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Effect of Varying Proportions of Fire Retardant to the Flammability Characteristic of Wood Plastic Composite

***[1]Aina K.S, [2]Oluyege, A.O, [2]Fuwape, J.A and [3]Varadarajulu, K.C**

**[1]Department of Forest Products Development and Utilization, Forestry Research Institute of Nigeria, P.M.B 5054, Jericho Estate, Ibadan, Oyo State*

[2]Forestry and Wood Technology Department, Federal University of Technology, Akure, P.O.Box 704, Akure, Ondo State.

[3]CENTEC division, Indian Plywood Industries Research and Training Institute, P.B. no 2273, Tumkur road, Bangalore – 560022, India

****Corresponding Author:** Aina K.S, Department of Forest Products Development and Utilization, Forestry Research Institute of Nigeria, P.M.B 5054, Jericho Estate, Ibadan, Oyo State*

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ABSTRACT

Fire retardance of wood plastic composites (WPC) made from Eucalyptus camadulensis was investigated in this study. Powder form of Eucalyptus camadulensis, Virgin high density polyethylene, Poly [ethylene-Co-glycidyl] methacrylate (GMAPE) and Aluminium trihydrate [Al(OH)3] also known as ATH were employed for the production of treated WPC. Treated WPC samples were produced at varying proportions of fire retardant from 0, 5, 10, 20, 30 and 40 %. Time of burning, rate of burning, smoke density index and smoke area covered were investigated on the treated WPCs. There was significant difference among the treatments examined at 5% level of probability. It was observed that WPC treated with ATH at higher proportions of 30 – 40 % performed better in fire retardance than the WPC treated with ATH at lower proportions. The results suggested that WPC treated with ATH at 30 – 40 % were less susceptible to fire damage than others and this could form a baseline guide for the production of fire proof WPC products.

Keywords: *Aluminium, Eucalyptus, Density, Polyethylene, Smoke.*

INTRODUCTION

Presently, the manufacturers of WPCs are facing the problems of fire intolerant in their products; several commercial WPCs are being manufactured for the residential construction industry, primarily as lumber for decking, siding, roof tiles and window profiles. WPCs manufacturers have also introducing new applications for the furniture items industry. To expand into the residential construction and furniture industry, it is critical to understand the fire performance of WPCs, and in some cases to improve on it [18]. Studies conducted on commercial samples show that WPC lumber performs better than unfilled plastic lumber in fire tests [14 and 7], but worse than solid wood [22].

Typically, the composition of the commercial lumber is proprietary while type of plastic matrix used and wood content may be known, but the additive type and content is not. Because some WPCs are used in building applications where fire performance standards must be met, it can be assumed that flame retardants have been used in some commercially available WPC. The number of studies conducted on manufactured WPC (where the fire-retardant type and concentration is known) and limited [18]. Some studies shows that fire performance of WPC can be improved by adding fire retardants and together with wood fiber into polyethylene. Stark *et al.*, [18] reported in his findings that addition of more wood fiber to polymer lowered the Heat Release Rate (HRR) peak of WPC. This may be attributed to some specific wood species or polymer since the research on fire performance of WPC was still limited, the information about the fire retardants and their reaction with various wood species are still unknown. Most importantly, the problems associated with fires during outbreaks are the smoke and toxic gases they produce particularly when plastic-containing materials are burning.

Smoke emitted gases, solid particles, droplets of liquids, including water and molten plastic. Smoke is harmful to health, obscures vision, causes choking and sometimes death. Generally, two approaches are used to deal with the smoke problem: limit smoke production or control the smoke produced. The smoke flow control is most often a factor in the design and construction of large or tall buildings. So therefore, this study seeks to investigate the effect of varying proportion of fire retardant to Time and Rate of burning, Smoke Area Covered and Smoke Density Index of wood plastic composites.

MATERIALS AND METHODS

Eucalyptus camadulensis wood employed in this study was supplied and milled to wood particle using hammer milling machine. The fresh wood particle was further milled into wood powder using pulverised machine. Wood powder was thoroughly screened with wire mesh of size 60 in 250µm (0.25mm) to obtain homogenous wood flour. Wood flour was thereafter oven dried at temperature of 103°C for 24 h to attain 2-3% moisture content. Virgin high density polyethylene (HDPE) of 0.965 g/cm^3 at melt flow index of (0.2 – 0.3) 10/min and a coupling agent Poly (ethylene-Co-glycidyl) methacrylate (GMAPE) employed in this study was supplied by Reliance Industries limited, Nagothane - 402125, Taluka - Roha, Raigad, Mahorashtra, India. This powder form of Al $[OH]_3$ is also known as [ATH] of SH 300 type, whitish in colour with bulk density of 0.9 g/cm^3 was employed and supplied by Chandan Chemicals and Industrial Corporation at 62/A1, Industrial Suburb, AP School Road, Yeshwanthpur, Bangalore, India. The main applications of the ATH chemical are for flame retardant, smoke suppressor, fillers in resins and also for pigment in polymer industries.

Composites Preparation and Production

Appropriate quantities of Eucalyptus spp flour with plastic, coupled agent and fire retardant at varied proportions of (0, 5, 10, 20, 30 and 40 %) were thoroughly oven dried at temperature of 65°C for 24 hrs to remove excess moisture gained during packaging and handling. This treatment was carried out to maintain the actual moisture content to appropriate 2% before feeding into in extrusion machine. The mixture of these particles at varying proportions were fed into Co-rotating twin-screw extruder with screws diameter of 28 mm which consist of four extruding zones (1, 2, 3, and zone 4) for mixing particles at the screw speed of 165 rpm. Two hoppers were incorporated into the machine for feeding wood flour and plastic mixed with ATH and GMAPE. Stranded treated WPCs were produced at the temperature range of 165°C - 180°C. The extruded and stranded WPCs pass through water bath at temperature of 26°C to cool and solidified the molten WPCs. The solidified WPCs were pelletized using polymer pelletizing machine. Treated WPC samples were produced after oven dried the wet pelletized WPCs at temperature of 65°C for 24 hrs and fed into injection molding machine at temperature of 185°C.

Properties Determination

The density of the treated WPC was determined based on the oven-dry weight and volume. Density is the ratio of the mass of a test piece to its volume and calculated to the nearest 0.01g/cm^3 in accordance with ASTM D [4]. The formula for density is stated below;

$$\varepsilon = m/v \tag{1}$$

Where ε is the density in (g/cm^3), m is the mass in (g) and V is the volume in (cm^3). The test pieces were square in shape with sides measuring 100 mm. The specimens were conditioned to a constant mass in an atmosphere of a relative humidity of 65 ± 5% and a temperature of 20 ± 2°C.

Rate of burning/Time of burning

The Rate and time of burning for the treated WPCs of dimensional size of 125 mm x 13 mm x 6.3 mm (thickness) were subjected to flame exposure. Treated WPC Specimen was clamped vertically in such that the other end of the specimen exposed to flame at temperature of 24.8°C. Specific gage mark was drawn across the specimen at 75 mm from one end; if the specimen burns to the 100 mm mark from the ignited end, time of burning to 75 mm and average burning rate (mm/min) are reported. If the specimen does not burn 100 mm, time and extent of burning are measured and reported along with a pattern of burning and/or flame self-extinguishing. The results of the test are intended to serve as a preliminary indication to WPCs fire resistance capability in accordance with ASTM D [2]. Rate and time of burning were calculated from these formulae below;

$$\text{Rate and Time of burning} = \sum (l - l1) \text{ and } \sum (t - t1) \tag{2}$$

Where; l is the length (mm) and t is the time taken (min) by the specimen to burn.

Smoke Density Index

Smoke Density Index (SDI) and Smoke Area Covered (SAC) were carried by subjecting the treated WPC Specimens of dimensional size of 75 mm x 75 mm x 25 mm by thickness into Smoke optical machine (S.A Associates) available at Indian Plywood Industries for Research and Training Institute, Bangalore, India. Smoke optical machine uses electrically heated radian energy source of a specified power. Treated WPC Specimens were pre-dried for 24 h at 60°C (140°F) and conditioned to constant weight at ambient temperature before testing. The test specimens are exposed to the flaming conditions within a closed 18-ft 3 chamber, equipped with a photometric system. The test was based on the decrease of optical density of a light beam by smoke accumulated within a closed chamber due to flaming pyrolytic decomposition and combustion. The machine was set to 5.72 DC Volts and 0.0 % absorbance at maximum time taken of 9 minutes. This flaming exposure of the test conducted using a specified flame burner at temperature of 24.8°C is in accordance with ASTM E [3]. The ASTM test describes calculations to obtain specific optical density of smoke as;

Smoke Density Index = V/LA [Log 10 (100 %/T)] (3)

Where V is the volume of the smoke chamber, L is length of the light path, A is the surface area of the specimen and T is the time taken. Photometric was set to full scale correction at 977.52mV (97%) of absorbent with pressure of 10 kg/cm2 to determine the SDI and SAC.

The methods used in processing the test data obtained for the appraisal of the study variables incorporated in this study included graphical analysis and analysis of variance. The graphical analysis provides an easy means of observing the trend of any relationship which might exist between the study variable and a specific board property. All statistical analyses was conducted using completely randomized design and the separations of means were carried out using Duncan's Multiple Range Test [DMRT] at 5 % level of probability.

Results and Discussion

The density of the composites ranges from 0.72 to 0.83 g/cm^3. The observation in this study shows that density of the composite increased with decrease in proportion of polymer in formulation (fig 1). As the proportion of the filler increases, it resulted in high viscosity of the molten plastics and when pressure was exerted, the existing free spaces within the matrix reduces to give better compatibility between the particles. It implies that polymer proportion to fire retardant proportion in WPC has influence on density of composite produced. This observation is in agreement with previous studies of composite treated with or without coupling agents [17, 20, 13, 22 and 16]. The same observation was recorded when treated with varied proportions of fire retardant, the densities increased as the proportion of ATH increases in the composition, gradual increase of ATH to the molten plastics makes the composite to have very high viscosity. So therefore, high temperature and pressure was required to force the molten composite to fill the available space, this conditions increases the rate of plastic-wood interaction bond in the matrix.

The mean values of fire resistance properties carried out on treated WPCs were presented in Table 1. The mean values obtained range from 0.44 to 3.73 min, 19.64 to 118.22 mm/min, 55.84 to 93.50 mV and 31.72 to 62.32 % for Time of burning, Rate of burning, SDI and SAC respectively. The densities of WPCs treated with fire retardant in this study were lower to previous finding of [1] and [6]. The density of the WPCs increased with increase in varying proportion of ATH, this might be due to the chemical interaction between the particles that permit better compatibility. The result obtained for densities were consistent with some previous studies with coupled treated composites [13, 22 and 16]. In the values obtained for the Time and Rate of burning in this study are in agreement with previous findings of [10], the varying proportions of ATH treatment applied to WPC were significantly different at 5 % level of probability for Time, Rate of burning, SDI and SAC. This significantly implies that the addition of ATH chemical positively affect the Time and Rate of burning of treated WPCs. This study could also implies that heat releases rate in higher polymer increases than when wood fiber increasing to polymer concentration in composites, this observations agrees with previous finding of [18]. The Time and Rate of burning is also related to flame spread index which shows that the faster or further the flame travel down the specimen. It was observed in this study that untreated WPC specimens at 0 % had the high flame spread index; this might be due to the higher proportion of polymer at 60 to

40 of wood (w/w). This agrees with previous findings that show that WPC with more polymers has high flame spread index than WPC with more wood [7] and [12].

Following increased in the proportion of ATH to polymer, increase and decrease was observed in Time and Rate of burning (Fig 2 and 3). It was also observed in Fig 2 and 3, that plastic composite treated with ATH at 40 % performed better than WPCs treated with ATH at varying proportion of 0 – 30% for Time and Rate of burning. But when compared with the WPC treated with ATH at 40%, it performed better than the plastic composite treated with 40 % ATH, this might be due to the chemical reaction that occurs during the flaming treatment, when exposed to flame at a certain temperature of 280^0C, the incorporated ATH release H2O that slows down the movement of flames in the composites. This observation was similar to other previous findings in [9, 10 and 21] that reported that effectiveness of ATH begins within the range of 40 to 50 % in plastic composite.

The SDI and SAC of untreated WPC at 0% was relatively higher than WPC treated with ATH, irrespective of untreated WPC at 0% and the treated at 5 – 20 %, the SDI and SAC remain unchanged (Fig 4 and 5). The values obtained in this study for SDI and SAC are in agreement with previous finding of [10]. ATH being used as a smoke suppressant in polymer products also proves useful to wood based products. Addition of fire retardant filler (ATH) into WPC significantly influenced the SDI and SAC at varied proportions. It was observed that as the addition of ATH to polymer proportion increases in the composite from 5 to 40 %., SDI decreased by 18.4 % and SAC by 31.72 %. In Fig 4 and 5, the SDI for the WPC treated with varying proportion of ATH attains maximum peak values at exactly 6:00 min and further increase in the period of exposure leads to gradual falling. The values obtained for SDI of WPC treated with varying proportion of fire retardant decreased from 0 to 30%.

This observation could be attributed to the action of ATH in WPC, ATH acts by preventing oxygen from getting to the flammable gas that can be ignited in the plastic. The free carbon that can react with oxygen to give CO and CO 2 are prevented by ATH and as the proportion of ATH increases, the more the oxygen is being protected from free carbon, and less smoke is being emitted during burning. Klyosov [10] noted that plastic composite industry generally considers SDI above 450 as hazardous and not acceptable particularly for indoor applications. The values for SDI obtained in this study for WPC treated with varying proportion of ATH were lower when compared to the values reported by [10] for the SDI of ¾ inch panel of red Oak flooring product and wood based panels. However, the values for the SDI for WPC treated with varying proportion of ATH in this study were higher than those reported for asbestos cement based board [11]. Klyosov [10] reported that ATH is preferable to other inert fillers which include calcium carbonate, talc, clay, glass fiber. These inert fillers were reported to also slow down the flame spread of polymer composite by removing fuel for flame propagation or slow heat generation. The dilutions of flammable gases by these inert fillers are very high at 825^0C than when compared to 180 - 240^0C of ATH [10].

In separation of mean values carried out using Duncan Multiple Ranged Test (DMRT) at 0.05 % level of probability. The results showed that there were significant differences among the mean values of the WPCs treated with varying percentage of fire retardant for all the properties tested at ($P \leq 0.05$) level of probability (Table 2). Composites with the same alphabetical letter were not significantly different to each other but significantly different to different alphabetical letters (Table 2).

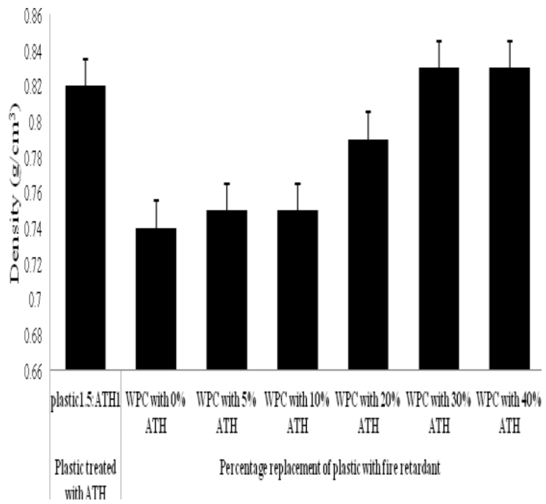

Figure1. *Effect of fire retardant on density of treated wood plastic composites*

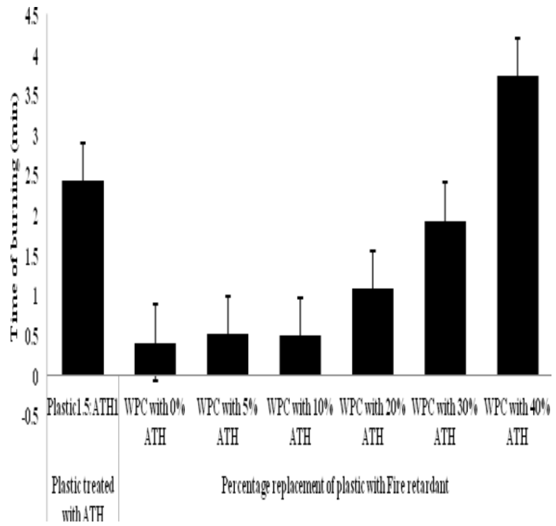

Figure2. *Effect of fire retardant on Time of burning of treated wood plastic composites*

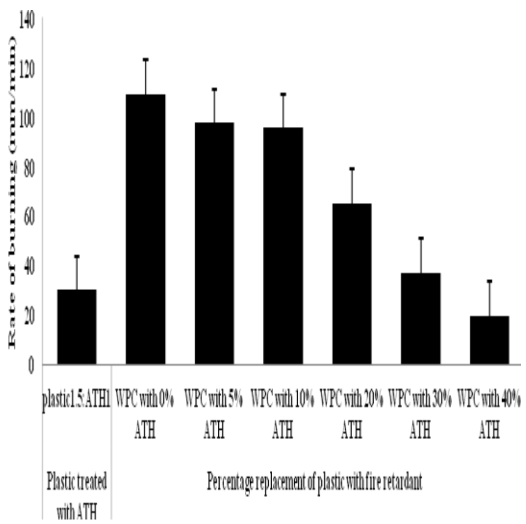

Figure3. *Effect of fire retardant on rate of burning of treated wood plastic composites*

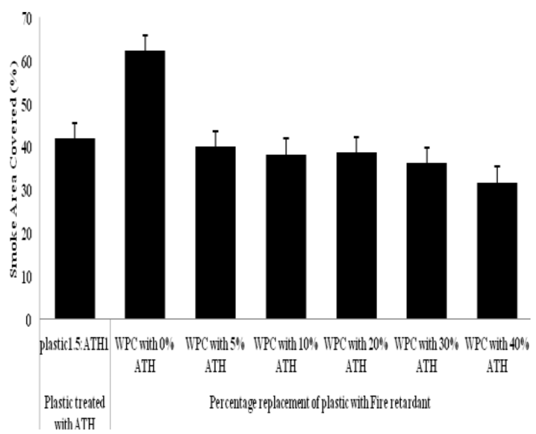

Figure4. *Effect of fire retardant on Smoke Area Covered of treated wood plastic composites*

Table1. *The result of Analysis of variance carried out on fire retardance properties of treated Wood Plastic Composites*

Source of Variance	Df	Time Of Burning		Rate Of Burning		SAC		SDI	
		F-Cal	Sig	F-Cal	Sig	F-Cal	Sig	F-Cal	Sig
Treatments Error	640	405.710	0.000*	480.480	0.000*	8.808E5	0.000*	1.108E3	0.000*
Total	46								

*P≤0.05 mean significantly different at 5% level of probability. * represent significant while ns represent not significant*

Table2. *Result of DMRT at (P < 0.05) level of probability for fire retardance properties of treated Wood Plastic Composites*

Woodplastic Composites With	Density (G/Cm^{-3})	Rate of Burning (Mm/Min)	Time of Burning (Min)	SDI (Mv)	SAC (%)
ATH 0 %	0.72	109.13^{e}	0.41^{e}	93.50^{f}	62.32^{e}
ATH 5%	0.75	97.69^{d}	0.51^{e}	60.65^{c}	36.26^{b}
ATH 10%	0.75	95.50^{d}	0.49^{e}	69.67^{e}	38.18^{c}
ATH 20%	0.79	65.05^{c}	1.08^{d}	62.00^{c}	40.01^{d}
ATH 30%	0.83	36.96^{b}	1.93^{c}	64.26^{d}	38.66^{c}
ATH 40%	0.83	19.64^{a}	3.73^{a}	49.48^{a}	31.72^{a}
Plastic 1.5: ATH 1	0.82	30.04^{ab}	2.43^{b}	55.84^{b}	41.94^{d}

Each value is the mean of 5 replicates and the means of different superscript are significantly different at 5% level of probability

SDI = Smoke Density Index, SAC = Smoke Area Covered, ATH = Aluminium trihydrate

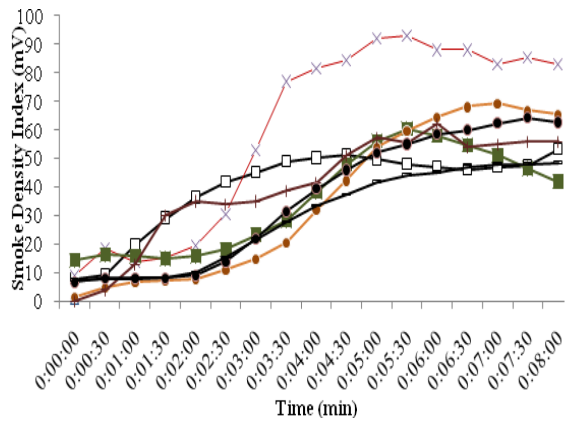

Figure5. *Effect of fire retardant on Smoke density index of treated wood plastic composites*

Conclusion

WPCs were successfully produced at varying proportions of fire retardant. The fire retardance properties of treated WPCs were also investigated. Based on the results findings in this study, the addition of ATH at range proportions of 20 - 40% significantly improved better retardance against fire exposure.

RECOMMENDATIONS

The information provided in this study could form a baseline guide for the production of WPC products that would be useful in manufacturing fire proof ceiling, flooring and wall tiles. It could also be useful for the production of kitchen utensils; handles of spoons, knife, fry-plates and iron pots.

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REFERENCES

[1] Adhikary, B.K (2008): Development of wood flour-recycled polymer composite panels as building material. PhD Thesis in Chemical and Processing Engineering, University of Canterbury, P – 229

[2] ASTM D 635 "Standard Test Method for Rate of Burning and/or Extent and Time of Burning of Plastics in a Horizontal Position"

[3] ASTM E 662 "Standard Test Method for Specific Optical Density of Smoke Generated by Solid Materials"

[4] ASTM D 638-90 (1991): Annual Book of ASTM Standards, Vol. 8.01 American Society of Testing and Materials, Philadelphia, PA.

[5] Chen HC, Chen TY, Hsu CH. (2006): Effects of wood particle size and mixing ratios of HDPE on the properties of the composites. Holz als Roh- und Werkstoff 2006; 64(3):172-77.

[6] Dietenberer, M.A; Grexa, O; White, R.H; Sweet, M and Janssens, M. (1995): Room/Corner Tests of Wall Linins wit 100/300 Kw Burner Proc. Fire and Materials,4tInt. Conference, Interscience Communications Ltd, London 4 (53) 1995

[7] Fabian, T. (2008): Fire testing of deck materials. In Proc. 10th Int. Conf. on Progress in Biofibre Plastic Composites. May 12–13, 2008. Toronto, Canada

[8] Innes, J. A. Innes, M. Wajer, D. Smith, and L. Granada (2006): Nano materials as flame retardants in metal hydrate FR formulations. In: 15th International Conference ADDITIVE 2006, Plastics Additives for Special Effects, ECM, Plymouth, MI, Las Vegas, NV, January 30–February 1, 2006.

[9] Klyosov A.A (2007): Wood plastic composites. Wiley-Interscience; 2007, p. 697

[10] Kollmann F, F.P; Kuenzi, E.W and Stamm, A.J (1975): Principles of Wood Science and Technology, Springer-Verlag, Berlin Heideber, New York, 1975, vol I. Pp 153

[11] Levan, S.L and Trans, H.C (1990): The Role of Boron in Flame-retardant treatments; Proc First Intl Conf. on Wood Protection with Diffusible Preservatives Margaret Hamel, ed., (1) 39

[12] Lu JZ, Wu Q, Negulescu II (2005): Wood-fibre/high density polyethylene composites: coupling agent performance. Journal of Applied Polymer Science 2005; 96:93-102.

[13] Lu, J. Z.; Wu, Q.; and McNabb, H. S. (2000): Wood Fiber Sci 2000, 32, 88

[14] Malvar, L.J., D.E. Pendleton, and R. Tichy (2001): Fire issues in engineered wood composites for naval waterfront facilities. SAMPE J., 37(4):70–75.

[15] Raj R.G, and Kokta B.V (1991): Reinforcing high-density polyethylene with cellulosic fibres. I: The effect of additives on fibre dispersion and mechanical properties. Polymer Engineering and Science 1991; 31(18):1358-62.

[16] Soucy, J. (2007): Master's Thesis, Universite´ du Que´bec a` Chicoutimi, Canada, 2007

[17] Stark, N.M; White, R And Clemons, C.M (1997): Heat Release Rate of Wood Plastic Composites; SAMPLE Journal, Vol.33 (5) pp 5

[18] Stark, N., Clemons, C., Ibach, R.; Matuana, L. (2003): Durability of Wood and Polyethylene Composite Lumber: Report; U.S Dept of Housing and Urban Dev. I-OPC-21763, USDA For. Ser. Prod. Madison, WI

[19] Steckel, V.; Clemons, C. M.; and Thoemen, H. (2006): J Appl Polym Sci 2006, 103, 752.

[20] Troitzsch. J (2004): Plastics Flammability Handbook. Principles, Regulations, Testing, and Approval, 3rd edition, Hanser, Munich-Cincinnati, 2004, p. 147

[21] Wang Y, Yeh F.C, Lai S.M, Chan H.C, and Shen H.F (2003): Effectiveness of functionalized polyolefin as compatibilizers for polyethylene/ wood flour composites. Polymer Engineering and Science 2003; 43(4):933-45

[22] White, J.E., Silvis, H.C., Winkler, M.S., Glass, T.W., Kirkpatrick, D.E., (2000): Poly (hydroxyaminoethers): A new Family of Epoxy-Based Thermoplastics". Journal of Advanced Materials, Vol.12, No. 23, pp. 1791- 1800.

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