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Effect of Resin Content on the Properties of Roofing Tile for Building Materials

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ABSTRACT

The production process of roofing tile materials uses among other materials thermosetting adhesive resins normally urea formaldehyde (UF), phenol formaldehyde (PF), di-isocyanate (PMDI) at various content mixtures, 3wt%, 5wt%, 7wt%, 9w% and 11wt% with a usual thickness of 6 mm. The fibers, adhesives, and other materials are then placed into a steel mold with the standard dimensions of 400 mm x 400 mm, to be then hydraulically pressed at high pressure and the required temperature. Overall, PMDI synthetic adhesives have better physical and mechanical properties than PF synthetic adhesives, however the thermal properties of UF and PF synthetic adhesives are better than PMDI. The physical properties testing were density, humidity content, absorption of water, thickness inflated and water permeability. The mechanical properties such as modulus of rupture (MOR) and modulus of elasticity (MOE), impact strength and tensile strength are all measured according to JIS A 5908-2003, ASTM D 256-2006a,TIS 535-2556 and ASTM D1037-12. The testing for the thermal conductivity, thermal resistivity and solar reflectance were done according to ASTM C177-2010 and ASTM E 891-87. The type of resin content and adhesive used had a significant impact on the physical, mechanical and thermal properties of the roofing tile materials of showed in the results of the analysis of variance (p >0.05). The produced roofing tile has an improved thermal conductivity and heat insulation which can be a substitute for hazardous asbestos based roofing materials.

Keywords: urea formaldehyde, phenol formaldehyde, di-isocyanate, properties, roofing tile materials, building materials

1. INTRODUCTION

Building materials are essential to modern building and home designs. Today the trend of energy-saving is becoming popular for consumers who are environmentally responsible. Natural fiber roofing materials are one of the materials that may be used. This roofing material can be produced from agricultural waste. The implementation however must take into account considering many factors such as usability, strengths and break-even point, health and safety. There have been studies in the past as well as research and development of roofing materials made from fibers derived from various natural materials, due to minimal cost and locally available, providing a new

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choice for consumers. The use of natural fibers with roofing materials as a component will help to reduce the price as well as weight, without causing health issues. Such improved materials also have a low thermal conductivity. They can also be used as a roofing material to reduce heat inside the building [1,2,3]. It should go without saying that global regions with high ambient temperatures, such as Thailand, have an increased need for new nonhazardous materials like asbestos, and that such a country also has a large agricultural production with waste that has yet to be identified for building materials. Such materials are rarely re-used and are typically disposed of by incineration, contributing to an increase in fine particles in the atmosphere. At present, such materials are scattered nationwide by their respective agricultural-areas with some variations in product quantity. Agricultural waste materials, including cellulose, hemicellulose and lignin have a fiber ratio of 4:3:2 [4]. Oil palm empty fruit bunch fibers are composed of cellulose 65%, hemicellulose 19% and lignin 2% [5,6]. In the past, there were more than 43 million tons/annually of such lucratively agricultural waste, with oil palm empty fruit bunch fibers waste was the largest volume [7]. Obviously the gathering of fibers could be a lucrative benefit if they are developed into new industrial products. Oil palm empty fruit bunch (OPEFB) fibers is a kind of agricultural waste material with highly nutritional value compared to fresh grass [8]. Many of these agricultural waste products are left by farmers which are very low value to this industry. The waste materials are suitable for use in the production of new forms roofing materials. The application of natural plant fibers, agricultural waste and biomass materials is a new field and these natural fibers can be recycled [9]. The advantages of agricultural waste utilization include low cost, light weight, biodegradability, ecologically non-toxic insulation, provide sound insulation, and the fact that such materials can be recycled [10,11]. The production of reinforced concrete using low-cost natural fibers, resulting in a readily available versatile and renewable material, is already in use.. Past research has produced several fiber treatment processes to increase the durability of such natural fibers [12]. Bamigboye et al. experimental study on the use of waste polyethylene terephthalate (PET) and river sand in roof tile production[13]. Santhosh et al. studied the strength of corrugated roofing elements reinforced with coir [14]. Pasilo and Teeboonma Investigation of the properties of roofing tiles manufactured from agricultural residues [15]. Kittisak and Prayoon studied and comparison the physical, mechanical and thermal properties of roof tiles from OPEFB fibers[16]. Jessada et al. studied the mechanical and physical properties of roof tiles prepared from sugarcane fibers [17]. Akindapo et al. studied the development of roofing sheet material using groundnut shell particles and epoxy resin as composite material [18].

This study show how to produce roofing tile materials from OPEFB fibers ,with the three basic types of adhesive properties are compared physically, mechanically and thermally using the same quantity. Because PF is a durable adhesive, it has good adhesion to wood, high strength and has excellent thermal stability. The disadvantage of UF resin is that it bonds with amino methylenic at high temperatures and humidity conditions [19,20]. The PMDI is also widely used in the wood panel industry, where it is used in the production of MDF and particle board (PB) with thermosetting adhesives, and provides material properties of high strength [21,22,23,24]. One of the topics of this paper is the effect of resin content on the properties of roofing tile materials.

2. MATERIALS AND METHODS

2.1 Preparation of fibers and chemicals

The fibers were taken from the palm oil industry from in Surat Thani Province, Thailand. The OPEFB fibers were washed in water and then treated with sodium hydroxide (NaOH grade, 1310-73-2 by a Thai manufacturing company) for 24 hours. The treated fibers were then cleaned with water, dried then ground into shorter fibers, having an average length of 5 mm. According the calculated size of the fibers used in the manufacturing of roofing sheets, it was found that the number of remaining oil palm empty fruit bunch fibers of 73.17%, with an average width of 0.74 mm, length 4.75 mm, thickness 0.16 mm, and slimness ratio 28.91. The chemicals used in this experiment were ammonium chloride (NH4CL-CAS No.:12125-02-9) and paraffin emulsion (SE-331). Urea formaldehyde (UF 10L617A), Phenol formaldehyde (PF TOA-DOV Chem), and Di-isocyanate (pMDI PM-2000) resin synthetic adhesives were used in the experiment as a bonding medium for roof tiles.

2.2 Experimental procedure

The roofing tiles were formed using a hot press machine process. The OPEFB fibers are cleaned to remove residual oil before they are processed to form roof tiles. During drying the fibers are standardized to a moisture of 3-5% by weight of dry fibers. Amount of binder resin used are, 3,5,7,9 and 11wt% UF,PF and PMDI, with 1% paraffin emulsion (SE-331) and 2% ammonium chloride (NH4CL-CAS No.: 12125-02-9). After mixing they are sprayed onto the fiber mixture in a rotating drum mixer at a speed of around 40 rpm. The UF, PF and PMDI resin are then added in the same manner as described to make raw roofing material. The adhesive coated fibers are evenly distributed into the mold of a standard dimensional size 400 × 400 × 6 mm^2. The sheet is called a preform board (Figure 1 b). A hot press is used to produce the required roof tiles a compression pressure of 150 kg cm^{-2} at a temperature of 120 °C for 10 minutes. The hot press machine conditions required for all methods are as follows, OPEFB fibers using thermosetting adhesives based on UF, PF and PMDI resins. The finished roofing material must be kept at room temperature for 24 hours to allow the resin to set and cooling before subjected to physical, mechanical and thermal properties testing (Fig. 1 d, e).

(a) (b) (c) (d) (e)

Figure 1. OPEFB fiber (a), preform board (b) mold (c) corrugated roofing tile materials (d,e)

2.3 Specimen preparation and testing method

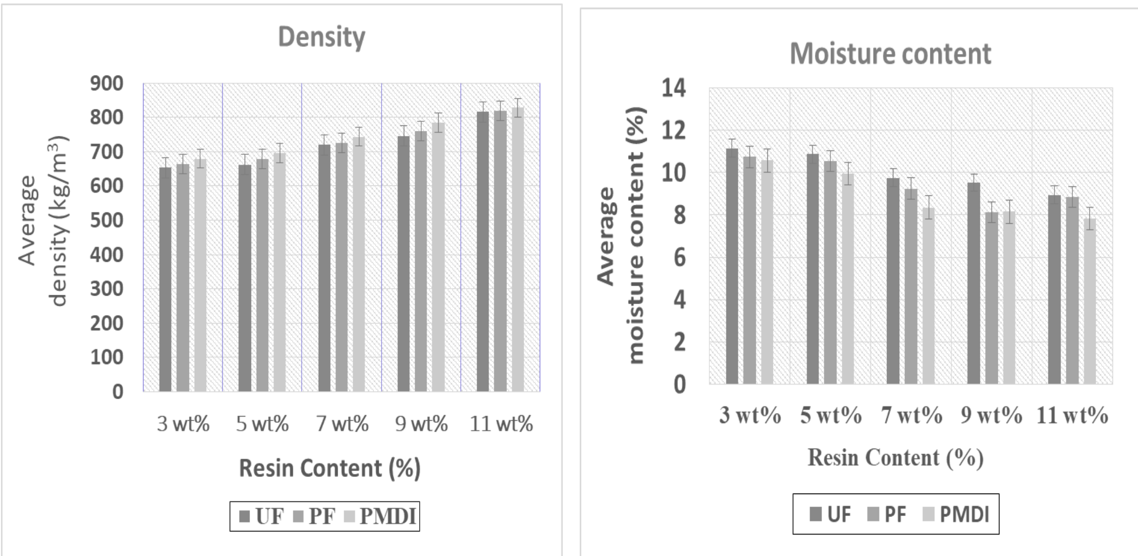
The dimension of specimens tested for density, humidity content, water absorption, thickness inflation were 50×50 mm and permeability of water is 400×400 mm, according to JIS A 5908-2003 (8 type) [25] and TIS 535-2556[26]. The mechanical properties test consisted of impact test is

12.70×63.50 mm dimension(ASTM D 256-2006a)[27] while for modulus of rupture and modulus of elasticity are 50×200 mm. Tensile strength test was done according to ASTM D 1037-12[28]. Samples of 300×300 mm were used to test thermal properties according to ASTM C177-2010[29], and while for test of conductivity, resistivity and solar reflectance is 100×100 mm. The solar reflectance machine was UV-VIS-NIS spectrophotometer (Shimadzu: MPC 3100), ASTM E891–87[30]. The number of specimens tested for each test was 5 samples on averaged for each test.

3. RESULTS AND DISCUSSION

3.1 Density properties

The density of the roofing tile materials made of OPEFB fibers with resin content at 3,5,7,9 and 11wt% showed UF resin had an average density ranging from 652.85 to 816.12 kg.m^{-3} and the PF density was ranging from 663.22 to 819.72 kg m^{-3} and the binder PMDI resin had a density between 679.69 to 827.63 kg.m^{-3} respectively. Determining the normal distribution of density based on density distribution considerations, it was found that the density values were distributed along a straight line with a p-value of 0.369 (greater than 0.05) proving that the density value had a normal distribution (Figure 2 a). The roofing material has thus passed the JIS A 5908-2003 standard level.



(a) (b)

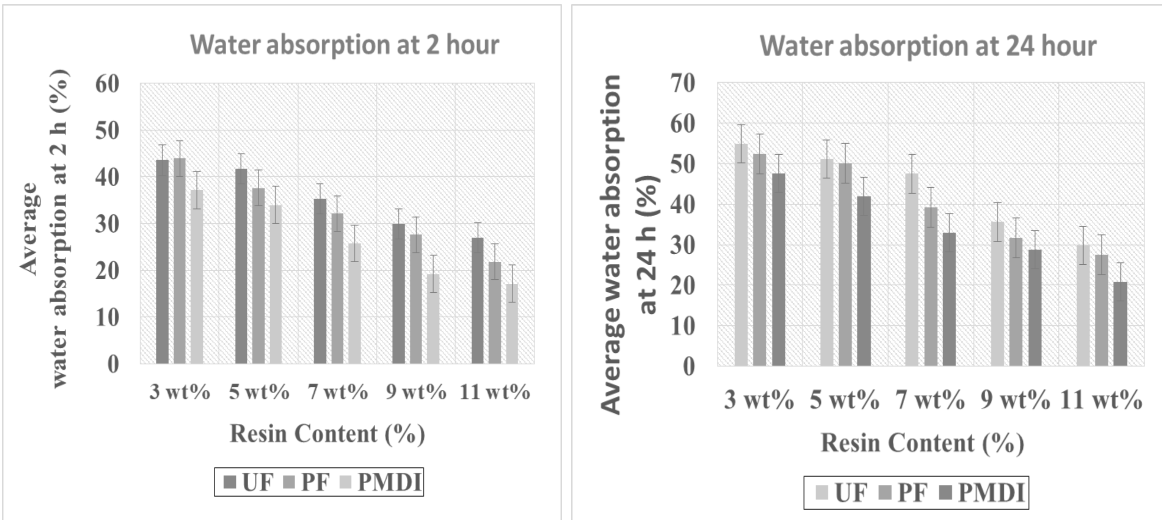
Figure 2. Effect of resin types and content on (a) density and (b) moisture contents ($p > 0.05$)

3.2 Moisture content properties

Figure 2 (b) shows that the effect of moisture content for roofing tile materials where the resin content was 3, 5, 7,9 and 11wt%. UF, PF and PMDI resin as the adhesive gave moisture contents ranging from 11.15 to 8.94%, 10.73 to 8.85% and 10.57 to 7.82% respectively. Determining the normal distribution of moisture contents based on distribution considerations. It was found that the moisture contents values were distributed along a straight line with a p-value of 0.476 (greater than 0.05). Thus, it was estimated that the moisture content was of the required distribution (Figure 2 b). The results showed that PMDI material had an average moisture content lower than expected PF this is because of the material's high density followed by a roofing material that used adhesives type PF and UF respectively.

3.3 Water absorption Properties

Water absorption was performed at 2 h and 24 h interval soaking time for the roofing tile materials using UF, PF and PMDI with a resin content of 3, 5, 7,9 and 11 wt% for each sheet respectively. The roofing sheet material had the average water absorption at 2 h ranging from 43.54 to 26.92%, 43.91 to 21.82%, 37.15 to 17.12% and at 24 hour ranging from 52.42 to 27.42%, 54.85 to 29.75% and 47.57 to 20.75%, respectively. The results showed that the sheet using UF type adhesive gave the highest water absorption value followed by PF-type adhesive plates and PMDI-based plates with low water absorption and best properties. Determining the normal distribution of WA for 2 and 24 hours based on distribution considerations, it was found that the water absorption values were distributed along a straight line with a p-value of 0.906 and 0.357 (greater than 0.05). Thus, it was estimated that the water absorption value had a normal distribution (Figure 3 a, and b).The value met so the standard level of JIS A 5908-2003[25].

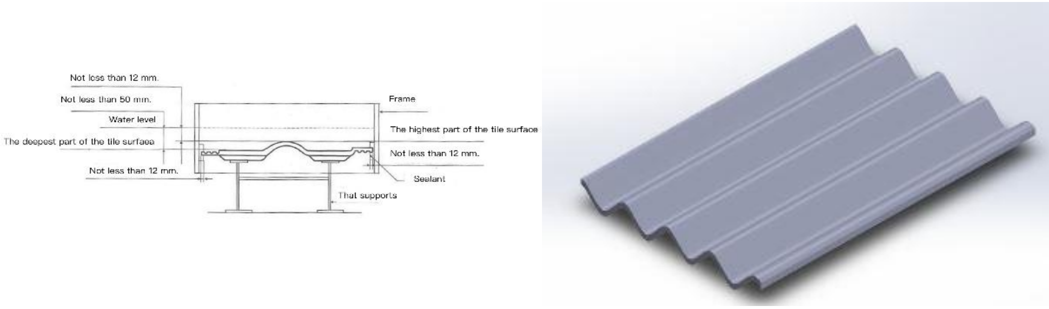


(a) (b)

Figure 3. Effect of resin types and content water absorption at 2 (a) and 24 hour (b) (p > 0.05)

3.4 Water permeability properties

Water permeability at 24 hours exposure of roofing tile material made of OPEFB fibers using UF, PF and PMDI resin where the resin content was 3,5,7,9 and 11wt% for the sheet respectively. The 24 hour test results showed no leakage of water through the roof tiles and so prevents water penetration (Figure 4 a, b). The results is from Fig. 4 a, by applying the such structure in (b) to the water column and allowing the water to seep through all types of tile adhesives. It was found that sheets using PMDI-type adhesive showed better properties than PF and UF, respectively. The value meets the standard level of TIS 535-2556 [26].

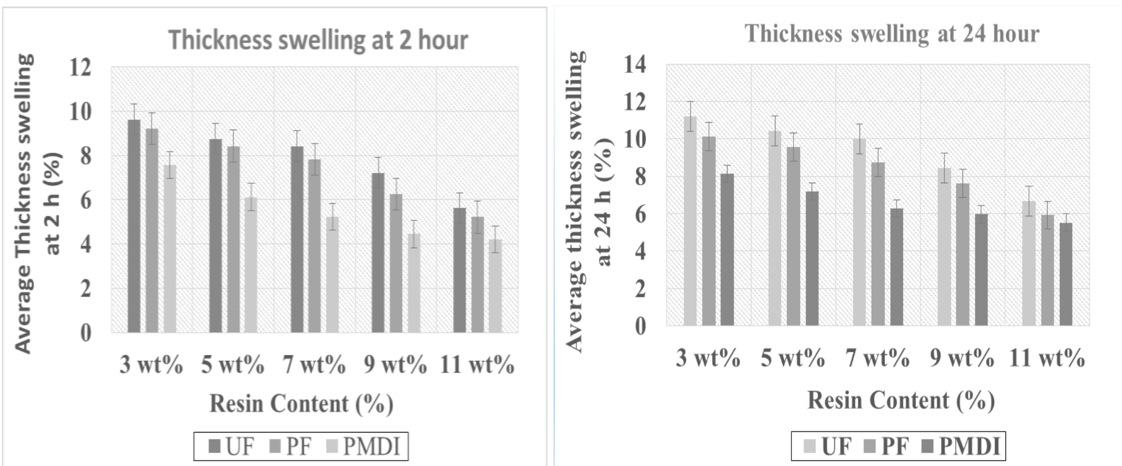


(a) (b)

Figure 4. Water permeability test equipment (a),Tiles used for testing (b)

3.5 Swelling properties

Again the sheets were tested for 2 h and 24 hour periods using different UF, PF and PMDI resin content were 3,5,7,9 and 11wt% was used for the sheets respectively. The adhesive resin produced a thickness swelling ranging from 9.21 to 5.63%, 9.62 to 5.18% and 7.57 to 4.21%, after the 2 hour period and a thickness swelling of UF,PF,PMDI adhesives to 11.21 to 6.68%, 10.12 to 6.91% and 8.14 to 5.52%, respectively after 24 hours. The experiment revealed that when the amount of adhesive substance in the roof tiles was increased, the value of thickness swelling decreased. This is due to the fact that more binder can penetrate into the fibers than less binder. It was found that PMDI-type adhesives showed better properties than PF and UF-type adhesives, but they were not significantly different Determining the normal distribution of thickness swelling at 2 h and 24 hour periods, based on distribution considerations, it was found that the thickness swelling values were distributed along a straight line with a p-value of 0.521 and 0.546 (greater than 0.05). Thus, it was estimated that the thickness swelling value had a normal distribution as required (Figure 5 a and b).

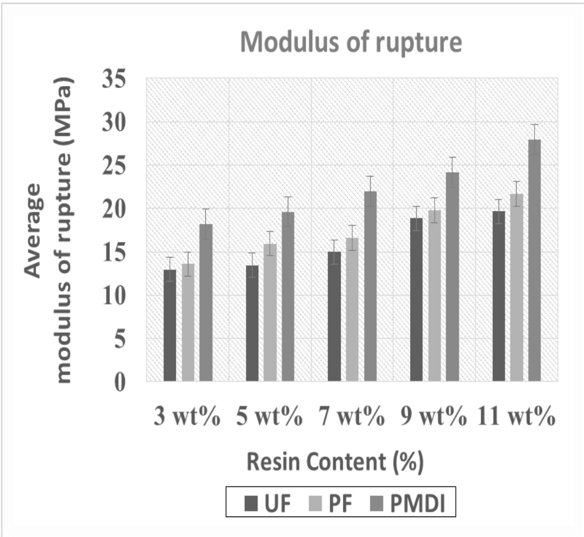


(a) (b)

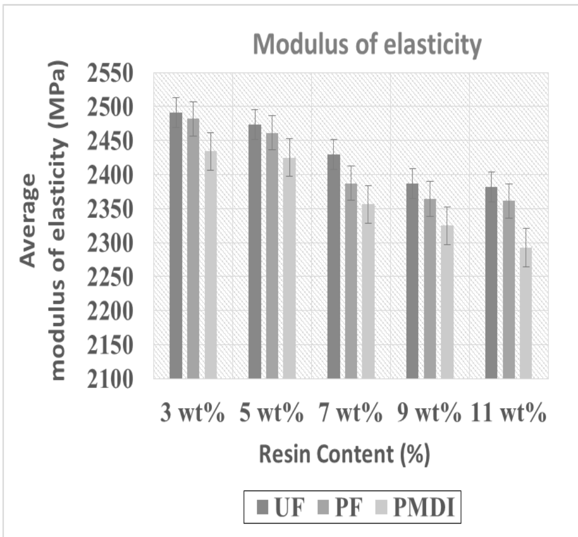
Figure 5. Effect of resin types and content thickness swelling in water at 2 h (a) and 24 h (b) ($p > 0.05$)

3.6 Modulus of rupture (MOR) and modulus of elasticity (MOE)

Regarding MOR and MOE, the roofing tile materials with a resin content of 3,5,7,9 and 11wt% of UF, PF resin gave an average ranging from 12.95 to 19.65 MPa, 13.57 to 21.65 MPa and PMDI resin an average ranging from 18.15 to 27.97 MPa respectively (Figure 6 a). At a resin content of 3,5,7,9 and 11% of UF, PF results gave an average ranging from 2491.32 to 2381.73 MPa 2481.73 to 2361. 43 MPa, 2434. 41 to 2292. 52 MPa respectively (Figure 6 b). Determining the normal distribution of MOR and MOE based on distribution considerations. It was found that the MOR and MOE values were distributed along a straight line with a p-value of 0.715 and 0.724 (greater than 0.05). Thus, it was estimated that the MOR and MOE value had the required distribution.



(a)



(b)

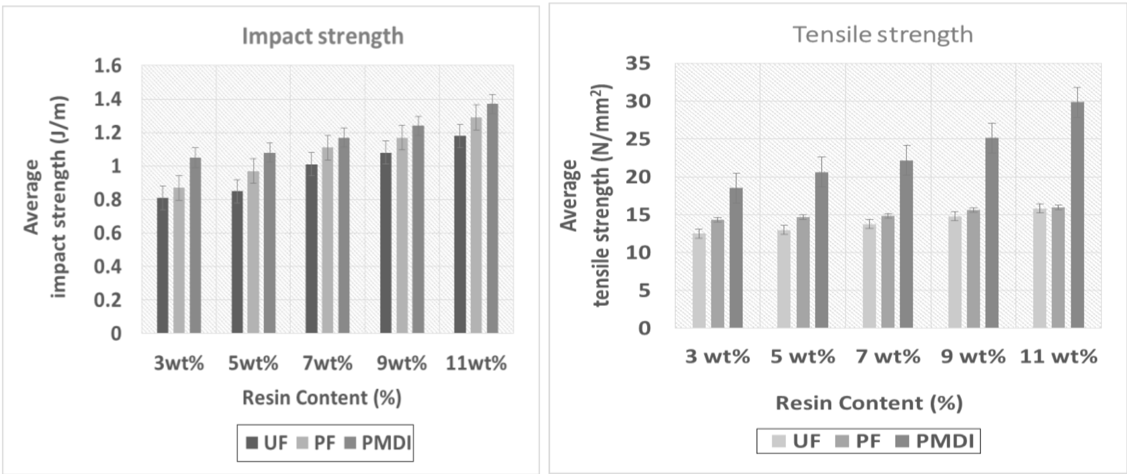
Figure 6. Effect of resin types and content MOR (a) and MOE (b) ($p > 0.05$)

3.7 Impact strength properties

The effect of impact strength where the resin content was 3,5,7,9 and 11wt% of UF, PF resin gave an average ranging from 0.81 to 1.18 J.m and 0.87 to 1.29 J.m. The synthetic adhesive PMDI resin gave an average ranging from 1.05 to 1.37 J.m respectively. Determining the normal distribution of impact strength based on distribution considerations, it was found that the impact strength values were distributed along a straight line with a p-value of 0.898 (greater than 0.05). Thus, it was estimated that the impact strength value had a normal distribution as required (Figure 7 a).

3.8 Tensile strength properties

Regarding the effect of tensile strength with a resin content of 3,5,7,9 and 11wt% of UF, PF with a resin average ranging from 12.52 to 13.82 $N.mm^{-2}$ and 14.16 to 14.95 $N.mm^{-2}$, respectively. The binder of PMDI resin, had a value ranging from 15.05 to 15.68 $N.mm^{-2}$. Determining the normal distribution of tensile strength based on distribution considerations. The tensile strength values were distributed along a straight line with a p-value of 0.846 (greater than 0.05). Thus, it was estimated that the tensile strength value had a normal distribution as required. (Figure 7 b).

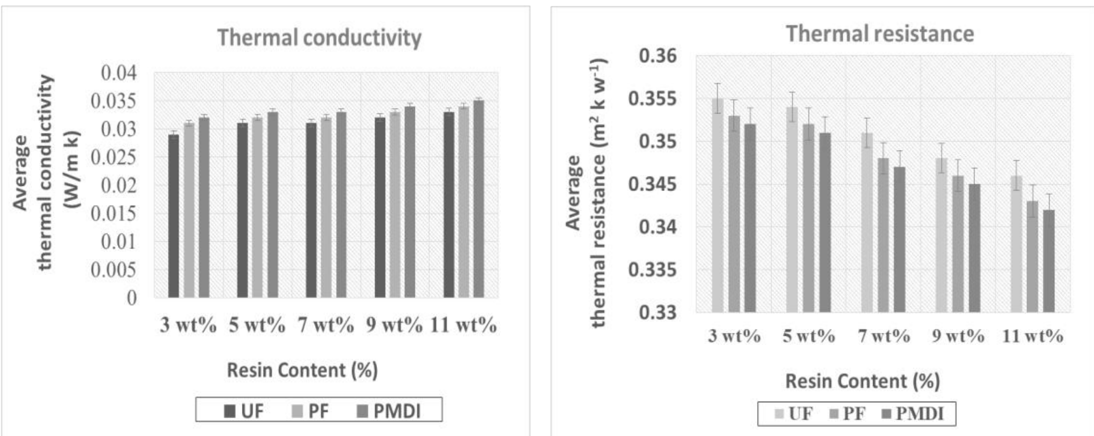


(a) (b)

Figure 7. Effect of resin types and content impact strength (a) and tensile strength (b) ($p > 0.05$)

3.9 Thermal conductivity and resistance properties

Figure 8 (a ,b) shows the effect of thermal conductivity and resistance where the resin content was 3,5,7,9 and 11wt% of UF and PF resin values were ranging from 0.029 to 0.033,0.031 to 0.034 w.m k^{-1} and 0.355 to 0.346 $m^2.k\ w^{-1}$. The adhesive PMDI resin produced an average ranging from 0.032 to 0.035 w.m k-1 and 0.352 to 0.342 $m^2.kw^{-1}$ respectively. Determining the normal distribution of thermal conductivity and resistance based on distribution considerations and the thermal conductivity and resistance values were distributed along a straight line with a p-value of 0.641 and 0.564 (greater than 0.05). Thus, it was estimated that the thermal conductivity and resistance value had a normal distribution as required.



(a) (b)

Figure 8. Effect of resin types and content thermal conductivity (a) and thermal resistance (b) ($p > 0.05$)

3.10 Solar reflectance properties

Evaluating the value of solar reflectance of the roofing tile materials from OPEFB, fibers with a resin content of 3,5,7,9 and 11wt% were tested this gives a solar reflectance at a wavelength of 350–2,500 nm. This gave an average solar reflectance value ranging from 21.18 to 24.18% and 21.24 to 25.18% for UF and PF resin, respectively. A roofing material with PMDI binder resin, gave a solar reflectance ranging from 22.18% to 24.91% respectively (Figure 10). Determining the normal distribution of solar reflectance based on distribution considerations, it was found that the solar reflectance values were distributed along a straight line with a p-value of 0.267 (greater than 0.05). Thus, it was estimated that the solar reflectance value had a normal distribution as required.

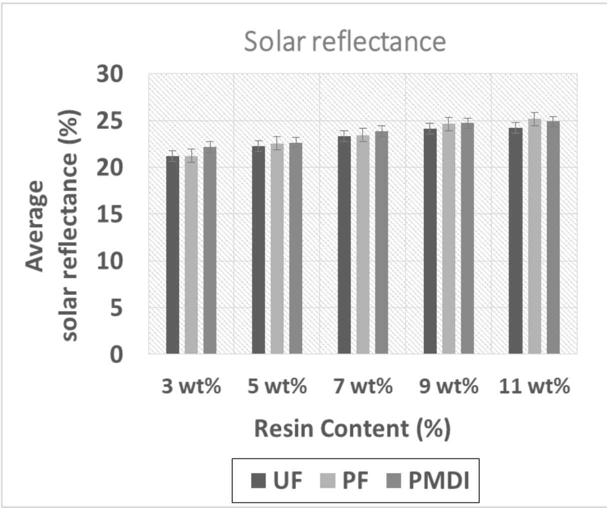


Figure 9. Effect of resin types and content solar reflectance at wavelength 350–2,500 nm ($p > 0.05$)

4. CONCLUSION

Regarding the effect of resin content on the properties of roofing tile materials for use as a building material the following conclusions were made. The density of the roofing material using UF, PF and PMDI adhesives with 3, 5,7,9 and 11wt% binders the density increasing as the amount of binder increases, this is due to the increased amount of binder that penetrates deeper into the fibers and PMDI-type adhesive gave the highest density of 827.63 kg m^{-3}, PF of 819.72 kg m^{-3} and UF 816.12 kg m^{-3}. That PMDI resin provides higher physical properties, and the performance of the sheet was influenced by the adhesive types and quantity of adhesives. The heat resistance is higher at lower density and amount of adhesive content and decreases as the density and amount of adhesive increases, UF-type adhesive is 0.355 $m^2.kw^{-1}$, PF-type adhesive 0.346 $m^2.kw^{-1}$ and PMDI is 0.352 $m^2.kw^{-1}$ respectively. The reflection of radiation at a wavelength of 350-2500 nm increased with the amount of binder, with PMDI of 24.91%, PF of 25.18% and UF of 24.18%.

With a p> 0.05, the results of the analysis of variance revealed that the type of resin content used had a significant influence on the physical mechanical and thermal properties of the roofing sheet materials. Having a such roofing tile material that reduces thermal conductivity and able to work as heat insulator, this new material may be used as a substitute material for heavy stone fiber roof tiles and cement tiles.

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REFERENCES

[1] N.A. Ramlee, J. Naveen, M. Jawaid " Potential of oil palm empty fruit bunch (OPEFB) and sugarcane bagasse fibers for thermal insulation application –A review " Construction and Building Materials 271, (2021). https://doi.org/10.1016/j.conbuildmat.2020.121519

[2] J. Khedari, S. Charoenvai, J. Hirunlabh "New insulating particleboards from durian and coconut coir" Building and Environment 38, (2003) 435-441.

[3] J. Khedari, N. Nankongnab, J. Hirunlabh, S. Teekasap "New low-cost insulation particle Boards from mixture of durian peel and coconut coir" Building and Environment 39,(2004) 59-65.

[4] R.C. Kuhad "Lignocellulose Biotechnology: Currentand future proaspects" Critical Reviews in Biotechnology 13,(1993) 151-172.

[5] R. Nadlene, S.M. Sapuan, M. Jawaid, M.R. Ishak, L. Yusriah "A Review on roselle fiber and its composites " Journal of Natural Fibers 13, (2016) 10-41.

[6] M. S. Sreekala, M. G. Kumaran, S. Thomas "Oil palm fibers : Morphology, chemical composition, surface modification, and mechanical properties" Journal of Applied Polymer Science 66,(1997) 821-835.

[7] S. Tengkaew & D. Wiwattanadate, "Study of source and potential of biomass from field corn in Thailand" Princess of Naradhiwas University Journal 6, (2014) 102-111.

[8] P. Wangwan, W. Tamthong, S. Kraisuwan " Fibrous webs from corn husks" Proceedings of The 55 th Kasetsart University Annual Conference, Kasetsart University, Bangkok,Faculty of Agriculture, Department of Home Economics (2018) 969-976.

[9] K. Majeed, M. Jawaid, A. Hassam, A. Abu Bakar, H. P. S. Abdul Khalil, A. A. A. Slema and Inuwa "A.Potential materials for food packaging from nanoclay/natural fibers hybrid composites" Materials &Design 46, (2013) 391-410.

[10] Asim, Khalina M. Abdan, M. Jawaid, M. Nasir, Zahra Dashtizadeh, M.R. Ishak and M. Enamul Hoque "A review on pineapple leaves fiber and its composites" International Journal of Polymer Science 2015, (2015) 16.

[11] D. Ray, B.K. Sarkar, A.K. Rana, N.R. Bose" The Mechanical properties of vinyl ester resin matrix composites reinforced withalkali-treated jute fibers, composite" Part A: Applied Science 32, (2001) 119–127.

[12] M.Sivaraja, N. Kandasamy, Velmani, M. Sudhakaran Pillai " Study on durability of natural fiber concrete composites using mechanical strength and micro structural properties"Bulletin of Materials Science 33, (2010) 719–729.

[13] G.O. Bamigboye, B.U. Ngene, D. Ademola, J.K. Jolayemi "Experimental study on the use of waste polyethylene terephthalate (PET)and river sand in roof tile production" Journal of Physics: Conference Series 1378, (2019) 10.

[14] B.S. Santhosh, N.R. Raghavendra, Deepesh Jain, Vishal Singh, Ayush Pareek "Strength of corrugated roofing elements reinforced with coir"International Research Journal of Engineering and Technology 04, (2017) 2371-2374.
[15] A. Pasilo & U. Teeboonma,"Investigation of the properties of roofing tiles manufactured from agricultural residues " International Conference on Sustainable Energy, Environment and Information Engineering. (2016) 509-514.
[16] B. Kittisak & S. Prayoon, "Compared and properties of oil palm empty fruit bunching fibers to be used as a roofing material " Psychology and education 58, (2021) 1553–6939.
[17] W.O. Jessada, S. Prayoon, A. Chaiyaprek, E. Kritte, M. Sunate, A. Kaichai.and T. Supaphorn "Mechanical and physical properties of roof tile prepared from sugar cane fiber" International Journal of Advanced Culture Technology 3, (2015) 86-89.
[18] J.O. Akindapo, U. A. Binni, O.M. Sanusi "Development of roofing sheet material using groundnut shell particles and epoxy resin as composite material" American Journal of Engineering Research 4, (2015) 165-173.
[19] F. Ferdosian, G. Pan, Z. Gao, B. Zhao " Bio-based adhesives and evaluation for composites Application" Polymers (Basel) 9, (2017) 70.
[20] M. Dunky " Urea Formaldehyde (UF) adhesive resins for wood" International Journal of Adhesion and Adhesives 18, (1998) 95-107.
[21] A. N. Papadopoulos, C. A. S. Hill, E. Traboulay, J. R. B. Hague "Isocyanate resin for particle board : PMDI vs EMDI "European Journal of Wood and Wood Products 2,(2002) 81-83.
[22] C.E. Frazier "Isocyanate wood binder" In Handbook of Adhesive technology" second ed., Marcel Dekker Inc., (2003).
[23] A. Nuryawan, B. D. Park, A. P. Singh "Comparison of thermal curing behaviour of liquid and solid urea formadehyde resin with different formadehyde/urea mole ratios " Journal of Thermal Analysis and Calorimetry 118, (2014) 397-404.
[24] K. Grostad & A. Pedersen "Emulsion Polymer Isocyanates as Wood Adhesive: A Review" Journal of Adhesion Science and Technology 24, (2010) 1357–1381.
[25] Japanese Standards Association JIS A 5908-2003" Particleboard " Japanese Industrial Standard Tokyo, Hohbunsha Co. Ltd, (2003) 23.
[26] Thailand Industrial Standards Institute, TIS 535-2013 "Concrete Roof Tiles" Ministry of Industry. (2013)14.
[27] American Society for Testing and Materials. ASTM D 256-06a. "Standard Test Methods for Impact Resistance of Plastics and Electrical Insulating Materials" In Annual Book of ASTM Standards MD, U.S.A. 08.01, (1990) 57-73.
[28] American Society for Testing and Materials. ASTM D1037-12 "Standard, Standard Test Methods for Evaluating Properties of Wood-Base Fibre and Particle Panel Material" In Annual Book of ASTM Standards ASTM D1037-12 8.01, (2020) 17.
[29] American Society for Testing and Materials. ASTM C 177-10. "Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Quarded-Host- Plate Apparatus" In Annual Book of ASTM Standards MD, U.S.A. 04.06, (2010) 21-32.
[30] American Society for Testing and Materials. ASTM E 891-87 "Tables for terrestrial direct normal solar spectral irradiance for air mass 1.5. Technical report" West Conshohocken, PA, (1987).