Journal of Engineering Science and Technology
Special Issue on SOMCHE 2014 & RSCE 2014 Conference, January (2015) 61 - 72

ENHANCEMENT OF COIR FIBER FIRE RETARDANT PROPERTY

MOHAMMAD HOSSEINI FOULADI[1,*], SATESH NARAYANA NAMASIVAYAM[1], CHONG CHIEN HWA[1], PANG ZONG XIN[1], SIM YENG PENG XIN[1], MASOMEH GHASSEM[2], HAMIDREZA SOHEILI NAJAFABADI[3]

[1]School of Engineering, Taylor's University, 47500 Subang Jaya, Selangor, Malaysia
[2]Faculty of Science and Technology, Universiti Kebangsaan Malaysia, Selangor, Malaysia
[3]School of Industrial Engineering, Iran University of Science and Technology, Tehran, Iran
*Corresponding Author: hosseini@taylors.edu.my

Abstract

Application of porous material in acoustic panel has shown its effectiveness to control noise in term of sound absorption. Optimizing synthetic fiber as resource in current market contributed several issues related to the depletion of environment. Hence, engineer has turned to natural fiber from agriculture waste as alternative strategic solution. Despite having certain beneficial properties in acoustical field, to fulfill the building standard, property of fire retardant are yet to be implemented. This study has focused on three potential fire-retarding chemicals on coir fiber, namely, Di-Ammonium Phosphate (DAP), Borax and urea. Vertical burning experiment was executed based on standard of ASTM E69–02 (Standard Test Method for Combustible Properties of Treated Wood) using Fire-tube Apparatus prior to chemical treatment. Based on experimental results, DAP, Borax and urea-treated fiber shows mass loss of 6.67%, 7.60% and 9.48% respectively. Compliance with NFPA 704, DAP was shown to exhibit superior ability to retard fire in coir fiber over other additives based on mass loss and low degree of hazards in terms of health, flammability and reactivity. In conclusion, fire retardant chemical like DAP is an essential component to be improved on to bring about the success commercialization of the acoustic panel.

Keywords: Acoustic absorption panel, Fiber, Fire retardant, Chemicals.

1. Introduction

With the advancement of scientific technology into a new era, sound exposures become inevitable in daily life. A widespread of environmental potency that has shown to disrupt the balance of life is termed nuisance or noise pollution. One should not judge the above issue lightly because cumulative, excessive exposure

to high-intensity sound level consequences to sensorineural hearing deficit called Noise-Induced Hearing Loss (NIHL) of which the hearing damage would be permanent. Hence, one vital way of eliminating this hazard is through noise-control equipment called acoustic absorption panel. Strike of incident sound waves onto the surface of acoustic panel gives rise to vibration of air molecules outside and within the fibres' pores. Thus, energy to heat conversion is accomplished through friction [1]. Despite acoustic panel has been employed since the early 90s to provide good sound coverage for pleasing environment, sound-absorbing materials constituent often associated with asbestos, mineral wools and foams have brought about reluctance to consumers. The drawbacks of being non-biodegradable, hazardous and costly thus provoked the study of feasibility of natural fibre as optimal substitution.

Ordinarily, natural fibre is hairlike structures originated from plants and animals, having the advantages of being low-density, economical and eco-friendly. One example of natural fibre that has been vastly-produced in Malaysia is coir fibre, obtained from the fibrous husk of a coconut. Besides having good acoustical properties, stress resistant, bio-degradable and being buoyant, coir also comes cheap and abundant as it is the second largest agricultural product in Malaysia. However, characteristics of natural fibre such as fire retardant and anti-fungus are far more significant issues to be pondered for the applications of acoustic panel in buildings. Coir fibre is made of cellulose fibres having lignin and hemicellulose as the bonding material. Thus, being a lignocellulosic material, it catches fire and propagates promptly [2].

Liodarkis et al. [3] had researched on the effectiveness of di-ammonium phosphate (DAP) and ammonium sulphate (AS) on flammability and thermal degradation of forest fuel by implementing spontaneous ignition tests and TG analysis. The outcomes proven that both of the tested fire retardants (DAP and AS) considerably raised the ignition delay time and the pyrolysis mass residue. However, DAP has a better performance compared to AS. Another research done by Liodakis et al. was to investigate the efficiency of phosphorus compounds in retarding the combustion of cellulosic materials. It was postulated that both mono-ammonium phosphate (MAP) and DAP were effective in lowering the combustion rate of cellulosic materials and substantially increased the mass residue [4]. This study obtained a better comprehension of pyrolysis and combustion of cellulosic materials.

On top of that, Levan and Tran have studied on the role of boron compounds as fire retardants in wood. Different loading levels of borox-boric acid were applied to clearwood and plywood specimens and results deduced that a loading level of more than 7.5% add-on by weight of boron compounds conformed the ASTM E84 of class I [5]. The studies executed by Khidir et al. [2] have attested that the application of urea-diammonium phosphate as flame retardant for coir fiber was effective and the mass residue was increased.

As declared in the Uniform Buildings By-Laws 1984, it is imperative for the acoustic panels to comply with the fire resistance requirement of building regulation for applications in high rise buildings [6]. Fire retardant chemicals have been an invisible yet essential elements in most of the innovations due to its ability to diminish the spread of fire and delay the combustion process, conforming the required standard of fire. Liodarkis et al. [7] has mentioned that phosphorus, chlorine, antimony, boron, bromine, and nitrogen are the major

chemical elements responsible for fire retardancy. In accordance to this statement, urea, DAP and Borax have been chosen to be used in the enhancement of fire retardant property of coir fibres.

Nagieb et al. [8], who previously studied on the fire retardancy of Borax with three different concentrations, 0.1%, 0.5% and 5%, has postulated that the latter concentration was the best. Similar studies on the effect of DAP on laminated veneer lumber with melamine-urea-formaldehyde (MUF) adhesive showed that a concentration of 5% of DAP had the best performance [9]. On the other hand, the fire retardancy of urea itself will be figured out in this research since it is often being used in a mixture with different fire retardant chemicals. Henceforth, a concentration of 5% has been selected in preparing the chemical solutions of urea, Borax and DAP in order to perform the chemical treatment of coir fiber.

The growing demands of biodegradable and sustainable raw materials for most of the industrial products have encouraged the manufacturers and engineers to seek alternative resources for a healthy and more eco-friendly environment. Natural fiber, of which is easily adaptable to a variety of applications and possesses good acoustical properties have been chosen as a substitution for the synthetic fiber in acoustic absorption panel. With the aim of reducing the fire risks and contributing to a substantial refinement in living quality, this research was proposed to enhance the fire retardant property of natural coir fiber in acoustic absorption panel by treatment of fire retardant addictives. Flame retardants have enabled the usage of natural raw materials which have evident environmental and sustainability benefits over man-made materials while assuring the accomplishment of fire standard by the materials.

2. Apparatus and Material

2.1. Preparation of coir fiber

Coir fibers are of great importance in the agricultural industry in Malaysia and they have attracted substantial attention as alternative renewable resources in various applications. The coir fibers used in this research were purchased from Leong Nursery, Sungai Buloh, Malaysia. No specifications were stated regarding the physical characteristics of coir fibers such as staple length, diameter, density and processing conditions. The specimen used in this experiment was prepared by twisting the coir fibers into rope shape with a weight of 25.0 ± 1.0 g (Fig. 1).

Fig. 1. The rope-shaped specimen.

2.2. Preparation of chemicals

Three outstanding chemicals, as shown in Table 1, were selected based on their fire retardant abilities, degree of hazards against the health and reactivity in order to accomplish chemical treatment for coir fibers. These chemicals were purchased from Merck. Sdn. Bhd, Bandar Sunway, Malaysia. These chemicals are DAP, Borax and urea and one litre of each chemical solution was prepared.

Table 1. Details of chemicals.

Chemicals	Chemical Formula	Molar Mass [g/mol]	Concentration [M]	Mass in 1L solution [g]
Urea	$NH_2CO.NH_2$	60.06	0.05	3.003
di-ammonium Hydrogen Phosphate (DAP)	$(NH_4)_2HPO_4$	132.06	0.05	6.603
di-sodium Tetraborate (Borax)	$Na_2B_4O_7.10H_2O$	381.37	0.05	19.0685

2.3. Preparation of fire-tube apparatus

A modified fire-tube apparatus in accordance with ASTM E69-02 was peculiarly constructed for use in vertical burning test. The dimension of the apparatus is shown in Fig. 2.

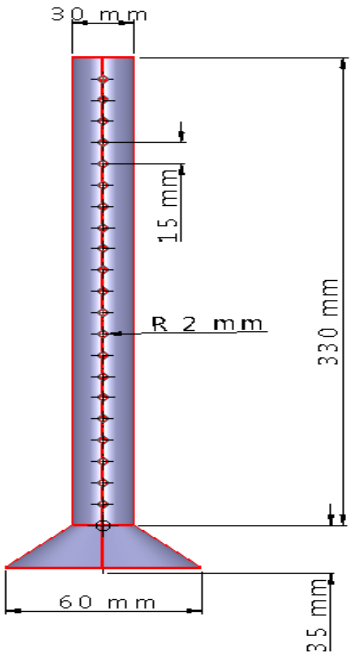

Fig. 2. Dimension of fire-tube apparatus.

3. Methodology

3.1. Chemical treatment

The prepared specimen was treated with chemicals at the room conditions. At every 10 minutes, the specimen was removed from the chemicals and allowed to settle down for 3 minutes. Subsequently, the weight of each specimen was weighed / measured and recorded. This process was repeated until the specimen reaches an equilibrium level, in other words, no change/ increment in weight has been observed.

3.2. Bone dry weight

Bone dry weight is stated as the weight without a trace of moisture. In order to determine the bone dry weight of the specimen, it was dried in the oven (Protech, Model: FAC-350) under constant temperature of 105°C for 24 hours (AOAC,1990) [10]. The final weight of the specimen was weighed/ measured and recorded.

3.3. Drying kinetic

The treated specimen was dried in oven under constant temperature of 60°C [2]. The weight of the specimen was measured and recorded at 15 minutes interval until no increment in weight is observed. By combining the results for all three chemicals, a graph of drying rate against moisture content which is well known as drying kinetic was plotted to give a better view of the outcomes.

3.4. Moisture content

The moisture content of the specimen was maintained at 7±3 weight % throughout the experiment. It was calculated as follows:

$$\text{Moisture Content}(\%) = \frac{\text{Drying Kinetic Weight} - \text{Bone Dry Weight}}{\text{Bone Dry Weight}} \text{x } 100. \quad (1)$$

3.5. Vertical burning test

The test method was in accord with ASTM E69-02 Standard Test Method for Combustible Properties of Treated Wood by the Fire-Tube Apparatus. The weight of the ovendry test specimen was diminished to 15g beforehand and it was then hung in the fire-tube apparatus. Thereafter, the Bunsen burner was placed beneath the fire-tube apparatus, so that the top of the burner is 6cm below it. The flame of the burner was regulated further to give a blue flame of approximately 4cm in height. The flame was applied to the test sample for a duration of 4 minutes and then it was removed from the fire-tube apparatus. The percentage loss of mass experienced by the test specimen was measured and recorded at half minute interval. The equation of percentage loss in mass is given as follow:

$$\% \, Mass \; loss = \frac{M_i - M_f}{M_i} \times 10 \quad (2)$$

where M_i = initial mass, g and M_f =final mass, g.

All figures especially graphs must be clear. Use different line patterns/shapes instead of different line colours as the hardcopy if printed, will be in black and white. All single figures should be "In Line with Text". All tables should have no "Text Wrapping". Format of references must be **strictly** adhered to the examples shown below.

4. Results and Discussions

4.1. Chemical treatment

Figure 3 shows the increment in mass of fibre against the dipping time of all three chemicals for a period of 210 minutes. It is observed from the graph, it is notable that a rapid absorption occurred at the first 15 minutes when the 25 grams specimen was dipped into the chemical solution.

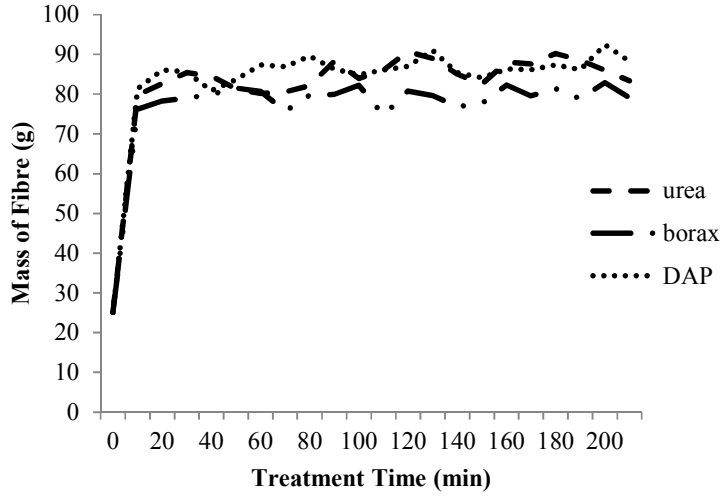

Fig. 3. Mass of fiber against treatment time for urea, Borax and DAP with 5% concentration under dry bulb temperature of 26ºC and humidity ratio of 17.

This phenomenon is because initially the coir fiber is dry and pore of the fiber are empty. Therefore, rapid absorption is allow to take place when coir fiber treated with chemical. In the first 15 minute, the slop for coir fiber treated with DAP is about 5.63, followed by urea and borax, with the slope of 5.47 and 5.12. From 15 minutes onwards up to 210 minutes, the mass of fiber fluctuated within the range of 70 to 90 grams. This phenomenon elucidates that the equilibrium condition is reached since no obvious increment in mass of fiber was achieved. Of all three chemicals, DAP has the greatest chemical absorption in term of weight along the treatment process from zero until 200 minutes. The maximum weight of coir fibre treated with DAP is about 92 grams at 200 minute, followed by urea and Borax, with the values of maximum mass of fiber of 90 grams and 82 grams respectively. Thus DAP-treated fiber was predicted to have the strongest fire retardant property since its absorption rate was the highest. This prediction was verified by later experiment, which is the vertical burning test.

4.2. Drying

The liquid diffusion theory states that the diffusion of liquid occurs when there is a concentration difference between the surface and the inner parts of the solid. Basically, drying via evaporation process from the exposed surface of solid involves the moisture movement from the depths of the solid to the surface [11].

In accordance with ASTM E69-02, it is necessary to maintain the moisture content of the specimen at 7± 3 weight% of the dry material during the execution of vertical burning test. Equation (1) was used to calculate the moisture content of all specimens. The bone dry weight of coir fiber was obtained as 21.11g after 24 hours of drying while the drying time for urea, Borax and DAP were 300 minutes, 375 minutes and 360 minutes respectively.

The drying kinetics of the chemically treated coir fibres is shown in Fig. 4. The drying process was divided into three sections; initial transient period, first falling-rate period (F1) and second falling-rate period (F2).

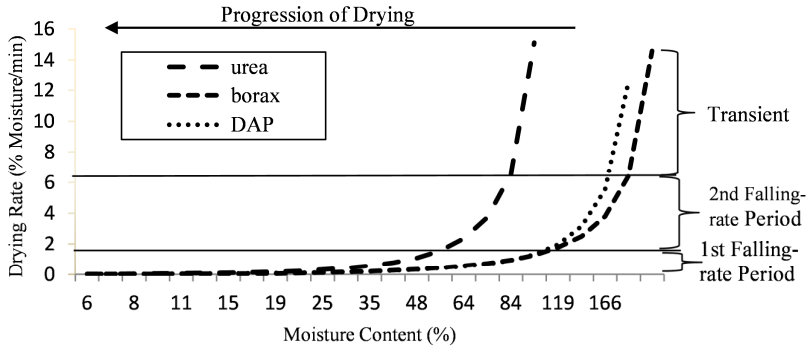

Fig. 4. Drying kinetics of urea, borax and DAP treated fibers.

The initial transient period merely lasted for 15 minutes, where the temperature of the treated coir fiber was continuously increased until thermal equilibrium was attained. The second region describes the first falling rate period. And, the point that marks the beginning of the first falling rate is at the critical free moisture content. At this point, a continuous film of water was difficult to maintain as a result of insufficient amount of water on the surface of the coir fibers. The wetted area was constantly dried up until complete dryness on the surface was achieved. The drying process was then proceed to the second falling rate period where the evaporation plane was subsided from the surface. Vaporized water was then allowed to move through the solid to the air stream due to heat transfer from the solid to the zone of vaporization. Usually, drying process in the falling rate period is long but only small amount of moisture will be removed [11].

4.3. Vertical burning test

Fire resistance is a crucial property of the acoustic absorption panel in terms of fire safety. With the aim of examining the flame resistance of fire retardant materials, the vertical burning test was invented and being widely used to determine various

parameters concurrently. The vertical burning test, being one of the flammability tests, is capable of measuring and anatomizing the ignition time and optimum temperature to initiate the burning process; the propagation rate; the percentage loss in mass as well as the consequences of removing the flame [12]. In this research, the vertical burning test was executed with the treated specimens to determine the percentage loss in mass, in which emerges to be a measure of the combustibility of the specimens [13]. However, as hot air rises, the specimen, of which hanging vertically in the fire-tube apparatus was allowed to burn at a faster rate [12]

The impact of fire retardant chemicals on mass loss of the specimens throughout the vertical burning test is shown in Fig. 5.

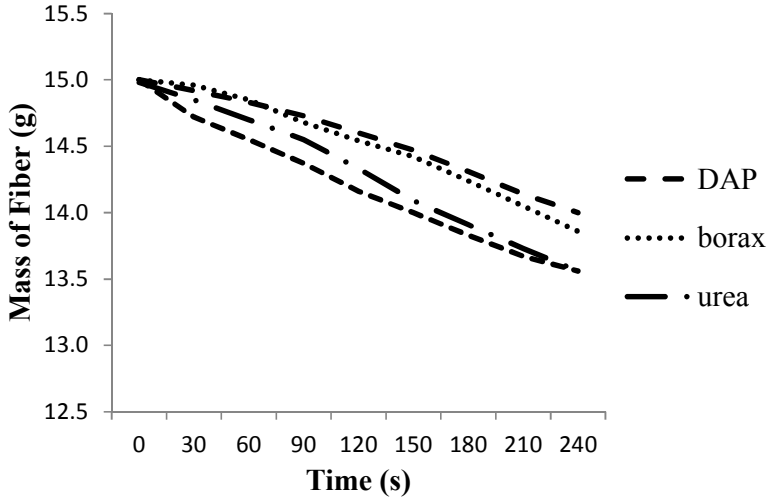

Fig. 5. Changes in mass of fiber in the vertical burning test.

It is notable that the DAP-treated fibers possess the highest mass after combustion process, compared to that of Borax-treated and urea-treated fibers. No remarkable distinction was observed from Fig. 5 between the urea-treated fibers and the untreated fibers, of which serving as a control in this experiment. Numerations from Equation (2) demonstrates that the percentage mass loss of the DAP-treated fibers, with a value of 6.67%, was the lowest among the three chemicals, indicating that DAP itself owns the strongest ability of fire resistance. Meanwhile, the combustion process has reduced the mass of Borax-treated fibers, urea-treated fibers and untreated fibers by 7.60%, 9.48% and 9.60% respectively.

Combustion process is often expressed as to inhibit or even suppress by a flame retardant, however the mode of action of flame retardants depends fully on their nature. The presence of phosphorus based flame retardants phosphorylates the fibers upon fire exposure via thermal decomposition which leads to the formation of phosphorus acids. This chemical action tends to inhibit the production of levoglucosan and expedites the char formation [14, 15]. Also, phosphorus compounds amend the fire resistance by forming a carbon layer on the fibers functions as a physical barrier through dehydrating process [16]. The advantageous

outcomes of phosphorus compounds as fire retardants include less emission of hazardous gases in flames, and less devastation to the environment [17]. Final results of this research have postulated that DAP was the most effectual flame retardant chemical which upholds the fact that phosphorus compounds are able to interfere the combustion process via physical and chemical means.

Apart from DAP, which retards the combustion both physically and chemically, Borax has been utilized to impede the surface flame spread by forming a glassy protective coating on the fibers [18]. This can be accomplished by endothermic reactions, of which Borax decomposes under heat and gives off non-flammable gases like water and carbon dioxide. This inorganic flame retardant interferes with the combustion process via physical action by cooling the fibers, and hence diminishes the evolvement of pyrolysis products. As a result, the impacts of oxygen and heat to the treated fibers were fended off and neglected [16]. Utilization of boron compound as flame retardant addictive not only poses less impacts on mechanical properties of coir fiber, but also have good preservative effectiveness [5].

In comparisons with phosphorus compounds and boron compounds, the nitrogen compounds such as urea are predicted to restrain the combustion process by releasing non-flammable nitrogen gases via decomposition of nitrogen compounds upon fire exposure [19]. Urea, of which functions as a blowing agent, liberates non-flammable gases at temperature lower than that of pyrolysis process. The non-combustible gas tends to dilute the combustion gases released in pyrolysis, thus impeding the flame spread and burning process from taking place. In spite of that, merely slight improvement in fire retardant performance was exhibited by urea-treated fiber compared to that of untreated fiber as insufficient inert nitrogen gas was liberated to dilute the combustion gases [18].

4.4. Comparisons of chemicals

The quotation of price of each chemical (Table 2) was acquired from LGC Scientific Sdn. Bhd., Malaysia for further comparisons of chemicals.

Table 2. Price of chemicals from LGC Scientific Sdn. Bhd. on 15/09/2011.

Chemicals	Mass (g)	Price
Borax (di-sodium tetraborate)	500	RM 48.00
Urea	500	RM 44.00
DAP	500	RM 45.00

The prices of chemicals range from RM44 to RM48 and hence no significant difference in price was shown. However, from the vertical burning test, DAP which consumes dosage of 5% exhibits a distinctive result among Borax and urea with the same concentration. Urea, being the cheapest, yet shows the highest percentage loss in weight in the vertical burning test. In contrast, DAP gives the best results onto the coir fibers yet costing only RM45 for 500g which is average in price compared to the rest.

On the other hand, a colour coded, numerical standard, namely NFPA 704 was developed by the National Fire Protection Association (NFPA) to denote health, flammability and reactivity hazards of chemicals which enables easy

identification of risks posed by a material. As shown from Table 3, the diamond-shaped NFPA label is subdivided into four categories as follows: blue for health, red for flammability, yellow for reactivity and white for additional information regarding unique hazards. Severity of the hazard is conveyed by a rating range from 0 indicating the least hazardous to 4 representing the most hazardous [20]. The rating was voted by 60,000 volunteers in the committee and has been accredited by American National Standards Institute (ANSI).

Table 3. Types of chemical and hazard.

Chemicals	Types of Hazard			NFPA Label
	Health	Flammability	Reactivity	
Borax	1	0	0	
DAP	1	0	0	
Urea	2	1	0	

In accordance with the NFPA diamond, the blue section for the health hazards clarifies the types of possible injuries of exposure. Despite a health rating of "1" was appointed to Borax and DAP, their exposures induce irritation with only minor residual injury [20]. Urea on the other hand threatens the blood and cardiovascular system while organs damage might befall as a result of prolonged exposure. Therefore a health rating of "2" was assigned to urea [21].

Meanwhile, flammability hazard as depicted by the red diamond describes the potential of a material to ignite and burn. Both DAP and Borax possess a numerical rating of "0", elucidating that they do not burn in air or exhibit flash point [22, 23]. On the contrary, a rating of "1" was assigned to urea as it may be combustible at high temperature. Substances such as carbon dioxides and nitrogen oxides might form due to combustion of urea [21].

The yellow diamond emerging on the right side of the label conveys information about reactivity or stability. This rating deals with the susceptibility of a chemical to emit energy if it is heated, jarred or shocked [20]. Borax, DAP and urea by themselves are stable and do not react violently with water. Thus, their reactivity ratings assigned by the NFPA are "0" indicating that they do not detonate upon exposure to fire.

Considering all the properties and prices of chemicals DAP not only has a fair price, but also poses low degree of hazards in terms of health, flammability and reactivity in accordance with NFPA 704. Therefore, DAP was opted as the best and well-rounded chemical among urea and Borax.

5. Conclusion

With the goals of enhancing the characteristics of coir fiber and meeting the safety demands, this study was executed to investigate the impacts of treating coir fiber with flame retardant addictives such as DAP, Borax and urea for the production of acoustic absorption panels. Combustibility of the chemically treated coir fiber was evaluated by the vertical burning test. Of all three chemicals used, DAP-treated fiber has exhibited superior fire retardant property with the percentage mass loss of 6.67%, followed up by Borax-treated fiber and urea-treated fiber with values of 7.60% and 9.48%. Overall, fire retardant addictive such as DAP, of which having good fire retardant performance and negligible impacts on environment and human's health, allows engineers to consider natural fiber as a substitute for synthetic fiber in acoustic absorption panel, which would otherwise have been neglected due to its high risks of fire. Natural fiber is acting a key role in the emerging green technology since its intrinsic properties such as outstanding mechanical strength, low density and low cost have attracted substantial attentions from various industries. It would be fruitful to pursue further research about the potential of natural fiber as an alternative resource besides raising global awareness of the importance of natural fiber to consumers and the environment with the aims of reducing carbon emissions and minimizing waste materials.

References

1. Kannan, J. (2005). *Acoustical absorptive properties of nonwovens*. M.Sc. Thesis, North Carolina State University, Raleigh, N.C.
2. Khidir, E.A.; Nor, M.J.M.; Zulkifli, R.; Tahir, M.F.M.; and Leman, Z.A. (2011). Studies on flame retardants on Malaysia coir fiber. *Proceedings of the International Conference on Advanced Science, Engineering and Information Technology*, 541-544.
3. Liodakis, S.; Bakirtzis, D.; and Dimitrakopoulos, A.P. (2003). Autoignition and thermogravimetric analysis of forest species treated with fire retardants. *Thermochimica Acta*, 399(1-2), 31-42.
4. Liodakis, S.; Fetsis, I.K.; and Agiovlasitis, I.P. (2009). The fire retarding effect of inorganic phosphorus compounds on the combustion of cellulosic materials. *Journal of Thermal Analysis & Calorimetry*, 98(1), 285-291.
5. LeVan, S.L.; and Tran, H.C. (2009). The role of boron in flame-retardant treatments. In the proceedings of 1st *International Conference on Wood Protection with Diffusible Preservatives:* 47355, 39-41, Nashville, TN. Madison, WI: Forest Products Research Society.
6. Uniform Building By-Laws 1984, MDC, Kuala Lumpur. (2006), 1-174.
7. Liodakis, S.; Vorisis, D.; and Agiovlasitis, I.P. (2006). Testing the retardancy effect of various inorganic chemicals on smoldering combustion of Pinus halepensis needles. *Thermochimica Acta,* 444(2), 157-165.

8. Nagieb, Z.A.; Nassar, M.A.; and El-Meligy, M.G. (2011). Effect of addition of boric acid and borax on fire-retardant and mechanical properties of urea formaldehyde saw dust composites. *International Journal of Carbohydrate Chemistry,* Volume 2011, Article 146763, 1-6.
9. Sahin Kol, H.; Ozbay, G.; Köse, L.; and Kurt, S. (2010). Effect of some impregnation of chemicals on combustion characteristics of laminated veneer lumber (LVL) produced with oak and poplar veneer. *BioResources*, 5(1), 70-80.
10. Helrich, K. (1990). *AOAC Official methods of analysis*, Volume 1 (15th Ed.). Association of Official Analytical Chemists, Inc. AOAC, Arlington, VA.
11. Geankoplis, C.J. (2003). *Transport processes and separation process principles*. (4th Ed.) Prentice Hall.
12. Bhatt, P. (2000). Flammability of cabin crew uniforms. University of New South Wales Aviation Air Transport Safety II, AVIA 3710. Retrieved August 17, 2014, from http://www.asasi.org/apcswg/papers/flammability.pdf.
13. ASTM E 69-02 (2002). American Society for Testing and Materials. *Standard test method for combustible properties of treated wool by the fire-tube apparatus*.
14. Mercimek, H. (2010). *Effect of chemicals and binders on the durability of flame retardant treated cotton nonwovens*. M.Sc. thesis, Polymer Engineering, University of Tennessee, Knoxville, Tennessee, 21-26.
15. Bisschoff, K.; and Focke, W.W. (2000). *Oxygenated hydrocarbon compounds as flame retardants for polyester fabric*. University of Pretoria, Pretoria, South Africa, 13-44.
16. Troitzsch, J.H. (1998). Overview of flame retardants. *Chemistry Today*, 16, 1-19.
17. Mostashari, S.M.; and Fayyaz, F. (2007). A combination of red phosphorus-zinc chloride for flame-retardancy of a cotton fabric. *International Journal of Polymeric Materials*, 57(2), 125-131.
18. Levan, S.L. (1984). *Chemistry of fire retardancy*. Washington, DC, American Chemical Society, 207, 531-574.
19. EFRA (2010). Flame retardants for a changing society. Available online: http://www.ceficefra.com/Content/Default.asp?PageID=116.
20. National Fire Protection Association (2007). *Standard system for the identification of the hazards of materials for emergency response*. NFPA 704, Quincy, MA., 4-9.
21. Urea Material Safety Data Sheets MSDS (2012). Sciencelab.com, Inc., Houston, Texas, 1-5.
22. Di-Ammonium Phosphate Material Safety Data Sheets MSDS (2010). Mosaic, Lithia, Florida, 1-7.
23. Sodium Borate (Borax, fused) Material Safety Data Sheets MSDS (2010). Sciencelab.com, Inc., Houston, Texas, 1-5.