INNSPUB

Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 25, No. 3, p. 121-128, 2024
http://www.innspub.net

RESEARCH PAPER | OPEN ACCESS

The physical properties of wood-plastic composite produced from red meranti (*Shorea* spp.) sawdust, polyethylene and polypropylene

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Article published on September 10, 2024

Key words: Wood-plastic composite, Polyethylene, Polypropylene, Red meranti, Sawdust

Abstract

This study aims to analyze the effect of polyethylene (HDPE) and polypropylene (PP) mixture composition on the physical properties of wood-plastic composites (WPC) with red meranti (*Shorea* spp.) sawdust as filler. The target of density of the wood products was 0.7 g/cm^3. The ratio of sawdust and plastic was 40%:60% by adding 3% of MAH as coupling agent. The HPDE and PP ratio treatments consisted of 100% HDPE (treatment A); 75% HDPE: 25% PP (B); 50% HDPE: 50% PP (C), 25% HDPE: 75% PP (D) and 100% PP (E). The process of making composites by compression method at a temperature of 180°C, pressure of 30 bar for 20 minutes. The physical properties of WPC tested according to ASTM standards. The results showed that WPC produced had the range of density was 0.63 - 0.73 g/cm^3, moisture content 26 - 3.63%, water absorption after soaking for 24 hours 15.34% - 24.15% and thickness swelling 0.94% - 3.74%. Based on ANOVA, it was found that the ratio of HDPE: PP influenced the physical properties of WPC, except for moisture content. The Density, water absorption and thickness swelling of WPC tend to increase with increasing PP content. The best mixture of HDPE and PP is a composition of 75% HDPE and 25% PP because it produces the lowest water absorption and thickness swelling values.

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Introduction

Wood Plastic Composite (WPC) can be formed into various shapes, so it can be used for a wide variety of applications, including windows, door frames, car interior panels, fences, landscaping timber, cladding and siding, garden benches, molding, and furniture (Taylor *et al.*, 2009). The quality of the WPC is influenced by many factors, one of which is the polymer matrix (Spear *et al.*, 2015).

Generally, the thermoplastics used in WPC as polymer matrixes are polyethylene, polypropylene, polystyrene, and polyvinyl chloride. These types of thermoplastics are commonly used in the WPC production because they have a melting point below 200°C, which is considered the maximum temperature for processing sawdust or natural fibers without causing significant degradation (Klyosov, 2007; Taylor *et. al.*, 2009; Stark *et.al.*, 2010; Spear *et.al.*, 2015).

This study used two types of thermoplastics, namely polyethylene and polypropylene, with the aim of being able to improve the weaknesses of each matrix to produce better boards. Polyethylene has various advantages, such as a relatively low melting temperature, being soft, influencing easy work, and having a relatively high resistance to oxidation. Moreover, it possesses a high modulus of rupture (MoR) and low compressive strength. Meanwhile, polypropylene has the disadvantage of being more brittle than polyethylene, especially at low temperatures, making it difficult to fasten using nails or screws.

The purpose of this study was to utilize red meranti sawdust as a raw material for wood-plastic composite production and to analyze the effect of the composition of a mixture of polyethylene and polypropylene plastics on some physical properties of wood-plastic composites.

Materials and methods

The materials used in the manufacture of the wood-plastic composite consist of red meranti sawdust residue obtained from a wood processing industry in Samarinda, East Kalimantan Province, Indonesia. High-density polyethylene (HDPE) and polypropylene (PP) plastic pellets were obtained by an extruder at our laboratory. The chemicals used were obtained from the highest purity available.

Sawdust preparation

The sawdust was first sieved through a 4-mesh sieve and continued through a 16-mesh sieve. The sawdust was soaked in 1% NaOH for 2 hours, followed by washing with clean water until the pH was neutral (pH 7). The sawdust was then air-dried for 2 days, followed by oven drying for 5 hours at 100°C. The sawdust moisture content was measured using the TAPPI-T 264 cm-97 method (TAPPI, 1997).

Manufacture of wood-plastic composites

The wood-plastic composite was targeted to have dimensions of 30 cm x 30 cm x 0.7 and a density of 0.7 g/cm^3. The ratio of sawdust and plastic was 40%: 60% and the addition of Maleic Anhydride as a coupling agent (3% of the weight of the plastic) was applied. Five concentrations of HDPE and PP were used: 100% HDPE (A), 75% HDPE: 25% PP (B), 50 %HDPE: 50%PP (C), 25%HDPE: 75%PP (D) and 100%PP (E). The compositions for the wood-plastic composite production were presented in the Table 1.

The process of making composites involved the compression molding or thermoforming (pressing). Before being pressed, the sheets were formed manually by spreading the polymer matrix after mixing it with coupling agent and sawdust layer by layer on the mold. The number of layers was adjusted to 9, consisting of 5 plastic layers and 4 sawdust layers. The distribution of plastic and sawdust layers in the board sheet can be observed in Fig. 1. The sheets were then pressed at 180°C with a pressure of 30 bar for 20 min. After conditioning, the board sheets were cut into pieces according to the size of the test standard.

Table 1. Combination treatments used in this study

Sample	Sawdust	Polymer matrix composition (57%)	Coupling agent (Maleic anhydride)
A	40%	100% HDPE	3%
B	40%	75% HDPE : 25% PP	3%
C	40%	50% HDPE : 50% PP	3%
D	40%	25% HDPE : 75% PP	3%
E	40%	100% PP	3%

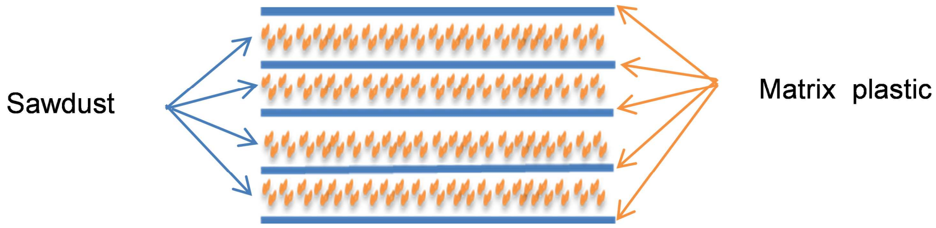

Fig. 1. Layers of plastic matrix and sawdust in the formation of board sheet

Evaluation of physical properties

Testing the physical properties of wood-plastic composites refers to ASTM standards, including density (ASTM D 2395-14), moisture content (ASTM D 4442-16), water absorption, and thickness expansion (ASTM D 1037-12).

Morphology observation

The cross-sectional morphology of the edges of the wood-plastic composite was observed using a Stereocopic Microscope (Nikon SMZ 645) with 30x magnification.

Data analysis

Data analysis used a completely randomized design and further tests of LSD (Least Significant Difference) to determine the effect of the HDPE: PP composition on the physical properties of WPC.

Results and discussion

The average value of all experiments involving testing the physical properties of the wood -plastic composite by arranging the composition of HDPE: PP was presented in Tables 2 and 3. The analysis of variance (ANOVA) and LSD test were also displayed.

Table 2. ANOVA of wood-plastic composite with the combination of HDPE and PP

Physical properties of WPC	F-value	F crit (5%)	F crit (1%)	Notation
Density	10.17	2.87	4.43	**
Moisture content	1.88	2.87	4.43	ns
Water absorption	6.53	2.87	4.43	**
Thickness swelling	4.54	2.87	4.43	**

Note : ** = very significant, ns = not significant

Table 3. LSD of wood-plastic composite with the combination of HDPE and PP

Sample	Physical properties of WPC			
	Density (g/cm3)	Moisture content (%)	Water absorption (%)	Thickness swelling (%)
A	0.63^{a}	3.40	15.34^{a}	1.50^{a}
	(0.04)	(0.19)	(1.29)	(0.77)
B	0.67^{b}	3.62	16.73^{ab}	0.94^{a}
	(0.03)	(0.36)	(3.78)	(0.27)
C	0.69^{b}	3.36	18.94^{bc}	2.11^{ab}
	(0.03)	(0.22)	(1.05)	(0.90)
D	0.67^{b}	3.63	24.60^{d}	2.23^{b}
	(0.02)	(0.28)	(5.06)	(1.82)
E	0.73^{c}	3.26	20.15^{c}	3.74^{c}
	(0.02)	(0.26)	(2.51)	(1.14)

Note: Different superscript letters in the same column indicated the significant different value. The numbers in brackets are the standard deviation values.

Density and water content

The board density measurement showed the weight of the board per unit volume of the board. The average density value of the resulting wood-plastic composite ranged from 0.63 to 0.73 g/cm³, and the water content ranged from 3.26 to 3.63% (Fig. 2). The ANOVA results in Table 2 show that the HDPE and PP mixture composition treatment had a significant effect on density, but water content had no significant effect. The LSD test results in Table 3 showed that the composition of 100% HDPE (sample A) and 100% PP (sample E) was very significant different compared to other compositions, while the arrangement of the HDPE and PP (samples B, C, and D) showed an insignificant difference.

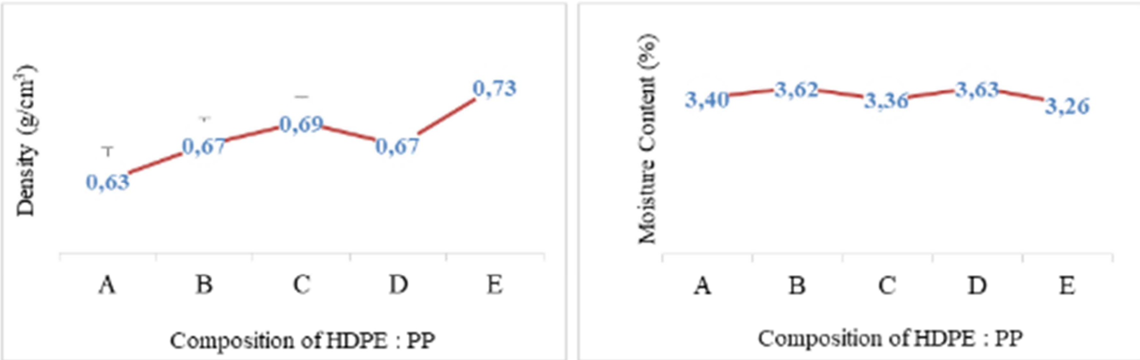

Fig. 2. Density and moisture content measurement of plastic wood composites from sawdust of red meranti wood (*Shorea* spp.), HDPE, and PP

Fig. 2 showed that the density of the wood-plastic composite tended to increase with increasing PP concentration. The low density of wood-plastic composites containing polyethylene (HDPE) might be due to the low melting characteristic of HDPE, which formed a layer that coated the wood particles. Simultaneously, when the plastic matrix melted, it released volatile organic compounds. The release of these volatile organic compounds during hot pressing was indicated by the presence of smoky steam on the pressed boards, followed by a burning smell. The loss of volatile matter could indirectly reduce the weight of the board per unit volume, so its density also decreased. According to Felix *et al.* (2012), volatile compounds included alkanes, alkenes, phenols, aldehydes, aromatic hydrocarbons, terpenes, carboxylic acids, esters, nitrogenous compounds, ketones, and alcohols. The most abundant compounds are furfural, a-pinene, 2-ethyl-1-hexanol, 2-methoxyphenol, N-methylphthalmide, butylate hydroxytoluene, 2,4-di-tert-butylphenol, and diethyl phthalate. Espert *et al.* (2005) suggested that the degradation of the polymer matrix in composite materials produced odors associated with aldehydes, ketones, and carboxylic acids. On the other hand, degradation of the lignocellulosic portion released acetic acid, formaldehyde, formic acid, aldehydes, and other acids. Also described by Felix *et al.* (2012), the main causes of odor were acetylfuran, acetic acid, 2-methoxyphenol, diacetyl, hexanoic acid, diethyl phthalate, and aldehydes.

The moisture content defines the amount of water contained in the board, expressed as a percentage by mass of the dried board. Based on the results, the average value of the board's moisture content was quite low, ranging from 3.26 to 3.63% (Fig. 2). Statistically, based on the ANOVA (Table 2), it showed that the composition of the plastic matrix did not affect the moisture content significantly. This phenomenon might be because plastic polymers were not hygroscopic, so they did not interact with moisture around them. Clemon (2008) stated that the polymer matrix tended to shrink and expand with temperature and could be an effective barrier to moisture intrusion in well-designed composites.

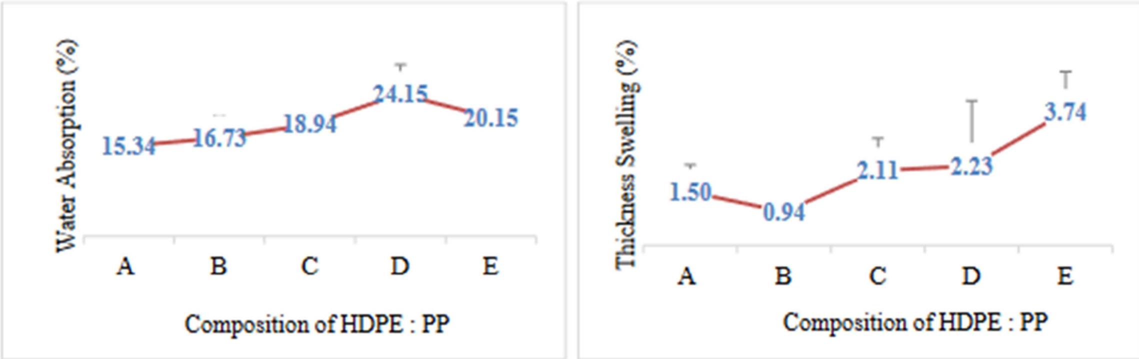

Fig. 3. Average value of water absorption and thick development of plastic wood composite from sawdust of red meranti wood (Shorea spp.) based on composition of HDPE and PP

The density value that was close to the target density was achieved by a composition of 50% HDPE and 50% PP (sample C) with a density of 0.69 g/cm3. The target density was 0.70 g/cm3. Overall, the board density values for all treatments met the standards set by SNI 03-2105 and JIS A 5908: 2003, with the values ranging from 0.5 to 0.9 g/cm3. While the average value of the board moisture content in this study according to the standards of SNI 03-2105 and JIS A 5908:2003 met the criteria since they were not more than 14%.

Water absorption and thickness swelling

The average value of water absorption in all plastic wood composites after soaking for 24 hours ranged from 15.34% to 24.15%. The average value of the swelling thickness ranged from 0.94% to 3.74%. It can be seen in Fig. 3. The ANOVA results in Table 2 showed that the HDPE and PP mixture composition treatment has a significant effect on water absorption and thickness swelling. The LSD test results in Table 3 showed that the treatments of A, B, C, and E did not different significantly according to the water absorption value. On the other hand, the thickness and swelling values of treatments E and B were significantly different.

The lowest average value of water absorption was achieved by the composition of 100% HDPE (A) with a value of 15.34%, whereas the highest value was obtained by the composition of 75% HDPE and 25% PP (D) with a value of 24.15%. Meanwhile, the lowest percentage of thickness swelling was obtained from the composition of 75% HDPE and 25% PP (B) with a value of 0.94%, and the highest percentage was shown by the composition of 100% PP (E) with a value of 3.74%. The water absorption value increased with the increasing number of PP compositions.

Water absorption and thickness swelling tended to increase with the increasing number of PP plastic compositions. The lower melting point of HDPE could form a thin layer that inhibits the water absorption of sawdust. Conversely, since the PP could not melt completely, it created gaps between plastic and sawdust, which were easily filled by water. Thus, increasing PP composition contributed to high water absorption and thickness swelling. Saddem *et al.* (2022) stated that wood fiber was responsible for water absorption in wood-plastic composites due to its hydrophilic characteristic. The water absorption phenomenon of wood-plastic composites was caused by capillary transport into the gaps and broke the interface between the fibre and polymer due to poor adhesion, incomplete wettability, and impregnation. It caused water transport by the microcracks formed during processing. Bhaskar *et al.* (2021) and Barbos *et al.* (2020) stated that the water absorption of wood-plastic composites will be reduced by the use of thermoplastic and the presence of wood residue will increase the water absorption capacity of wood-plastic composites. Furthermore, Klyosov (2007) stated that water absorption by composite materials depended on their porosity, the amount of cellulose fibres, and the availability of water. When the composite material was immersed in water, the water filled the accessible pores and capillaries and penetrated the most available cellulose particles and fibres, usually in the top layers of the board. According to Rowell (2005), fibre composites did not only receive normal expansion but also swelling caused by the release of residual compressive stress due to the pressing process. Absorption of water causes reversible and irreversible swelling.

The average water absorption values of the obtained wood-plastic composite after soaking for 24 hours were not in line with the standard of JIS A 5741:2006 since all values were higher than 10% (JIS A, 2006). However, based on the value of thickness swelling, all boards met the criteria according to the standards of SNI 03-2105 (2006) and JIS A 5908: 2003 (2003).

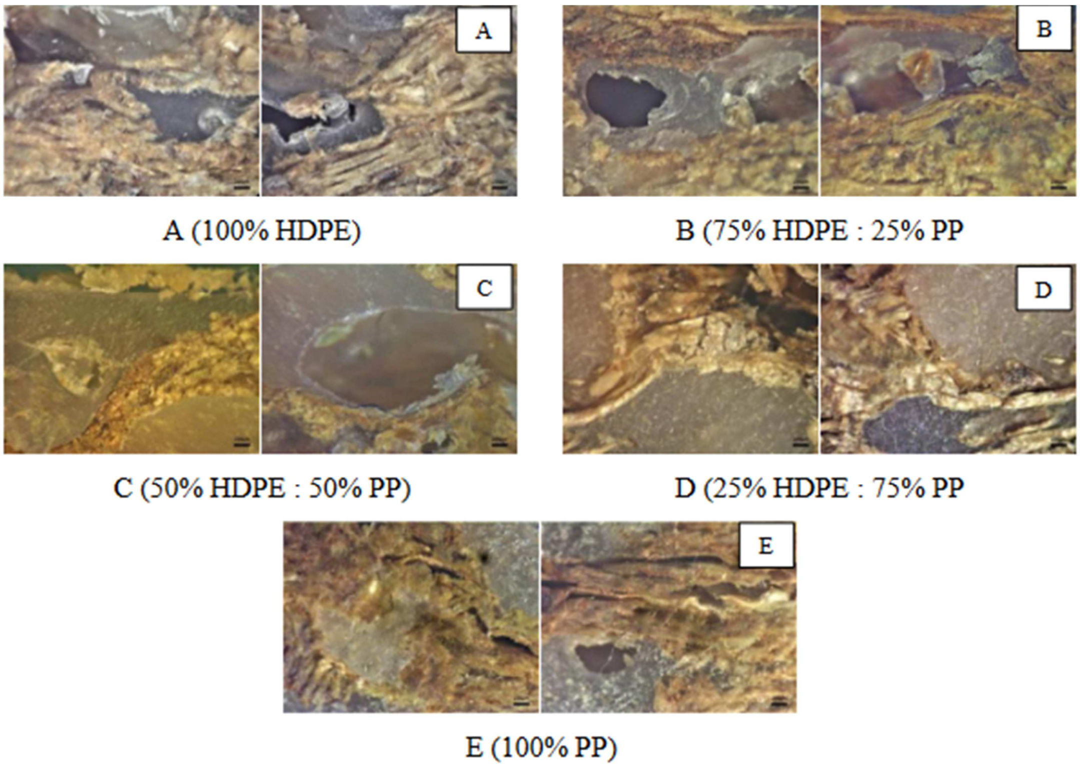

Fig. 4. Morphology of the cross-edge section observed by NIKON SMZ 645

Surface morphology

The results of the morphological observation of the cross-edge section of the wood-plastic composite using the Nikon SMZ 645 Stereocopic Microscope with 30x magnification can be seen in Fig. 4. It showed that the excessive addition of PP polymer matrix affected the poor adhesion or interfacial bond between the powder and the plastic because it did not melt properly, creating gaps or cavities that potentially reduced the mechanical strength of the boards.

Conclusion

Finally, we concluded that the composition of the polymer matrixes used matrix used in this study, namely high-density polyethylene (HDPE) and polypropylene (PP) affects the physical properties of the obtained resulting wood-plastic composite, including density, water absorption and thickness swelling. However, only the moisture content was not affected by various concentrations applied. The density, water absorption and thickness swelling tended to increase with the increasing number of PP compositions. The best mixture composition between polyethylene (HDPE) and polypropylene matrix is the composition of 75% HDPE and 25% PP.

Acknowledgements

The authors would like to express their gratitude to the Ministry of Research, Technology, and Higher

Education for providing the Doctoral Program Scholarship (Determination letter No. 1265.29/E4.4/2015) through the Domestic Postgraduate Education Scholarship Program (BPP-DN). Additionally, the authors would like to thank Cahaya Samtraco Utama Ltd. for donating red meranti sawdust for research purposes and the Faculty of Forestry at Mulawarman University for providing financial assistance and laboratory facilities for this study.

References

ASTM D 1037-12. 2012. Standard Test Methods for Evaluating Properties of Wood-Base Fiber and Particle Panel Material. ASTM International. West Conshohocken, PA, United States.

ASTM D 2394-14. 2014. Standard Test Methods for Specific Gravity of Wood and Wood-Based Materials. Copyright © ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States.

ASTM D 4442-16. 2016. Standard Test Methods for Direct Moisture Content Measurement of Wood and Wood-Based Materials. ASTM International. West Conshohocken, PA.

Barbos JDV, Azevedo JB, da Silva MCardoso P, da Costa Filho F, Gomez del Rio T. 2020. Development and characterization of WPCs produced with high amount of wood residue. Journal of Materials Research and Technology **9**(5), 9684-9690. https://doi.org/10.1016/j.jmrt.2020.06.073.

Bhaskar K, Jayabalakrishnan D, Vinoth Kumar M, Sendivelan S, Prabhahar M. 2021. Analysis on mechanical properties of wood plastic composite. Material Today: Proceedings **45**(7), 5886-5891. https://doi.org/10.1016/j.matpr.2020.08.570.

Clemons C. 2008. Raw materials for wood–polymer composites. In: Oksman Nisca K, Sain M, ed. Wood-Polymer Composites. Boca Raton, FL: CRC Press; Cambridge, UK: Woodhead Publishing Series in Composites Science and Engineering, 1-22. https://doi.org/10.1533/9781845694579.1.

Espert A, de las Heras LA, Karlsson S. 2005. Emission of possible odourous low molecular weight compounds in recycled biofibre/polypropylene composites monitored by head-space SPME-GC-MS. Polymer Degradation and Stability **90**, 555-562. https://doi.org/10.1016/j.polymdegradstab.2005.03.009.

Félix JS, de la Cruz C, Navarrete C. 2012. Characterization of wood plastic composites made from landfill-derived plastic and sawdust: volatile compounds and olfactometric analysis. Waste Management Journal **33**(3), 645-655. https://doi.org/10.1016/j.wasman.2012.11.005.

JIS A 5741:2006. 2006. Wood-Plastic Recycled Composite. Japanese Industrial Standard.

JIS A 5908:2003. 2003. Particleboards. Japanese Industrial Standard. Translated and published by Japanese Standards Association. ICS 79.060.20.

Klyosov AA. 2007. Wood-Plastic Composites. Wiley-Interscience, A John Wiley & Sons, Inc., Publication.

Rowell RM. 2005. Chemical modification of wood. CRC Press LLC. USDA, Forest Service, Forest Products Laboratory, and Department of Biological Systems Engineering, University of Wisconsin, Madison, WI. This page was uploaded by Roger M. Rowell on 01 October 2014 at: https://www.researchgate.net/publication/43286917.

Saddem M, Ahmed K, Bernard R. 2022. Properties of high-density polyethylene-polypropylene wood composites. In: Kumar B, ed. Biocomposites. IntechOpen.

SNI 03-2105-2006. 2006. Standar Nasional Indonesia. Papan Partikel. Badan Standardisasi Nasional.

Spear MJ, Eder A, Carus M. 2015. Wood polymer composites. In: Ansell MP, ed. Wood Composites. Woodhead Publishing Series in Composites Science and Engineering. Elsevier, 195-249. https://doi.org/10.1016/B978-1-78242-454-3.00010-X.

Stark NM, Cai Z, Carll C. 2010. Wood-based composite material - panel products, glued-laminated timber, structural composite lumber, and wood-nonwood composite materials. In: Forest Products Laboratory, ed. Wood Handbook-Wood as an Engineering Material. General Technical Report FPL-GTR-190. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, 508p.

TAPPI T 264 cm-97. 1997. Preparation of wood for chemical analysis. Approved by the Pulp Properties Committee of The Process and Product Quality Division.

Taylor A, Yadama V, Englund KR, Harver D. 2009. Wood plastic composites – a primer. University of Tennessee of Agriculture, US. UT Extension PB1779.