EFFECT OF CHEMICAL TREATMENT ON FIRE-RETARDANT PROPERTIES OF MEDIUM DENSITY COIR FIBER BOARDS

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Abstract. Coir fiber is a natural fiber extracted from the husk of coconut and medium-density panel boards made from coir are being investigated worldwide for their ability to substitute wood. Fire-retardant properties of the panel boards made from coir fiber need to be enhanced for its wider acceptance. In the present study, panel boards have been subjected to chemical treatment with an aqueous solution containing preservative boron compounds and the samples after treatment showed very significant improvement in resistance to flammability, flame penetration, and reduced rate of burning. The test for limiting oxygen index showed reduced values of ignitability, suggesting the use of the earlier methods to enhance the fire-retardant properties of coir fiber–based panel boards and use of the panels as substitute for wood-based applications.

Keywords: Fire retardants, boron, limiting oxygen index, medium-density coir fiberboard.

INTRODUCTION

The use of wood for industry and construction has been long established. However, the alarming rate of depletion in forest resources has led to stringent environmental regulations to check their exploitation in several countries including India, which mandates the conservation of available wood resources and makes it a necessity to find alternative sources. With the development of wood composites, several natural fiber reinforced materials are being produced wherein inexpensive and sustainable alternatives like agricultural waste have attracted considerable interest (Hill 2006; Ozcifci 2007; Nagieb et al 2011). Lignocellulosic materials like coir fiber are considered as excellent reinforcing materials since they are a renewable natural resource. The growing concern about our environment promotes usage of recyclable raw materials and products, emphasizing the demand for lignocellulosic composite materials (Ruxanda et al 2008).

India together with SriLanka contributes around 80% (600,000 tonnes) of the annual estimated production (750,000 tonnes) of coir fiber worldwide, followed by Vietnam (115,100 tonnes) and Thailand (45,700 tonnes). Indonesia, Malaysia, Brazil, and the Philippines also cultivate coconuts in relatively smaller quantities. Apart from the main contributors, more than 90 countries in the world produce coir fiber and collectively accounts to 12,000 tonnes of the total annual production (FAO Statistical Bulletin 2015). A major share of the coconut husk is seldom used for making value-added products

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and therefore is treated as an agricultural by-product or waste. The development of medium-density coir boards from a green material like coir fiber has been gaining attention as it facilitates value addition (Gon et al 2012). Taking into account this largely unused potential, investment on manufacturing facilities to produce coir fiber–based panels looks justified. It also opens up new job opportunities particularly in developing countries which helps to wipe out poverty and unemployment. Coir composites such as medium-density coir boards can be considered as a good alternative to wood (Rejeesh and Saju 2015). The properties favoring coir fiber in comparison to synthetic fibers are less weight, good availability, low cost, and high specific strength. Coir is a biodegradable, renewable natural fiber containing 32.8% lignin (Abdul Khalil et al 2006; Siddika et al 2013). Medium-density coir boards do not pollute the environment to significant levels and are generally easily workable. Being a cost-effective material, its outstanding physical and mechanical properties coupled with aesthetics offer a distinctive advantage over other similar materials and can be used for various applications (Russell et al 2007; Rejeesh and Saju 2015).

Carbon-based lignocellulosic materials, such as bio-based composites, undergo combustion, pyrolysis, or burning when subjected to radiant energy or sufficient direct heat leading to concerns about medium-density coir boards for its potential ignitability and flame-resistant characteristics (Laufenberg et al 2006; Ozcifci 2007; Lowden and Hull 2013). Flame retardant treatment can be investigated to overcome these drawbacks and enable medium-density coir boards to satisfy better fire safety requirements and make it suitable for a wider range of applications (Russell et al 2007; Rejeesh and Saju 2015). Boron compounds are common preservatives used for protecting wood against fungi and insects, especially termites. Borates act as both wood preservatives and flame retardants and have low toxicity, low volatility, and are colorless and odorless (Ozcifci 2007; Nagieb et al 2011). The primary mechanism for imparting fire resistance is to form a coating or protective layer on the surface at high temperature. A combination of borax (BX) and boric acid (BA) exhibits a synergic effect on flame-resistant properties of the sample (Levan and Tran 1990; Wang et al 2004). BX tends to reduce flame spread, but promotes glowing, whereas BA suppresses glowing and improves mechanical properties such as internal bond strength and limit swelling of panel boards (Pedieu and Koubaa 2012).

This article enumerates a study on the effect of chemical treatment on medium-density coir board samples through a set of standard fire tests. An aqueous solution of BA and BX have been used for improving the flame-retardant properties of samples of medium-density coir board.

MATERIALS AND METHODS

Samples of medium-density coir board were subjected to chemical treatment using a water-borne preservative solution containing laboratory grade BA, H_3BO_3 and BX, $Na_2B_4O_7{\cdot}10H_2O$. The treated samples were then subjected to limiting oxygen index (LOI) test (ASTM 2010) and tested for flammability, flame penetration, and rate of burning for assessing the improvements in its flame-resistant properties (Sahoo et al 2015).

Preparation of Medium-Density Coir Boards

Medium-density coir board samples having a size of 300 × 300 × 12 mm, were manufactured as per IS 15491: 2004 by hot pressing of phenol formaldehyde resin–impregnated coir fiber mats. Coir fibers were extracted from the fibrous husk (mesocarp) of the seeds of coconut tree (*Cocos nucifera* L.) by mechanical process as per IS 9308 and was fed through a needled felt machine to make uniform nonwoven fiber mat in different densities according to the requirement (BIS 1999). To give a smooth surface, finer fibers like jute fibers were carded and spread to give a uniform layer on a suitable carrier like paper. The fiber mats thus produced were then impregnated with phenol formaldehyde resin and dried before processing. After drying, the impregnated fiber mats were stacked one over the other for the required thickness and density and pressed into coir boards with a hydraulic hot press (BIS 2004). The prepared samples were then subjected to chemical treatment.

Chemical Treatment

The samples were cleaned to remove any surface impurities. It was then dried in the sun and then subjected to chemical treatment with a waterborne preservative solution containing a mixture of 40% BA and 60% BX (ie 1:1.5) by their weight (Killmann and Fink 1996). Hot and cold bath treatment was employed on the samples. The dry sample is first dipped in boron solution at 100°C for 30 min and then transferred to the cold bath where it is soaked for a further 6 h at about 38°C followed by drying in sunlight until the MC is removed. During hot bath process, the air molecules present in the sample expanded as a result of rapid heating and were driven out, whereas the residual air in the sample contracted during the cold bath process creating a partial vacuum, which allowed the preservative boron to penetrate (Killmann and Fink 1996).

LOI Test

LOI characterizes the ability of the material to burn even at reduced oxygen concentration, especially during fire in buildings where the air supply to the area is very limited (Nadir et al 2011; Tureková et al 2011; Cavdar et al 2014). The LOI of both treated and untreated specimens measuring about 60 × 40 × 12 mm was determined as per ASTM D 2863 in an oxygen index tester model: CSI 178, make: Custom Scientific Instruments Inc, India.

Since air comprises about 20.95% oxygen by volume, any material with an LOI less than this will burn easily in air. Therefore, values below 21 are generally considered as flammable or combustible and a high index is indicative of a material that has lower ignitability and flammability (Nelson 2001). As per ASTM D 2863 the sample has to burn continuously for a period of 180 seconds after ignition to complete the test and obtain LOI value.

Determination of Fire Resistance

Chemically treated samples were prepared and tested along with untreated samples according to IS5509: 2000 for assessing their fire proofing characteristics. To evaluate the extent of fire resistance of samples after the chemical treatment, a combination of three fire resistance tests were carried out as per IS: 1734 (Part 3), 1) flammability test, 2) flame penetration test, and 3) rate of burning test (BIS 2000). The rate of heat energy added during the tests was found to be 752 J/s. A Junkers gas calorimeter was used to find the calorific value of fuel (liquefied petroleum gas) used and a gas flow meter (wet type) was used to record the volume flow rate (ASTM 2016; BIS 1998). The tests were performed at a constant volume flow rate of 28.8 L/h for all the three tests and the calorific value of fuel in the gaseous state was found to be 94 MJ/m^3.

Flammability test. The flammability test was conducted on six chemically treated samples and six untreated samples. The arrangement for the test is shown in Fig 1. Two test specimens measuring about 125 × 125 × 12 mm were held vertical, 15 mm apart, with one held 40 mm higher than the other. Flammability test apparatus was equipped with a Bunsen burner fitted horizontally so that the flame plays against the lower end of the inner face of the lower specimen. The axis of the burner disposed was kept by 22 mm above the lower edge of the lower specimen. The burner end was kept 12 mm away from the face of the specimen. Blue coloured flame by burning LPG was made to ignite the face of the lower specimen which in turn ignited the opposite face of the higher specimen. Time taken for the higher specimen to be ignited after the ignition of lower specimen is recorded. The specimen is deemed to be ignited if the burning is uninterrupted for not less than 50 s (BIS 1983).

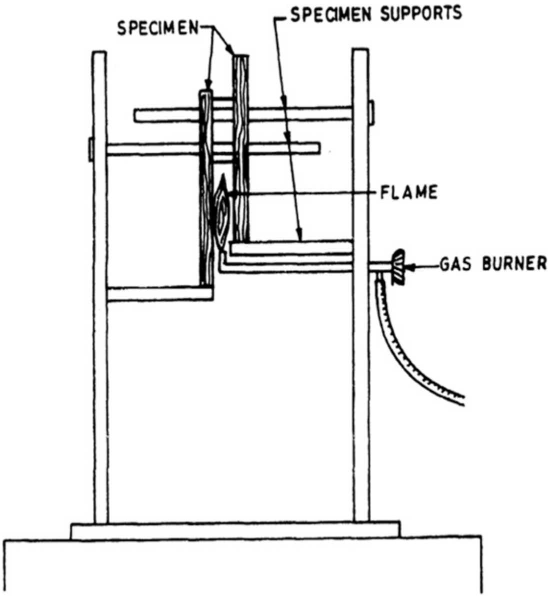

Figure 1. Arrangement for flammability test.

Flame penetration test. Flame penetration test was conducted on three chemically treated and three untreated samples measuring about 125 × 125 × 12 mm. The arrangement for flame penetration test is shown in Fig 2. The test specimen was held 50 mm away from the nozzle of a blowpipe and the time taken for the flame to penetrate the thickness of the sample was recorded.

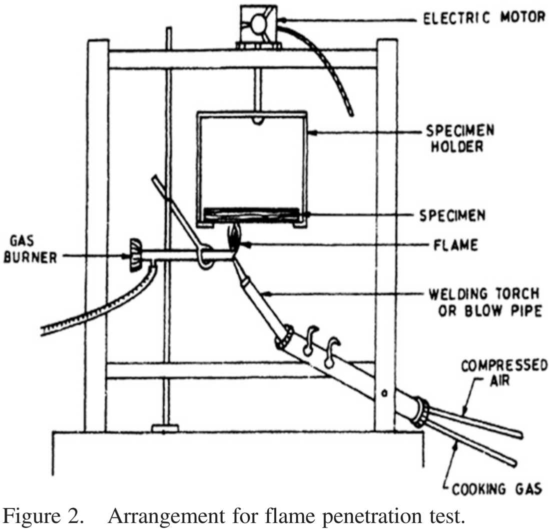

Figure 2. Arrangement for flame penetration test.

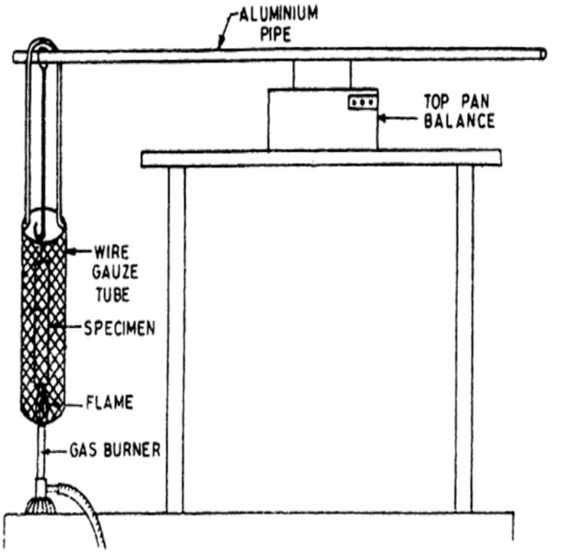

Figure 3. Arrangement for rate of burning test.

Rate of burning test. Rate of burning test was carried out on three chemically treated and three untreated samples measuring 100 × 12.5 × 12 mm. Figure 3 shows the arrangement for rate of burning test. The test specimen was suspended in a fire tube and adjusted for a height of 30 mm from the flame of the burner and was ignited by a blue flame. The time taken for each 10% loss in mass was recorded. The time was recorded for a loss in mass from 30% to 70% for the purpose of comparison.

RESULTS AND DISCUSSION

Any specimen showing LOI values from 24 to 28 are classified as limited fire-resistant materials (ISO 4589: 1996). LOI values of treated samples were found to be 100 which is a better result than untreated samples and indicated its high self-extinguishing nature, whereas the untreated samples showed an LOI of 28 which comes under the group of a material with limited fire resistance. The LOI value of treated samples was approximated as the maximum

Table 1. Consolidated results of flammability, flame penetration, and rate of burning tests.

Sl. no.	Test as per IS 1734 (part 3) 1983	Results (min) Untreated samples	Treated samples	Prescribed value as per IS 5509:2000
1	Flammability (time taken for second specimen to ignite after the first lower specimen ignites)	34	54	Not less than 30 min
2	Flame penetration (time taken for flame penetration from bottom to top surface)	27	38	Not less than 15 t/6 = 30 min (where t is the thickness of sample = 12 mm)
3	Rate of burning (time taken to lose weight from 70% to 30%)	12	44	Not less than 20 min

possible value of 100 as the flame could not sustain for 180 s as stipulated by ASTM D 2863. Even though the treated samples got ignited, there was no flame spread after ignition.

The consolidated results of the fire resistance measurement values are shown in Table 1. Even though the untreated samples exhibited a value of 34 minutes when tested for flammability and conformed to the acceptance parameter of 30 minutes, their performance was enhanced after chemical treatment and found to have a flammability time of 54 minutes. The untreated samples when tested for flame penetration exhibited a value of 27 minutes and failed to meet the minimum requirement of 30 minutes, while treated samples showed a value of 38 minutes which was more than the minimum requirement to qualify as a fire resistant material in this test. Treated samples when tested for rate of burning, showed significant improvements with a value of 44 minutes when compared to untreated samples which gave a low value of 12 minutes against a minimum requirement of 20 minutes to qualify as a fire resistant material. The flammability, flame penetration and rate of burning values for treated samples considerably improved over untreated samples and exhibited relatively higher values than the prescribed minimum requirements for all the three tests.

CONCLUSION

A large variety of fire-retardant chemicals and their treatment methods are being studied and the combination of BX and BA has been found to be effective in many cases. Coir fiber–based medium-density panel boards were subjected to treatment with specially prepared solution of BX and BA for enhancing their fire-retardant properties. The results encourage using medium-density coir boards for more varied applications involving stringent fire safety norms. The study also suggests the possibility of developing a new class of fire-proof coir fiber–based panel boards that can cater to a wide range of applications.

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