EFFECT OF FIRE-RETARDANT TREATMENT ON MECHANICAL PROPERTIES OF MEDIUM-DENSITY COIR COMPOSITE BOARDS

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Abstract. Composite boards manufactured from natural fibers such as coir can be a useful substitute for wood and plywood. They can also be chemically treated to improve its fire-resistant capabilities. To be rendered useful as a construction material, the chemical treatment has to impart fire resistance without affecting its structural properties. This article investigates the effect of fire-retardant (FR) treatment on mechanical and physical properties of medium-density coir fiberboards when treated with a waterborne solution containing boron compounds using the method of hot and cold bath treatment. Physical properties such as density, MC, and thermal conductivity were determined to compare the performance of treated samples against untreated samples. Investigation of mechanical properties such as tensile strength, bending strength, tensile modulus, and flexural modulus were also carried out using a combination of tensile, bending, and compression tests. The results obtained were encouraging, and it was observed that the coir fiberboards after FR treatment retained much of their properties and in many cases, even improved marginally.

Keywords: Fire-retardant treatment, boron, mechanical properties, coir fiberboard.

INTRODUCTION

The rapid depletion of forest reserves leads to an alarming scarcity of wood, which remains an ongoing concern in several countries, including India. Furthermore, this decline of resources has made it more difficult to stably acquire the wood needed for manufacturing products. The large amount of timber used for various applications reminds about the importance of conserving this precious resource and ensuring its availability for extended usage (Raut et al 2011; Madurwar et al 2013). The aforementioned factors call for the reduction in wastage of wood and to develop alternative engineered wood products that could substitute wood. The research and development of new materials to substitute wood is being driven by rising environmental concern and demand for alternative resources, which in turn, has initiated the use of renewable materials such as biomass (Mohanty et al 2002).

Coir fiber is a seed fiber, which is thick and coarse in nature. They are extracted from the fibrous husk (mesocarp) of the fruit of coconut palm tree (*Cocos nucifera* L.), which grows extensively in tropical areas. Natural fibers such as coir provide engineers with tremendous opportunities to develop more efficient, less expensive, lightweight, and renewable green products and they are increasingly being used because of their unique properties in terms of strength, elongation, durability, and ability to absorb moisture. They are also moldable, anisotropic, hygroscopic, nonabrasive,

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combustible, and compostable in nature. Their low density, good thermal insulation, and comparable mechanical properties coupled with favorable factors such as reduced tool wear and problem-free disposal make them an attractive choice (Israel et al 2011; Rejeesh and Saju 2017a).

In India, coir is regarded as a versatile fiber that is locally available in abundance and hence is cheaper. India enjoys an immense potential in the coir fiber composites industry as the country is endowed with a large area of coconut cultivation and is the leading producer and exporter of coir fiber in the world (Israel et al 2011; Rejeesh and Saju 2017a). Native supply of veneer for manufacturing engineered wood has become limited in India and a subsequent rise in felling acquisition cost while importing them made the producers to assay plausible alternatives. This is where coir fiberboard falls into place as they could offer a valuable alternative for the customers with competitive properties such as high stiffness, high strength, and low density at less weight and could decrease the overall utilization of wood resources (Mohanty et al 2002; Israel et al 2011). Biocomposites based on natural fibers such as coir fiber would get a wider acceptance as a substitute of wood in the area of building and construction, having enhanced fire-resistant capabilities. The application of coir fiberboards in the post disaster management of rehabilitation and rebuilding could become cost competitive compared with other conventional building materials (Raut et al 2011; Madurwar et al 2013).

The research on developing a new fire-retardant (FR) coir fiberboard without losing their properties after FR treatment assumes great significance. Although promising results have been reported for FR-treated (FRT) coir fiberboards, little is reported about corresponding changes in its properties after FR treatment. Apart from being a fire retardant, boron compounds are good preservatives that protect the material from decay and termite attack. An aqueous solution containing a mixture of boric acid (BA) and borax (BX) were found to improve the flame-retardant properties of medium-density coir board samples (Rejeesh and Saju 2017b); however, the effect of FR treatment on the physical and mechanical properties of the samples are scarcely reported. This article aims to investigate the effect of FR chemical treatment of medium-density coir board samples and the subsequent changes it imparts to some of the physical and mechanical properties of medium-density coir board samples.

MATERIALS AND METHODS

Coir fiberboard samples were manufactured and subjected to hot and cold bath treatment using a waterborne chemical solution containing a combination of laboratory-grade BA (H_3BO_3) and BX ($Na_2B_4O_7.10H_2O$). Physical properties such as density, MC, thermal conductivity, and thermal resistance of both treated and untreated samples were determined. The changes in mechanical properties of coir fiberboard samples after FR treatment were assessed by subjecting them to tensile, bending, and compression tests. Three samples each of treated and untreated coir fiberboards were subjected to each test.

Preparation of Medium-Density Coir Fiberboards

Medium-density coir fiberboard samples of size of 300 × 300 × 12 mm were manufactured as per IS 15491:2004 by hot pressing coir fiber mats impregnated with phenol formaldehyde resin. Coir fiber required for manufacturing coir fiberboards were mechanically extracted as per IS 9308:1999 from the husk of mature dry coconuts. The coir fiber thus separated from coconut husk is initially soaked in water, then washed and subsequently dried before it was fed through a needle felt machine to make a uniform nonwoven coir fiber mat (felt) of sufficient density (BIS 2004).

The fiber mats thus produced were then impregnated with phenol formaldehyde resin using a glue-spreading machine and is dried before further processing. After drying, the impregnated fiber mats were stacked one over the other for the required thickness and is pressed at a temperature of 140°C and a pressure of 12 kg/cm^2 for about 5 min with a hydraulic hot press to form coir fiberboards (BIS 2004). The prepared samples were then subjected to chemical treatment.

FR Chemical Treatment

The sample surface was cleaned to remove any impurities, followed by chemical treatment with an aqueous solution containing a mixture of 40% BA and 60% BX in the ratio 1:1.5 by their weight in it. When slightly heated, this combination of FR boron gives the maximum solubility in water without precipitates and accounts to around 35% FR boron (BA + BX) for 65% water in the solution. Hot and cold bath method of FR treatment was employed on the samples. The dry sample was first dipped in the FR solution at 100°C for 30 min and then transferred to the cold bath where it was soaked for a further 6 h at about 38°C followed by drying in the sunlight until the MC was removed. During hot bath process, the rapid heating of samples resulted in the expansion of air molecules present in the sample and were subsequently driven out, whereas the residual air present in the samples contracted during rapid cooling during the cold bath process which created a partial vacuum and allowed the preservative boron to penetrate (Rejeesh and Saju 2017b).

Physical Properties

The effect of FR treatment on various physical properties of coir fiberboard samples was investigated using standard procedures. Change in properties such as density and MC was determined. Thermal insulation properties such as thermal conductivity and thermal resistance were also determined. Three samples each were tested for both FRT and untreated coir fiberboards for the entire range of experiments.

Density and MC. Density and MC of both treated and untreated samples were determined as per IS: 1734 (Part 1)-1983 standards. Samples having a size of 75 × 150 × 12 mm were initially weighed before drying it. The samples were oven-dried at around 100°C for short intervals of time and subsequently weighed until further mass loss is not observed. Equations 1 and 2 were used to determine density and MC, respectively.

$$\text{Density} = \frac{M_o}{Lwt} \text{ in g/cm}^3 \quad (1)$$

$$\text{MC} = \frac{(M_i - M_o)}{M_o} \text{ X 100 in \%.} \quad (2)$$

Here,

M_i = initial mass of sample in g,
M_o = oven-dry mass of sample in g,
L = length of the sample in cm,
w = width of the sample in cm, and
t = thickness of the sample in cm.

Thermal conductivity. A heat flow meter (HFM 436 Lambda; NETZSCH, Selb, Germany) was used to measure the steady-state thermal transmission through flat slab samples having a size of 305×305×11 mm. The thermal conductivity and thermal resistance of both treated and untreated samples were determined as per ASTM C518-15 standards and were used to compare the thermal insulation performance of FRT coir fiberboards against untreated boards.

Mechanical Properties

The FRT and untreated coir fiberboard samples were tested in a universal testing machine (Z 100; Zwick Asia Private Ltd, Jurong East, Singapore) to measure and compare some of their mechanical properties. The effect of FR treatment on the strength of coir fiberboards was investigated with the help of standard procedures done for tensile, bending, and compression tests.

Tensile test. Tensile test performed on the samples was as per ASTM D3039-14 standards. Medium-density coir fiberboard samples measuring 250 × 50 × 12 mm were used for testing. The samples were subjected to a maximum operating force of up to 1.3 kN at a test speed of 10 mm/min. Mechanical properties such as tensile strength (MPa), tensile modulus (MPa), maximum tensile force to failure (N), and longitudinal strain at maximum tensile force (%)

were determined for both FRT and untreated samples.

Bending test. The flexural properties of both treated and untreated samples were determined as per ASTM D790-02 test standards. The three-point bending test was performed on coir fiberboards having a size of 250 × 50 × 12 mm at a crosshead speed of 5 mm/min and preload of 0.1 MPa. Properties such as flexural strength (MPa) and flexural modulus (MPa) were obtained to compare the performance of both FRT and untreated coir fiberboard samples.

Compression strength. Coir fiberboard samples having a size of 12 × 12 × 24 mm were tested as per ASTM D 695-15. Compression test on both treated and untreated samples was performed at a standard test speed of 1 mm/min. The compressive strength (MPa) of coir fiberboard samples were compared against that of FRT coir fiberboard samples to evaluate the performance of coir fiberboard samples after fire retardant chemical treatment.

RESULTS AND DISCUSSION

The various physical and mechanical properties of coir fiberboards were obtained after FR treatment and were compared against the values of untreated fiberboards.

Effect of FR Treatment on Physical Properties

The prescribed value of density of medium-density coir fiberboards (Grade-1) as per IS 15491 falls within a range of 650-900 kg/m^3 (BIS 2004). The untreated samples had a density of 650 kg/m^3 when tested, whereas samples after FR treatment exhibited an increase in density and recorded as 846 kg/m^3. This increase in density is due to the added weight of borates present in FRT coir fiberboard samples. The percentage of MC present in coir fiberboard samples have to be in a controlled level of within 5-15% as per IS 15491. The untreated samples had an MC of 5%, whereas FRT samples contained 7% MC, but is still within the range specified by the relevant standards. The MC of FRT samples increased as a result of the chemical treatment performed using a waterborne solution for about 7 hours. FRT coir fiberboards were found to have a reduced value of 0.0937 W/m-K for thermal conductivity, whereas the untreated samples exhibited 0.183 W/m-K. The thermal conductivity values for coir fiberboards are comparable to the thermal conductivity of hardwood species such as yellow poplar (0.11) as well as softwoods such as Douglas-fir (0.12) and redwood (0.10) in W/m-K (Green et al 1999). The thermal resistance of FRT samples increased considerably to a value of 0.117 m^2 K/W from a resistance of 0.060 m^2 K/W for untreated samples. The more-resistant and less-conductive FRT coir fiberboard samples turn out to have better thermal insulation characteristics.

The average values obtained for physical and mechanical properties of FRT and untreated coir fiberboard samples are consolidated and shown in Table 1.

Effect of FR Treatment on Mechanical Properties

The values for tensile strength perpendicular to the surface (Internal bond) and tensile modulus of treated coir fiberboards were found. As per IS 15491, the average values stipulated for tensile strength of coir fiberboards are within 0.8-0.9 MPa and the tensile modulus is expected to be between 2500-2800 MPa (BIS 2004). The average tensile strength perpendicular to FRT coir fiberboards were found to have increased to 1.26 MPa, whereas untreated boards were only exhibiting 0.8395 MPa. The tensile modulus of untreated fiberboards was found to be 2469 MPa, whereas the FRT fiberboards showed a substantial increase of 4846 MPa. The FRT coir fiberboards exceeded the minimum required values set by the standards after the tensile test.

The flexural strength (modulus of rupture [MOR]) and flexural modulus of coir fiberboards were found using a three-point bending test. The average flexural strength of FRT samples increased to 33.9 MPa from 17 MPa of untreated

Table 1. Average values determined for different properties with their standard deviations.

Sl. No.	Properties	Determined values with standard deviation	
		FRT samples	Untreated samples
1	Density (kg/m^3)	846 (5)	650 (3.51)
2	MC (%)	7 (0.57)	5 (1)
3	Tensile strength (MPa)	1.26 (0.04)	0.8395 (0.015)
4	Compressive strength (MPa)	11.6 (0.73)	15.7 (0.35)
5	Flexural strength (MPa)	33.9 (12.33)	17 (5.47)
6	Flexural modulus (MPa)	3.03 (0.42)	2.16 (0.42)
7	Tensile modulus (MPa)	4846 (51.05)	2469 (18.68)
8	Max. tensile force to failure (N)	1260 (40)	839 (14.53)
9	Longitudinal strain at maximum tensile force (%)	0.026 (0.006)	0.034 (0.005)
10	Thermal conductivity (W/m-K)	0.0938 (0.005)	0.183 (0.002)
11	Thermal resistance (m^2 K/W)	0.117 (0.003)	0.060 (0.002)

samples, whereas the flexural modulus of treated samples increased to 3.03 MPa from 2.16 MPa of untreated samples. As per IS 15491, the average values stipulated for MOR of coir fiberboards are within 17-31 MPa. The results of bending test on FRT coir fiberboards confirmed a substantial improvement in the properties such as flexural strength and flexural modulus.

The average compression strength for a coir fiberboard is comparable to that of similar wood fiber composite boards for general purposes. When compared with the average compressive strength of sheathing-grade oriented strand boards having values between 10.3 and 17.2 MPa, (Younquist 1999) coir fiberboards retained the required compressive strength after FR treatment. However, the average compressive strength of treated samples showed a negligible fall to 11.6 MPa from 15.7 MPa of untreated samples.

CONCLUSION

Coir fiberboards were subjected to FR treatment with a specially prepared chemical solution containing a combination of BX and BA to enhance their FR properties. The samples after FR treatment conformed to the required values for density and MC as put up by the standards. The treated samples exhibited reduced values for thermal conductivity and improved thermal resistance when compared with untreated samples, which shows an overall improvement in thermal insulation characteristics of FRT coir fiberboards. The study also determined the mechanical behavior of FRT coir fiberboards using a combination of tensile test, bending test, and compression test. The obtained values were used to compare the performance of treated samples against untreated samples. The results suggested that there was no substantial loss of strength in coir fiberboards after FR treatment. The results were encouraging and suggest the use of FR treatment on coir fiberboards for applications involving stringent fire safety norms. The study also proposes the possibility of developing a new class of fire-proof coir fiberboards that can cater to a wide range of applications.

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