, initial stiffnesses, displacement ductilities, energy dissipation capacities, failure mechanisms and general load displacement behaviors obtained from the experiments are analyzed and the effects of the strengthening method on the flexural behavior of the glulam beams are interpreted. In addition, nonlinear finite element analyzes of the test specimens were performed using the ANSYS finite element software and the numerical results were compared with the experimental results in terms of load-displacement behavior.

2. Experimental program

2.1. Test specimens and material

In the experimental study, flexural behavior of timber glue laminated beams is investigated. Variables considered in the study are: (i) the number, (ii) and thickness of laminates, (iii) the type of glue used to bond timber laminates, (iv) the netting type used to strengthen the lamination zones to improve the bending behavior of timber laminated beams, (v) and the flexural load applied to timber beams (i.e., parallel and perpendicular to the lamination surfaces). In order to determine the effects of the net types on the flexural behavior, massive beams that were not laminated are also produced and the obtained results are compared with those of retrofitted glue laminated beams. In the experimental program, a total of $33 \times 3 = 99$ timber beams are produced from 33 main timber beams (i.e., 3 beams for each type) and four point monotonic bending loading is applied to the test specimens. The properties of the test elements are given in Table 1**.**

The timber beams are 90×90 mm in size and 1710 mm in length. Tests of the specimens and determination of their properties were performed in accordance with EN 13183-1. The geometric dimensions of the test specimens are given in Fig. 1 in relation