Composites Part B 86 (2016) 152–159

Contents lists available at ScienceDirect

Composites Part B

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

Analysis of the flexural stiffness of timber beams reinforced with carbon and basalt composite materials

Pilar de la Rosa García [a,*], Alfonso Cobo Escamilla [b], M. Nieves González García [a]

[a] Architectural Construction Department, School of Building Engineering, Polytechnic University of Madrid, Juan de Herrera Street, 6, 28040, Madrid, Spain
[b] Edification Technology Department, School of Building Engineering, Polytechnic University of Madrid, Juan de Herrera Street, 6, 28040, Madrid, Spain

ARTICLE INFO

Article history:
Received 30 June 2015
Accepted 6 October 2015
Available online 22 October 2015

Keywords:
A. Polymer-matrix composites (PMCs)
Wood (pinus sylvestris)
B. Mechanical properties
D. Mechanical testing

ABSTRACT

In this work, an experimental study on the bending behavior of pine wood beams reinforced with carbon and basalt fiber reinforced plastics, externally glued with epoxy resins has been performed. Different grammage, unidirectional and bi-directional fabrics have been used, and one or three layers applied. The results show good behavior of basalt fiber reinforcements in the stiffness increase of timber beams, achieving similar results to those obtained with carbon fiber. Moreover, reinforcements made with bi-directional fabrics produced significant stiffness increases compared to the unidirectional fabrics. Finally, this work includes also the results obtained using the transformed section to predict the stiffness increase that the different types of reinforcement analyzed produces.

1. Introduction

Historically, wood has been a material used in the field of civil engineering and construction. On many occasions, after some time, the structures need to be reinforced for various reasons: they need to increase the capacity due to a change in use; because of pathological problems which diminish their resistance, or because the excessive deformations are incompatible with the partitions or finishes. The procedures used to reinforce structures have been the focus of numerous studies, due to the fact that the economic volume these types of actions imply is quite considerable. Traditionally, the reinforcement techniques used in timber structures have mainly steel or wood [1]. The use of composite materials and more specifically of fiber reinforced polymers (FRP) in the construction industry is relatively recent when compared to the traditional systems.

Wood is a natural material with an excellent relationship between mechanical characteristics and weigh. This feature is maintained with the use of composite materials as strengthening. In terms of the constitutive model, an elastic linear behavior under tensile stress parallel to the fiber up to fracture is admitted, while compression is considered as an initial linear elastic behavior followed by a plastic one [2,3].

In sawn timber beams subjected to bending, the predominant failure is due to tensile stress, frequently locating the fracture at the lower beam side. FRP have a linear elastic behavior up to fracture under tensile stress, and they have excellent mechanical properties, with high elasticity module and tensile strength values, in relation to the weight and volume. If a beam is reinforced at the bottom side, it increases tensile strength and it is likely to produce an increase in its stiffness. The first relevant application of the use of FRP to reinforce timber structures was carried out in 1995 in the bridge of Sins in Switzerland [4]. In this case, the cross beams of the bridge had an excessive deflection, and so the aim to strengthen it was to increase the stiffness of the beams.

The first studies published on the behavior of timber elements reinforced with FRP correspond to the 1960s [5,6]. Research studies have progressively increased in order to expand the knowledge on the matter. Several aspects are analyzed in this type of publications, being stiffness of the elements one of the most important, as well as other issues, such as the load capacity increase, the influence of reinforcement in the fracture mode [7] and the integrity of the bonding surface between wood and the composite material until failure occurs [8,9].

In addition, many studies compare the experimental values obtained in fracture load and stiffness with the analytical values obtained using different calculation models. Usually the models applied are the transformed section, and the ones derived from

* Corresponding author. Tel.: +34 687246944.
E-mail addresses: pilar.delarosa@upm.es (P. de la Rosa García), alfonso.cobo@upm.es (A. Cobo Escamilla), mariadelasnieves.gonzalez@upm.es (M.N. González García).

http://dx.doi.org/10.1016/j.compositesb.2015.10.003
1359-8368/

applying the equilibrium equations to the reinforced section, considering timber behavior model as an elasto-plastic for compression and a linear elastic one under tensile stress. A linear elastic behavior up to the fracture is always considered for composite materials [10]. More recent studies have modeled how strengthening works by applying a finite element method [11,12]. Quanfeng in 2010 [13] concludes that this is a reliable method to simulate the behaviour of timber beams reinforced with FRP. The results obtained by different authors concerning the increase in stiffness of tested beams varies depending on the volume of FRP applied in the section of the beams, the type of fiber that forms the composite material, the type and placement of reinforcements, and the previous characteristics of the reinforced elements, in addition to the type of bonding between the timber and the reinforcing material.

Some results concerning stiffness increase are presented in the work published by Tingley et al. (2001) [14], where in this case, the beam reinforcement was performed with aramid fiber, resulting in a stiffness increase of about 5% compared to beams without composite reinforcing. Fiorelli et al. (2002) [15] used fiberglass and carbon for the reinforcements, and obtained an increase between 15 and 30% with a reinforcement volume of 1% and 0.4% of glass fiber FRP (GFRP) and carbon FRP (CFRP), respectively. In addition, it was found that increasing the volume of GFRP to 3%, the stiffness increased reached up to 60%. At the same time, the work of Borri A. et al. (2005) [16] compared the behavior of three types of reinforcement – all of them CFRP – but with different characteristics: the first type consisted on prestressed sheets, the second one, sheets without being prestressed, and finally in the third case, pultruded rods were applied. The difference in the stiffness increase between the three applied types was not significant, being the stiffness increase in relation to non-reinforced beams of 22.5–30.3%. More recently, works have been published in which composite materials have been reinforced with sustainable fibers from the environmental point of view, such as basalt [17], hemp and flax [18], analyzing their performance on structural wooden elements. In 2014, Gary M. et al. [19] tested low quality laminated timber beams reinforced with pultrusion rods of basalt fiber-reinforced polymers. In this case, the stiffness increase was 8.4%, with 1.4% reinforcement volume applied to the beams section. Finally, in 2013 Borri A. et al. [20] published the findings after testing 45 beams stating that composite materials of different kinds of natural fiber (basalt, flax and hemp) showed a good performance to stiffness increase.

Fibers initially used for the manufacture of composite materials in timber beams reinforcement were glass fibers [20–24], and later carbon fibers [25] and aramid fibers [26] were subsequently incorporated. The latest trend is focused on the study of the behavior of natural fibers [17–20]. Some authors have analyzed the behavior of reinforced beams to shear stress through sheets arranged transversally and longitudinally to the direction of the wood fiber on the lateral beam sides [27,28]. Another form of shear reinforcement has been carried out with FRP pultruded rods embedded in epoxy resin into holes in the lower beam face [29]. This provision of the reinforcement is intended to diminish the possible early failure to shear effect that the drying splits may cause on beams subjected to bending. Integrity of the interphase between composite and wood has also been studied at various times [31], since this is one of the most important aspects influencing the proper functioning of the reinforcements.

This work studies the increase of stiffness experienced on Pine timber sawn beams when reinforced with composite fabrics. Basalt (BRFP) and carbon (CFRP) fabrics with different grammage have been applied, placed in “U” shape, wrapping part of the beam section.

2. Materials and testing method

Tests have been performed with 27 timber beams, 9 were tested in flat position and 18 in edge position. Timber used has been 78 × 155 mm of section and 1090 mm in length Valsain pine. The reinforcement placement has been in “U” shape in all cases, as shown in Fig. 1. Tests have been conducted with a universal press, Ibertest Mib, controlling the speed of the displacement (0.05 mm/s). The beams were subjected to three-points bending test, applying the load at the center point of the beam (Fig. 2). Bending test for each beam was conducted in two phases. In the first phase, beams were loaded before being reinforced up to a load value producing in the most stressed fibers a tensile stress of approximately 33% of the ultimate fracture strength, so as to obtain the initial load–displacement beam diagram without reinforcement. With this load value, beams did not exceed, in any case, the elastic and linear behavior. Subsequently, they were reinforced with the different types of fabric and number of layers, and were tested to fracture.

Reinforcements were performed with CFRP and BFRP, manufacturing the composite material in-situ, at the same time as the reinforcement was being carried out. Nine flat beams studied were reinforced with unidirectional fabrics, 3 of them with basalt fabric of grammage equal to 280 g/m^2 (FB280[1]), 3 with 600 g/m^2(FB600[2]) basalt fiber fabric and 3 with 300 g/m^2 (FC300[3]) carbon fiber fabric. From the 18 edge beams tested, nine were reinforced with unidirectional and nine with bi-directional fabric. The ones reinforced with unidirectional fabrics were divided into three groups, as done with the other flat beams, and were reinforced with FC300, FB600, and FB280 respectively. The nine remaining edge beams were reinforced with bi-directional carbon fiber fabric, of grammage 210 g/m^2 placing the reinforcements in three layers (FC210 #3[4]). Table 1 shows the characteristics of the fabrics used for performing the reinforcements. The last row shows the fabric stiffness when under axial stress, obtained as the product of its elasticity module by its thickness. In the case of FC210 #3, the thickness has been considered as the one corresponding to the three layers.

The matrix used for the manufacture of composite materials was epoxy resin, and the same resin has been used as adhesive between the wood and the reinforcement. Prior to the application of the first resin coat, the wood surface was cleaned with a brush and a primer coat applied to improve bonding between the composite and wood. After the primer was applied, an initial resin coat, with an approximate yield of 0.5 kg/m^2 was spread. Subsequently, the unidirectional fabric reinforcement was placed parallel to the longitudinal direction of the beam, and finally a finishing layer of the same epoxy resin, with an approximate yield of 0.3 kg/m^2 was applied. For the bi-directional fabric reinforcement, (FC210 #3) a similar process was followed, although 3 layers of fabric were applied. Fig. 3 shows pictures of six of the beams.

3. Test results

The software associated with the testing machine supplied the obtained data, and these corresponded to the applied loads and the vertical displacement experienced by the beams at

[1] Unidirectional basalt fibers of 280 g/m^2 grammage reinforcement.
[2] Unidirectional basalt fibers of 600 g/m^2 grammage reinforcement.
[3] Unidirectional carbon fibers of 300 g/m^2 grammage reinforcement.
[4] Bi-directional carbon fiber of 210 g/m^2 grammage reinforcement with a triple layer.