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The behavior of horizontally glued laminated beams using rubber wood

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HIGHLIGHTS

- Evaluated the flexural properties of solid rubber wood and laminated rubber wood.
- If laminated wood could be suggested as a replacement to the solid wood.
- Evaluated laminated wood flexural properties with different lamina thickness and jointed lamina.
- Evaluated joint efficiency, wood adhesive bond strength, durability of the adhesive bond.
- Rubber wood is found suitable for laminated and structural wood products.

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ABSTRACT

The process of manufacturing engineered wood products (EWP) is an effective technique for reducing or eliminating the negative properties of solid wood materials and for obtaining high performance materials. However, there is a dearth of information regarding the studies in glued laminated timber, one among the EWP, in India. Thus, this paper describes an experimental program which examines the flexural properties of horizontally glued laminated timber utilizing rubber wood, a sustainable, plantation grown timber in the country. The experimental test program involved the fabrication and testing in flexure of horizontally glued laminated rubber wood using polyvinyl acetate adhesive, with different lamina thickness and jointed laminas. The study also evaluated the joint efficiency, wood adhesive bond strength and the durability of the adhesive bond. The test results obtained show that the comparison of flexural properties between solid wood and horizontally glued laminated wood have no significant difference. Lamina thickness does not make any statistically significant difference in the flexural properties. Laminated beam and jointed laminated beam with the same lamina thickness have no significant difference in the flexural properties. The wood adhesive bond strength and the wood failure percentage obtained are appreciable. The experimental results obtained and a comparison with code provisions verifies the suitability of the wood species for composite products.

1. Introduction

Engineered wood is a composite material alternative to solid wood, consisting of wood and adhesives, and it is available in several varieties; the most commonly used types of structural EWP are: laminated veneer lumber (LVL), glued-laminated timber (glulam), composite I beam, cross-laminated timber (CLT) and parallel strand lumber (PSL). Western, European and South East Asian countries are extensively using timber, particularly the engineered wood products (EWP) both for structural and non-structural purposes [1]. Glulam is made from sawn lumber lamina arranged in horizontal layers using glue, with the grains parallel to the length of the member. Taking the benefit of end jointing of smaller timber pieces, glulam can be made to any indefinitely long beam offering larger size capability than solid wood [2].

Structural glulam members have been widely used in developed countries particularly in America, Europe and Japan. These members are used in straight or curved form in numerous construction applications including sport complexes, commercial buildings, churches and residential houses [3]. In horizontally glued laminated timber load is applied perpendicular to the glue surface.

The properties of laminated wood materials are affected by the type of wood, the defects it contain, thickness of layers, number of layers, type of glue used and the compression force used during pressing [4]. The characteristics of glued laminated beams using plantation timbers, African wood and Mangium have been studied by Evalina et al. [5] and found satisfactory performance as per JAS 234:2003. The performance of Acacia Mangium glulam beam was evaluated by Indah et al. [6] with different lamina thickness and found the flexural properties of glulam beam with 20 mm thick

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laminas having the lower values compared to 15 mm and 10 mm thick laminas. Bending strength properties of glued laminated timber from selected Malaysian hardwood timber were studied by Wan et al. [7] and compared the values obtained with JAS 234:2003 and found to be satisfactory.

Timber, the traditional construction material was used widely in India for structural works in the earlier days. The less use now is may be of the non-availability of large diameter logs. To supplement the imported timber from countries having intensively managed forestry plantations, low grade/less girth underutilized trees available domestically was gaining significance [8]. Rubber wood, a by-product of a crop grown for latex production is being used and marketed in many applications, substituting higher value and less available traditional hardwoods such as teak in Asian countries. India is the fourth largest producer of natural rubber in the world, 89% of which is produced in Kerala.

As is the case of all building materials, it is necessary to define the technical performance of the materials produced with laminates clearly, in order to be able to use them in buildings. Otherwise the material cannot hold up the conditions to which it is subjected [9].

In India the EWP such as the plywood products, particle board, and fiber board are used widely for non- structural works. Glulam is not a commercially established or available product in India. The product is developed for the present study on research interest. This study informs the utilization of rubber wood as glulam material.

The objectives of this study included the fabrication and testing in flexure of horizontally glued laminated rubber wood and comparing the properties with solid beam. The effect of lamina thickness and jointed lamina in the flexural properties were investigated. The efficiency of the finger joint strength in tension and bending was evaluated. Also the wood adhesive bond strength and the durability of the adhesive bond were obtained. The test results were checked with code provisions so as to verify the suitability of rubber wood for composite products.

As rubber wood is a sustainable timber leading to sustainable construction the authors proposed a thought of value addition of the material with this study. The results of this research can be very useful in realizing the potential usage of rubber wood in laminated products. Furthermore, it would be beneficial to carry out new research studies related to the same topic, but with different *l*/*d* ratios, different wood species, mixed wood, different glue types, contributing to the literature on this subject, opening a new area of research focus in the country.

2. Materials and methods

2.1. Manufacture and testing of glulam for its flexural properties

Rubber wood (*Hevea brasiliensis*) used was having an average density of 605 kg/m^3 and an average moisture content of 10%, achieved in the conditions of 27 ± 2 °C temperature and relative humidity 65 ± 5%. As the timber was obtained after the latex unproductivity, the age is above 20 years. The commercial adhesive poly vinyl acetate (PVAc) was used in the fabrication of the laminated beams.

Laminas having major defects were avoided and those having minor defects were placed in the neutral zone of the laminated beam. In the case of solid beam, specimens with defects such as knots and spiral grain were included for the study so as to demonstrate the real case. The PVAc adhesive used was with hardener DORUS R 7357 added in the ratio of 15% instructed by the manufacturer, applying on the specimens with the adhesive coverage of 250–300 g/m^2. Adhesive was spread on both the surfaces of the laminas using the roller spreader. A nail gun was used to hammer small nails into the ends of the laminated materials so that the glued layers would not slip during pressing. Specimens were pressed with a pressure of 3 MPa applied for a period of 3 h at room temperature, the minimum specified pressure for laminated specimens is 1 MPa [10]. The specimens were then kept undisturbed for one week, conditioned in a room at a temperature of 27 ± 2 °C and relative humidity 65 ± 5% before testing. The dimension of the beam specimen was 900 ∗ 60 ∗ 40 mm (Fig. 1). The dimension of the beam was prepared so that the ratio of shear span (a_v) and the depth of the beam was in the range 4–6 as specified in ASTM D198-09 [11] for the evaluation of flexural properties (bending strength and modulus of elasticity). The span to depth (l/d) ratio of the adopted specimen size corresponds to 14. The static bending test was conducted in accordance with the third-point loading method.

Laminated specimens were prepared with different lamina thickness and also with finger jointed laminas to have a comparison with solid beam. The jointing technique favors laminated beam of any size and is particularly useful for rubber wood, where lengthy plies on seasoning gets warped. Accordingly a comparison is made between the flexural properties of the jointed laminated beam with unjointed laminated and solid beam. The placing of joints in the laminas should be staggered, not coinciding with those above or below and the distance between the joints depends on the lengths of the input material [12]. The finger joint used in this study has a length of 12 mm, pitch of 3.6 mm and tip width of 0.7 mm. The joints were placed in a staggered manner in the beams. The joints were placed outside the maximum moment zone in the outer tension lamina and also placed at maximum spacing. In three specimens only, the joints were placed inside the maximum moment zone to verify the strength. The preparation plan of the test specimens for the study is shown in the Fig. 2. The laminated timber beam specimens comprise four groups, as explained in Fig. 2, three groups of varying lamina thickness and the fourth group with jointed laminas. Ten specimens were tested from each group.

A third-point loading static bending test was carried out, where the distance between the two loading points and the distance between the right and the left fulcrums was the same. The loading rate was 3 mm/min. Modulus of elasticity (MOE) and the modulus of rupture (MOR) were calculated by the following formula:

$$MOE = \frac{23PL^3}{108bh^3\Delta}$$

$$MOR = \frac{P_{max}L}{bh^2}$$

where P is the load within the proportional limit (N), L is the span of beam between the supports (mm), Δ is the mid span deflection (mm), P_{max} is the maximum or the ultimate load (N), b is the width of the beam (mm) and h is the depth of the beam (mm).

2.2. Joint efficiency

In much of the literature on finger joints, strength is expressed as a percentage of the strength of a piece of clear, unjointed wood of the same species and is referred to as the joint efficiency [13]. In this study the efficiency of the finger joint used for laminating was found in bending and tension as a basic data. For the joint efficiency testing, the finger joint was placed at the center of the specimen shown in Fig. 3(a and b). Small clear specimens were taken; dimension and testing were done as per ASTM D143-09 [14].

2.3. Wood adhesive bond strength

The evaluation of the adhesive bond was done by finding the shear strength of the adhesive bond by conducting the block shear test using the ASTM D905-08$^{\epsilon1}$ tool shown in the Fig. 4. The specimen dimension is shown in Fig. 5(a). The form and dimension of the specimen used for this test is adopted as per ASTM D905-08$^{\epsilon1}$ [15]. Since an adhesive transfers stress from one substrate to another through shear, shear test is commonly used to evaluate the bond performance of adhesive joints. Block shear test such as ASTM D905 is commonly used to evaluate mechanical properties of adhesive joints [16]. From the shear test, in addition to shear strength, percent wood failure on the fracture surface is also measured. During the test, the machine loading speed was adjusted to 5 mm/min; the maximum load (P_{max}) at the moment of breaking was measured. The longitudinal direction of the wood was parallel to the loading direction during the test. Shear resistance was calculated by the following equation P_{max}/A, where P_{max} is the maximum load at the moment of breaking (N) and A is the surface area glued (mm^2).

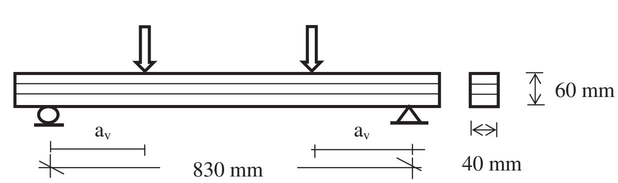

Fig. 1. Dimension of beam test specimen.