The effect of oil palm trunk particles and composite density on the physical and mechanical properties of rigid polyurethane foam composite

S S Munawar¹, C D Widyanto², L S Hutahean², D Purnomo¹, B Subiyanto¹, Ismadi¹, A Syahrir¹, F Akbar¹, D P Kosasih³

¹Research Center for Biomaterials, National Research and Innovation Agency (BRIN)
²Department of Polymeric Chemical Engineering, Polytechnic of STMI Jakarta
³Department of Mechanical Engineering, Faculty of Engineering, Subang University

Email: sasa001@brin.go.id

Abstract. The oil palm trunk (OPT) particle was used as a filler for the manufacture of rigid polyurethane foam composites (RPUFC). The purpose of this research is to investigate the effect of OPT particle content and variation of composite density on the physical and mechanical properties of RPUFC. The RPUFC was created with five different volume fractions of OPT particles (0, 2.5, 5, 7.5, 10 wt%) and three different composite densities (40, 50, 60 kg/m³). The OPT particles, polyols, and isocyanate were mixed, poured and formed in a closed mold. The moisture content (MC), water absorption (WA), compressive strength (CS), screw withdrawal (SW), and internal bonding strength (IB) properties were determined according to JIS A 5908-2003. The flexural strength (FS) properties were determined according to ASTM D790. The physical properties (MC, WA) were increased with increasing OPT particles in the RPUFC. The RPUFC with 2.5% OPT particle was higher in modulus of rupture, modulus of young (E) and CS values compared to RPUFC control. The IB and SW values were increased when 2.5% OPT particles were added to RPUFC. The best PURFCs were produced with the addition of 2.5% particles at a density of 50 and 60 kg/m³.

1. Introduction

The oil palm industry generates a huge amount of agricultural waste in Indonesia, such as OPT, oil palm fronds, and oil palm fruit bunches. The total oil palm plantation area in Indonesia was 8.34 million hectares in 2010 and it will increase to 14.85 million hectares in 2020 [1]. OPT is produced at the time of replanting plants that have decreased productivity, that is, those at the age of 25-30 years. OPT can produce up to 50-75 tons from a single hectare of oil palm land [2] [3] [4] [5] [6] [7]. Currently, the target for replanting plants is around 180,000 hectares/year, which is estimated to produce an OPT of 9-14 million tons/year. The abundant OPT potential has been widely used for structural parts, particleboards [8], fibreboard [9], cement boards [8], concrete mixes [10], and plastic composites [11], and others [12]. In addition, rigid polyurethane foam can be modified by natural fibers for product insulation applications [13]. Depending on the facings and thickness, rigid polyurethane foam can achieve a thermal conductivity as low as 0.022 W/mK to 0.028 W/mK. These make it one of the most efficient insulation materials available on the market. Rigid polyurethane foam (RPUF) has a thermal conductivity of about 18-21 mW/mK when using HFC as a blowing agent [16]. Several studies have been carried out to modify RPUFC using keratin feathers, potato protein, walnut shells [17] [18].
hardwood pulp [19] and EFB [20] [21]. However, there has been no research on the manufacture of RPUFC using OPT particles as filler. Therefore, investigation into the effect of OPT particles' content and variation of composite density on the physical and mechanical properties of RPUFC was conducted.

2. Materials and Methods

2.1. Preparation of materials
An oil palm trunk (Elaeis guineensis) with an approximate age of 30 years and an approx. 60-cm diameter was obtained from Bogor, Indonesia. After the oil palm tree was cut down, the bark was removed and chopped into chips. The chips were sun-dried for 24 hours before being oven-dried for 12 hours at 70°C. The dried chips were ground to particles with a ring flaker (Pallman Maschinenfabrik, Zweibrucken, Germany). The particles were screened with a vibrating sieve, and the particles that remained between the aperture sizes of 4 and 14 mesh were used as the raw material. The particles were oven-dried at 60°C for 24 h to reach a moisture content less than 7%. Isocyanate (ARK R32040/P) and Polyol (ARK R32040/P) purchased from PT. Anugerah Raya Kencana (Tangerang, Indonesia) were used. The appearance of the isocyanate was a dark brown liquid, with a specific gravity of 1.22-1.26 g/ml and a viscosity of 150-250 mPas. The polyol had the appearance of a light yellowish liquid with a specific gravity of 1.04-1.06 g/ml and a viscosity of 110-210 mPas. The material used is shown in Figure 1.

2.2. Free rise foaming of RPUF
Rigid polyurethane is a mixture of isocyanates and polyols before being used for various applications. With the addition of lignocellulosic material, there will be an effect on the polyurethane foaming process. Therefore, the free rise foaming test was conducted to determine the effect of adding OPT particles to the polyurethane foaming process. Parameters observed were cream time and tack free time. Cream time is the time it takes to start the reaction of the polyol mixture with the isocyanate, which is indicated by the liquid turning creamy and starting to expand. Meanwhile, tack free time is the time it takes polyurethane to stop reacting and the surface is not sticky [22]. The polyol solution and OPT particles were mixed by stirring in a 1000 mL plastic container until the polyol was evenly distributed over the surface of the OPT particles. Then, isocyanate was added to the mixture of polyol and OPT particles and stirred using a stirrer at a speed of about 2000 rpm for 10 seconds. The ratio of polyol and isocyanate was 1:1.1 (w/w) %. After that, the foam was expanded freely. Cream time and tack free time were measured by using a stopwatch and recorded [23].

2.3. Manufacture of RPUFC
The manufacture of RPUFC began by mixing polyols with OPT particles using a stirrer in a plastic container until the polyol was evenly distributed over the surface of the OPT particles. Then, isocyanate was added to the mixture of polyol and OPT particles and stirred using a stirrer at a speed of about 2000 rpm for 10 seconds. The ratio of polyol to isocyanate was 1:1.1 (w/w%) according to the technical instructions of the polyurethane manufacturer. The mixture of polyol, OPT particles and isocyanate were poured into a closed mold with a size of 40x40x5 cm for 45 minutes (Figure 2). RPUFC were created.
with target densities of 40 kg/m$^3$ (D40), 50 kg/m$^3$ (D50), and 60 kg/m$^3$ (D60), as well as four different OPT particle contents (2.5%, 5%, 7.5%, and 10% of the composite weight).

Figure 2. Manufacture of RPUFC

RPUFC without using OPT particles was made as a control. RPUFC were conditioned two weeks prior to testing. The types of RPUFC are shown in Table 1.

Table 1. Type of RPUFC

| RPUFC densities (kg/m$^3$) | OPT particle contents |
|---------------------------|-----------------------|
|                           | 0%        | 2.5%      | 5%        | 7.5%     | 10%       |
| 40                        | D40OPT0   | D40OPT25  | D40OPT50  | D40OPT75 | D40OPT100 |
| 50                        | D50OPT0   | D50OPT25  | D50OPT50  | D50OPT75 | D50OPT100 |
| 60                        | D60OPT0   | D60OPT25  | D60OPT50  | D60OPT75 | D60OPT100 |

2.4. RPUFC testing

The RPUFC was tested for its physical and mechanical properties. The MC, WA, TS, FS, CS, SW and IB were determined according to JIS A 5908-2003 [24]. The MC, WA, TS, IB, CS, and SW tests were carried out using samples with a size of 555 cm. The FS test was carried out using three-point bending (40x5x5 cm) in accordance with ASTM D790 [25] (Figure 3). Data analysis in this study was used to determine the effect of oil palm trunk fiber content on a number of responses. Testing was done using three replications for each test parameter.

Figure 3. Sample test for (a) MC, WA, TS, IB, CS, SW, and (b) FS, and testing samples of (c) IB, (d) CS, (e) SW and (f) FS
3. Result and Discussion

3.1. RPUF reactivity

Figure 4 shows the free-rising foaming conditions of RPUF. The RPUF foaming process without adding OPT particles was moved slightly vertical, while by adding OPT particles, RPUF foaming was greatly vertical. The final foaming height of RPUF without adding OPT particles was shorter than that of RPUF after adding OPT particles, and the RPUF height was increased with increasing OPT particles. It was predicted that the polyurethane foaming process was inhibited by the presence of particles, and the polyurethane moved between, enveloping the particles, and pushing them up. The upward movement of polyurethane foam caused more foam surface and accelerated the drying of the foam. It was in line with the tack free time data in Figure 5.

![Figure 4. RPUF free rise foaming conditions by effect of adding OPT particles](image)

Figure 5 shows the cream time and tack free time of RPUF free-rising foaming as affected by adding OPT particles. The cream time and tack free time of RPUF were shown to be in the range of 18 to 34 seconds and 340 to 340 seconds, respectively. The cream time was slightly increased by increasing the OPT particle content on RPUF. These results indicated that the addition of OPT particles causes the time for the RPUF to expand to be longer. Similar conditions occurred in other studies [26] [18] [27], where natural fibers became nucleating agents that made more bubbles form, thus making the cream time longer. The addition of fibers also reduces the expansion time of bubbles formed and the diffusion of gases into bubbles, which reduces molecular mobility and affects the speed of polymerization in foam formation. In addition, tack free time showed a decreasing tendency with the addition of OPT particles. This indicated that the OPT particles could be a curing accelerator. On the other hand, foam viscosity increases with increasing OPT particles, thereby reducing tack free time. Previous studies [26, 27] yielded similar results.

![Figure 5. Cream time and tack free time of RPUF free rise foaming by effect of adding OPT particles](image)

3.2 Density

Table 2 shows the comparison between the target density and the apparent density of RPUFC. The target densities were 40 kg/m³, 50 kg/m³, and 60 kg/m³. The density of polyurethane depends on the pore size.
The enlarged pore size caused a decrease in foam density [28]. The result showed that each density decreased when compared to the target density. There is a decrease of about 10 density points from each density target, both RPUFC without particles and with particles. This may be due to the lack of material calculations during the manufacture of RPUFC, where during the manufacturing process the weight of the material was reduced due to the gas that comes out from the reaction between polyol and isocyanate. On the other hand, the density value tends to be uniform even though it looks like it might slightly increase with the addition of particles. Another study found that when particle fraction was added to the PUF matrix, the pores were filled by the fiber particles themselves [29]. This has an impact on the pore size of the composite that shrinks, resulting in an increasing density value.

| Targeted Density (kg/m$^3$) | OPT particle contents (%) | Apparent Density (kg/m$^3$) |
|-----------------------------|---------------------------|-----------------------------|
| 40                          | 0                         | 34.29                       |
|                             | 2.5                       | 35.25                       |
|                             | 5                         | 35.68                       |
|                             | 7.5                       | 36.09                       |
|                             | 10                        | 35.51                       |
| 50                          | 0                         | 45.25                       |
|                             | 2.5                       | 44.10                       |
|                             | 5                         | 42.84                       |
|                             | 7.5                       | 42.68                       |
|                             | 10                        | 43.89                       |
| 60                          | 0                         | 50.80                       |
|                             | 2.5                       | 51.31                       |
|                             | 5                         | 50.03                       |
|                             | 7.5                       | 51.89                       |
|                             | 10                        | 50.18                       |

### Table 2. Comparison between target density and apparent density of RPUFC

3.3 Moisture Content

The MC average value of RPUFC ranged from 1.99% to 5.20% (Figure 6). The results showed that MC values were increased by increasing OPT particles in the RPUFC for all density targets. While the MC of 7.5% and 10% OPT particles on RPUFC with densities of 50 kg/m$^3$ and 60 kg/m$^3$ was lower than on RPUFC with a density of 40 kg/m$^3$.

![Figure 6. Moisture contents of RPUFC](image)

The same thing happened in other studies where the MC was increased by increasing the natural particle content in PUF [30]. This is due to the presence of -OH groups in the fiber. The higher particle
content resulted in a greater number of free-OH groups derived from cellulose and hemicellulose, which caused an increase in the MC. The highest value of MC against RPUFC without particles was 2.5 times. The difference in OPT particle content had a significant effect on the MC of RPUFC, but the difference in various densities did not have a statistically significant effect.

3.4 Water absorption
Water resistance is an important characteristic of RPUFC, especially for outdoor applications [31]. Figure 7 showed that the water absorption values were in the range of 25.87% to 130.87%. The WA values were increased by increasing the OPT particles in the RPUFC for all density targets. While the MC of 7.5% and 10% OPT particles on RPUFC with densities of 50 kg/m³ and 60 kg/m³ was lower than on RPUFC with a density of 40 kg/m³. This is comparable to other studies that found the WA of bamboo charcoal PUF [32]. The hygrometric characteristics of particles were affected by the WA performance. On the other hand, the increase in density has a very significant effect on the decrease in WA values of RPUFC with the same OPT particle content. It was because of the increased density that made the RPUF cell structure closer and made little space for water to come inside the foam structure. Similar results were found that the WA values of composites were increased when OPT fiber was added [18].

![Figure 7. Water absorption of RPUFC](image)

3.5 Flexural strength (modulus of rupture (MOR) and modulus of young (MOE))
The MOE values of RPUFC ranged from 1.246 to 8.633 N/mm² (Figure 8). Meanwhile, the MOR values ranged from 0.216 to 0.569 N/mm² (Figure 8). The MOE and MOR values of the control RPUFC were lower than those of the RPUFC containing OPT particles at a density of 40 kg/m³, while they were higher than those of the RPUFC containing OPT particles at other RPUFC densities. In fact, the MOR and MOE values of RPUFC at densities of 40 kg/m³ with 2.5% OPT particles were greater than those of the control and other treatments.

![Figure 8. Flexural strength properties of RPUFC](image)
The difference in MOR and MOE values is due to the presence of free-OH groups from lignin, which cause competition with -OH from polyols to interact with NCO from isocyanates. This will trigger the formation of an irregular cell structure in the foam composite as the fiber increases. Irregular cell structure is associated with poor load transfer, thereby reducing its strength [33]. It was also due to the regular arrangement of foam cells. The regular arrangement of foam cells caused better mechanical strength [34]. Another study also showed a lower MOE value of the composite with added fiber than the control [35]. The addition of fiber to the PU matrix can damage the structure of the foam. The presence of fillers or the addition of fiber tends to modify the PU microstructure into smaller cells and become non-uniform, as was found in previous research [36]. In general, the bonding between OPT fiber and rigid polyurethane foam is secondary bonding because it contains hydrogen bonding according to the hydroxyl group. Secondary bonding is weaker and easier to break up than primary bonding [37].

3.6 Compressive strength
The CS values of RPUFC ranged from 1,246 to 8,633 N/mm$^2$ (Figure 9). The result showed that the CS values of the RPUFC with adding 2.5% OPT particles were slightly higher than those of the RPUFC without OPT particles and with other OPT particles in all RPUFC densities. The CS values were decreased when RPUFC was added by 5% OPT particles and more, although their CS values were almost the same as the control ones. The decrease in CS value after the addition of 5% OPT particles was due to the foam structure having fewer smaller cells with thinner cell walls. It was not strong enough to maintain the load [17]. On the other hand, the CS value was increased by increasing RPUFC density. Their density affected the mechanical properties of the composite. Where the increased density made the cell structure closer and the CS increased [26].

![Figure 9. Compressive strength properties of RPUFC](image)

3.7 Internal Bond
An IB test was carried out to provide an overview of the adhesive properties between the foam matrix and the fiber filler. The IB value of RPUFC ranged from 0.090 to 0.367 N/m$^2$ (Figure 10). Based on the data, the IB value was increased by increasing OPT particles with the RPUFC density of 50 kg/m$^3$ but decreased when the RPUFC was produced at a density of 40 kg/m$^3$ and 60 kg/m$^3$ and the adding OPT particles were increased. The RPUFC with 2.5% OPT particles appeared to have an IB value close to the IB values of the RPUFC without adding OPT particles. In addition, the higher MC could lead to the reduction of adhesive crosslinking and accordingly weaken the bonding performance [38]. RPUFC with 10% particle content showed a highest MC value, and it was a reason that IB strength value was decreased. However, the IB value of RPUFC with 2.5 OPT particles and a density of 60 kg/m$^3$ appeared to have an IB value lower than previous studies, which had an IB value in the range of 0.3-0.6 N/mm$^2$ [39].
3.8 Screw withdrawal

The SW values of RPUFC ranged from 44.27 to 92.71 N (Figure 10). The characteristics of SW values are almost the same as the IB values. The SW values of RPUFC were increased by increasing the RPUFC densities. These results are similar to other research that suggests the increased density made the cell structure closer and the SW increased [17]. The RPUFC with 2.5% OPT particles at a density of 50 kg/m$^3$ and 60 kg/m$^3$ was higher in SW values compared to the RPUFC without adding OPT particles and other treatments. Although the SW values of RPUFC were slightly decreased by increasing OPT particles on composites, it was indicated that the increase in OPT particles would increase the MC in the composite and waken the screw.

![Figure 10. Internal bond properties of RPUFC](image1)

![Figure 11. Screw withdrawal properties of RPUFC](image2)

4. Conclusion

The addition of OPT particles as filler on RPUFC affects the increase in the cream time but decreases the tack-free time on RPUF. The physical properties of RPUF were increased by increasing OPT particles, while decreased by increasing PURFC densities. The RPUFC with 2.5% OPT particle showed good mechanical properties compared to the RPUFC control and other treatments. The best PURFCs were produced with the addition of 2.5% particles at a density of 50 kg/m$^3$ and 60 kg/m$^3$. Therefore, the addition of OPT particles in the RPUFC means reducing the use of polyurethane, hence the product is more environmentally friendly and can reduce production costs.

Acknowledgments

The author would like to thank the LPDP of the Ministry of Finance and the National Research and Innovation Agency (BRIN) of the Republic of Indonesia for its financial support through the National
References

[1] Directorat General Estate Crops 2020 Buku Statistik Perkebunan 2019-2021 Directorat General Estate Crops

[2] Abnisa F, Arami-niya A, Daud WMAW, Sahu JN and Noor IM 2013 Utilization of oil palm tree residues to produce bio-oil and bio-char via pyrolysis, Energy Convers Manag 76 1073–1082

[3] Azri M, Abnisa F, Mohd W, Wan A, and Abu N 2017 A review of torrefaction of oil palm solid wastes for biofuel production, Energy Convers Manag 149 101–120

[4] Suzuki K, Tsuji N, Shirai Y, and Ali M 2017 Biomass and Bioenergy Evaluation of biomass energy potential towards achieving sustainability in biomass energy utilization in Sabah, Malaysia, Biomass and Bioenergy 97 149–154

[5] Tajalli 2015 Panduan Penilaian Potensi Biomassa Sebagai Sumber Energi Alternatif di Indonesia, 1st ed., Penabuleni alliance

[6] Kong SH, Loh SK, Bachmann RT, Rahim SA, and Salimon J 2014 Biochar from oil palm biomass: A review of its potential and challenges Renew Sustain Energy Rev 39 729–739

[7] Abdullah A, Abdullah MMAB, Hussin K, Ghazali CMR, Salleh MAAM, Sang PK, and Faheem MTM 2013 Study on the Properties of Oil Palm Trunk Fiber (OPTF) in Cement Composite Applied mechanics and materials 421 395-400

[8] Mageswaran R, Sheng EL, and Ibrahim Z 2018 The Thickness Effects On Acoustic Properties Of Oil Palm Trunk Natural Fiber in Density of 170 Kg/m 3 Sci Int 30 (6) 845–849

[9] Ahmad Z, Saman HM, and Tahir PM 2010 Oil palm trunk fibre as bio waste resource for concrete reinforcement International journal of mechanical and materials engineering 5 199-207

[10] Khalil HPSA, Kang CW, Khairul A, Ridzuan R, and Adawi TO 2009 The effect of different laminations on mechanical and physical properties of hybrid composites Journal of Reinforced Plastics and Composites 28 (9) 1123-1137

[11] Dungani R, Jawaid M, Khalil HPSA, Jasni, Aprilia S, Hakeem KR, Hartati S, and Islam MN 2013 A review on quality enhancement of oil palm trunk waste by resin impregnation: future materials, Bio resources 8 3136-3156

[12] Bledzki AK, Zhang W, and Chate A 2001 Natural fibre reinforced polyurethane microfoams, Composite science and technology 61 2405-2411

[13] Okieimen FE and Bakare IO 2007 Rubber seed oil based polyurethane composites, fabrication and properties evaluation Advanced materials research 18 233-239

[14] Demiroglu S, Erdogan F, Akin E, Karavana HA, and Seydibeyoglu MO 2017 Natural fiber reinforced polyurethane rigid foam Journal of science 30 97-109

[15] Fangareggi A and Bertucelli L 2018 Thermostet-Structure, Properties, and Applications: Thermoset insulation systems Elsevier 401-439

[16] Czlonka S, Sienkiewicz N, Strakowska A and Strzalec K 2018 Keratin feathers as a filler for rigid polyurethane foams on the basis of soybean oil polyol Polymer testing 14 1-48

[17] Czlonka, Sylwia, Strakowska A, and Kairtye A 2020 Effect of walnut shell and silanized walnut shells on the mechanical and thermal properties of rigid polyurethane foams Polymer testing 87 106534

[18] Gu R, Sain MM, and Konar SK 2013 A feasibility study of polyurethane composite foam with added hardwood pulp, Industrial crops and products 42 273-279

[19] Kraitaapea N and Thongpina C 2016 Influence of recycled polyurethane polyol on the properties of flexible polyurethane foams Energy Procedia 89 186-197

[20] Badri KH, Othman ZB, and Razali IM 2015 Mechanical Properties of Polyurethane Composites from Oil Palm Resources Iranian Polymer Journal 14 441–448

[21] Alis A, Majid RA, and Mohamad Z 2019 Morphologies and Thermal Properties of Palm-Oil Based Rigid Polyurethane/Halloysite Nanocomposite Foams Chemical Engineering Transaction 72
415–420

[22] Banik I and Sain MM. 2008 Role of Refined Paper Fiber on Structure of Water Blown Soy Polyol Based Polyurethane Foams J Reinf Plast Compos 27 (14) 1515-1524

[23] Soberi NSM, Rahman R, and Zainuddin F 2017 Effect of kenaf fiber of morphology and mechanical properties of rigid polyurethane foam composite Materials Science Forum 888 188-192

[24] Japanese Standard Association [JSA] 2003 JIS A 5908: Particleboards. Japan (JP): Japanese Standard Association

[25] American Society for Testing Materials ASTM D790-02 2002 Standard test methods for flexural properties of unreinforced and reinforced plastics and electrical insulating materials Philadelphia (US): American Society for Testing Materials

[26] Czlonka, Sylwia, Bertino MF, and Strzelec K 2018 Rigid polyurethane foam reinforced with industrial potato protein Polymer testing 7 1-52

[27] Sienkiewicz N, Czlonka S, Kairyte A and Vaitkus S 2019 Curcumin as a natural compound in synthesis of rigid polyurethane foams with enhanced mechanical, antibacterial and anti ageing properties Polymer testing 79 106046

[28] Yusuf S 2016 Effect of alkali process and mass fraction on morphology, bending strength and sound absorption coefficient of polyurethane/coir fiber composites on Muffler components [Thesis] Surabaya (ID) : Institut Teknologi Sepuluh Nopember [In Indonesian]

[29] Rosamah E, Hossain MS, Abdul Khalil HPS, Nadirah WOW, Dungani R, Amiranajwa ASN, Suraya NLM, Fizree HM, and Omar AKM 2016 Properties enhancement using oil palm shell nanoparticles of fibers reinforced polyester hybrid composites. Advanced Composite Materials 26 (3) 259-272

[30] David NV and Azlan M 2018 Moisture absorption properties and shock cushioning characteristics of bio-based polyurethane foam composites. Journal of Mechanical Engineering 5 (2)157-168

[31] Yusuf AK, Mamza PAP, Ahmed AS, Agunwa U 2016 Physico-mechanical properties of rigid polyurethane foams synthesized from modified castor oil polyols. International Journal of Scientific and Research Publications 6 (7) 548-556

[32] Chen YC and Tai W 2018 Castor oil-based polyurethane resin for low-density composites with bamboo charcoal Polymers 10 (0) 1-12

[33] Azni MAN, Sinar AA, Firuz Z, and Supri AG 2013 Characterization and mechanical properties of biomass polyurethane, Journal of Advances in Environmental Biology 7 (12) 3696-3699

[34] Legiviani R 2016 Effect of the comparison of the composition of the polyurethane and the mass fraction of coconut fiber on the sound absorption coefficient and the flexural strength of the composite in the Muffler application [Thesis] Surabaya (ID) : Institut Teknologi Sepuluh Nopember [In Indonesian]

[35] Sismantoro A 2017 Characterization of oil palm shell particle reinforced polyurethane acoustic material [Thesis] Surabaya (ID): Institut Teknologi Sepuluh Nopember [In Indonesian]

[36] Buyukakinci BY, Sokmen N, and Kucuk H 2011 Thermal conductivity and acoustic properties of natural fiber mixed polyurethane composites Tekstil ve Konfeksiyon 21 (2) 124–132

[37] Nafa M, Limbong HP 2019 Pemanfaatan serat batang kelapa sawit sebagai lembaran serat semen Jurnal teknik dan teknologi 14 40-48

[38] Roffael E 1993 Formaldehyde from Particleboards and other Wood Based Panels Forest Research Institute Malaysia (FRIM), Kuala Lumpur, Malaysia

[39] Chaydarreh KC, Shalbafan A, and Welling J 2017 Effect of ingredient ratios of rigid polyurethane foam on foam core panels properties J Appl Polym Sci 134 (17) 44722