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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 mould with the standard dimensions of 400mm 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 as well as 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 thermal properties testing were used to test 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 ($p > 0.05$). Roofing tile material produced have improved thermal conductivity and heat insulation suitable for use as 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 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 of various materials of which natural fibers have been constantly studied, for reasons of minimal cost and local availability producing new choices 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 be obvious that global regions experiencing high ambient temperatures like Thailand have an increased need for new none hazardous materials like asbestos and such nation also have very large agricultural production with waste as yet not identified for building materials. Such materials have rarely been re-used and are left in cultivation areas normally being disposed of by incineration producing also an atmospheric fine particle problem . 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 of which oil palm empty fruit bunch fibers waste was the largest volume [7]. Obviously the gathering of fibers could be a lucrative benefit when developed into new industrial products. Oil palm empty fruit bunch 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 and biodegradability, none ecologically toxic insulation, sound insulation and such materials can be recycled [10,11]. The manufacture of reinforced concrete using low-cost, natural fibers, producing a readily available versatile and renewable material is already practiced . 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].

The study show how to produce roofing tile materials from OPEFB fibers ,with the 3 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 likewise popular in the wood panel industry used in MDF, Particle board (PB) production with thermosetting adhesives, pMDI provides material properties of high strength [21,22,23,24]. The effect of resin content on the properties of roofing tile materials is one of the subjects of this paper.

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 calculate 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, slimness ratio 28.91. The chemicals used in this experiment were ammonium chloride (NH4CL-CAS No.: 12125-02-9) and paraffin emulsion (SE-331). The adhesives tested as a bonding medium for roof tiles, were Urea formaldehyde (UF 10L617A, Phenol formaldehyde (PF TOA-DOV Chem) and Di-isocyanate (pMDI PM-2000) resin synthetic adhesive for the experiment were used.

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 400x 400 x 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 170 °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)

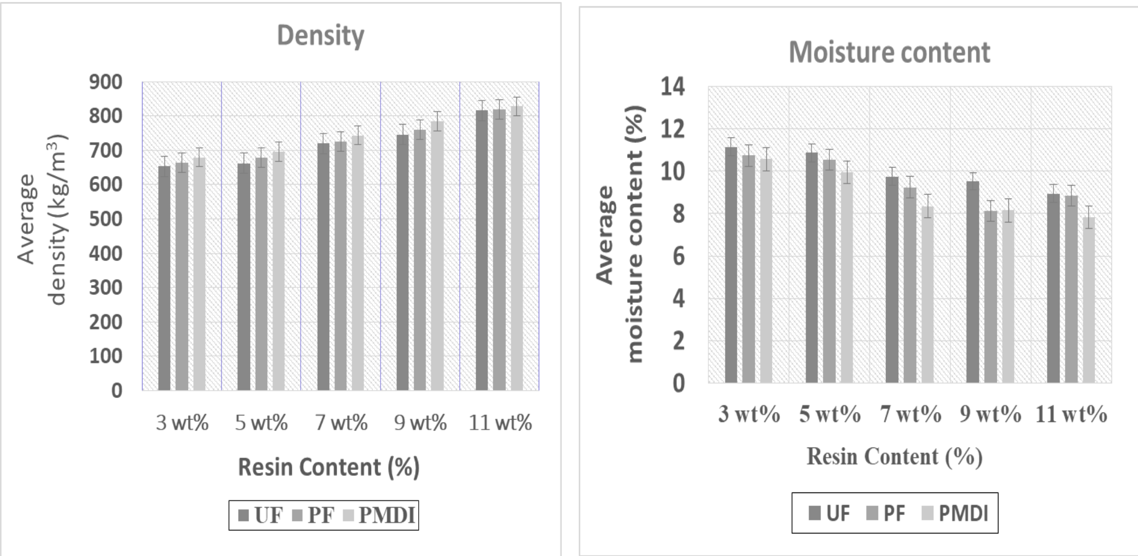
2.3 Specimen preparation and testing method

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 conductivity resistivity and solar reflectance is 100×100 mm, the solar reflectance was UV-VIS-NIS spectrophotometer (Shimadzu: MPC 3100), ASTM E891–87[30]. The number of specimens tested for each test was 5 samples an 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 between at 652.85 to 816.12 kg.m^{-3} and the PF density was between at 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 so has pass the standard level of JIS A 5908-2003.



(a) (b)

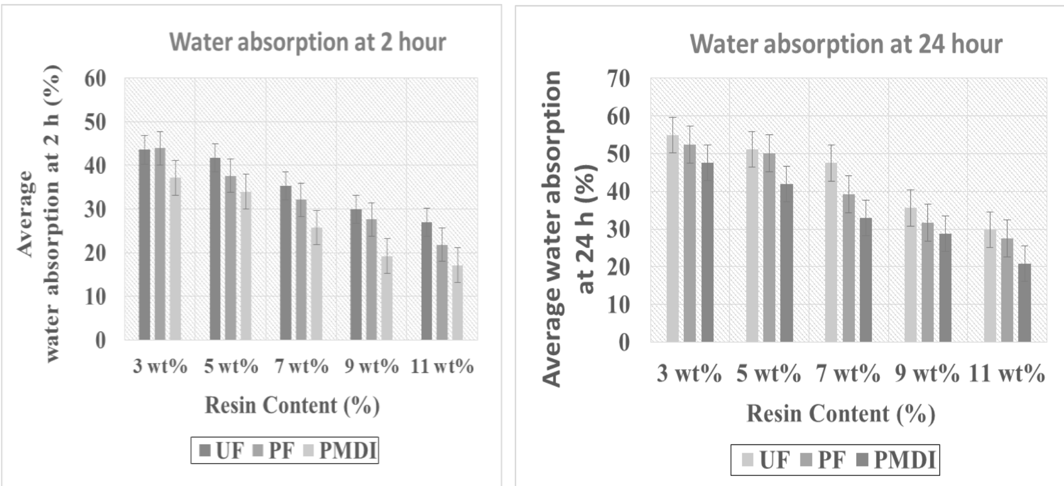
Figure 2. Effect of resin types and content on (a) density and (b) moisture contents (p > 0.05)

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% using UF, PF resin as the adhesive gave moisture contents between of 11.15 to 8.94%,10.73 to 8.85% and also adhesive PMDI between of 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 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 11wt% for each sheet respectively. The roofing sheet material had the average water absorption at 2 h between at 43.54 to 26.92%, 43.91 to 21.82%, 37.15 to 17.12% and at 24 hour between at 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].

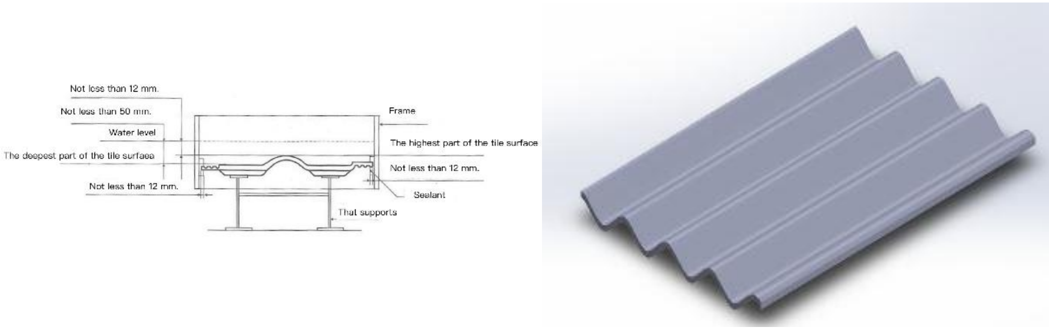


(a) (b)

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 showed that from Fig. 4 a, by applying picture (b) to the water column by 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].

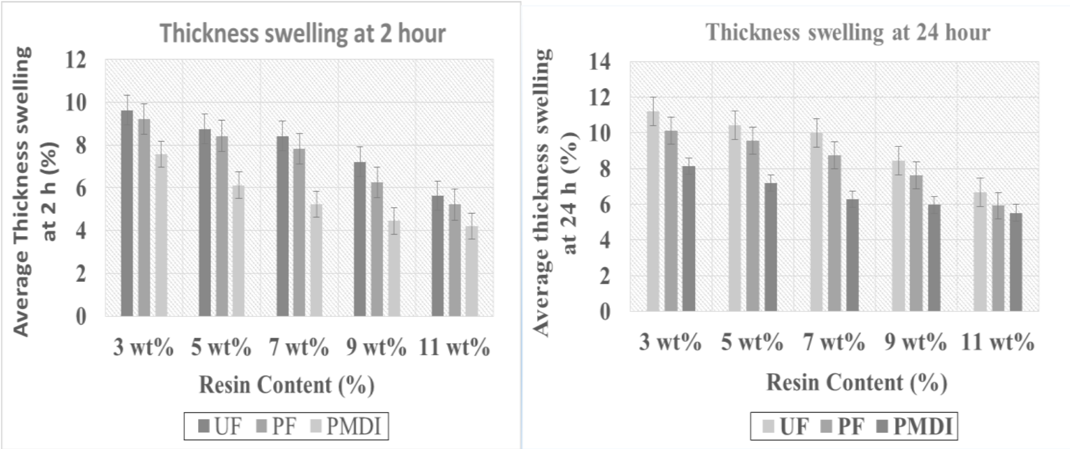


(a) (b)

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 between at 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. From the experiment, it was found that roof tiles with increased amount of adhesive substance there was a decrease in the value in thickness swelling. This is because the amount of binder can penetrate into the fibers more than the less binder content. It was found that PMDI-type adhesives showed better properties than PF and UF-type adhesives, but they were not significantly different, respectively. 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).

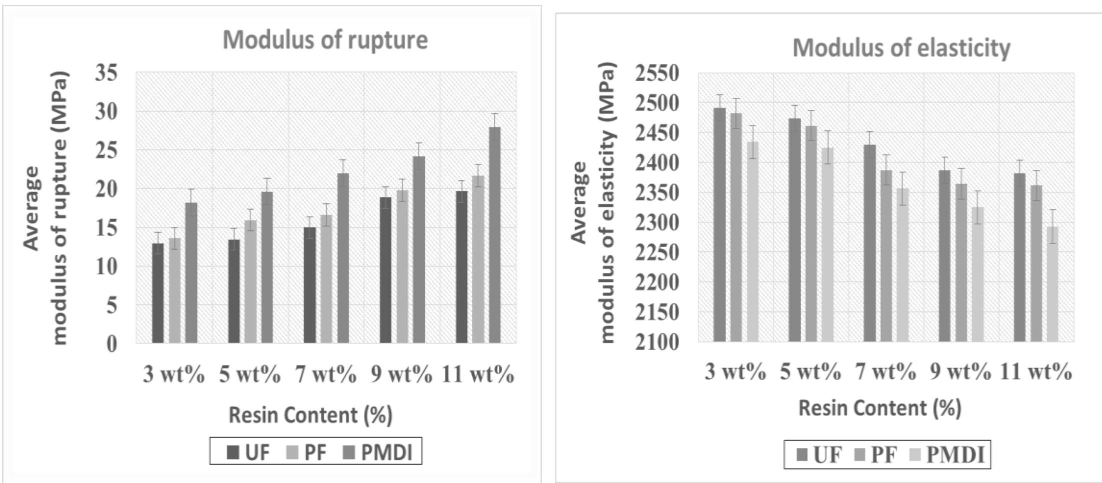


(a) (b)

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 between at 12.95 to 19.65 MPa, 13.57 to 21.65 MPa. and PMDI resin an average between at 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 between at 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)

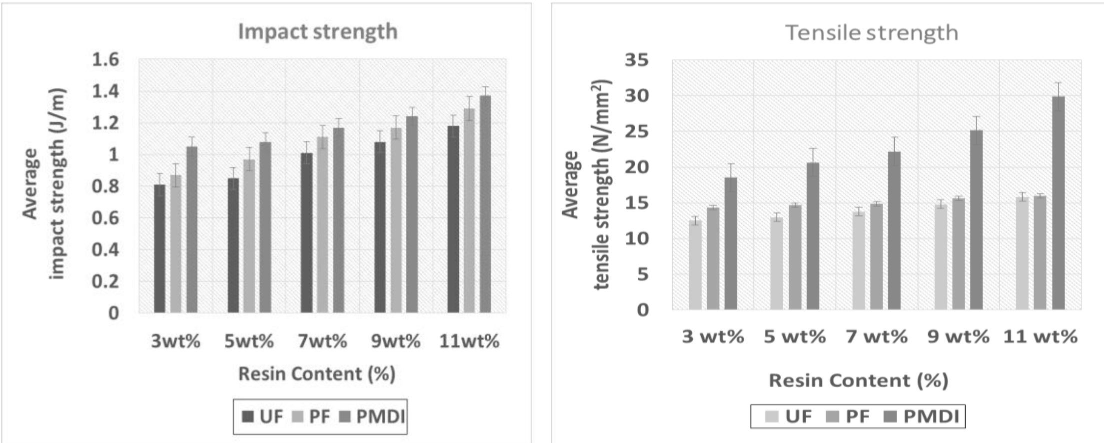
Figure 6. Effect of resin types and content MOR (a) and MOE (b) ($p > 0.05$)

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 between at 0.81 to 1.18 J.m and 0.87 to 1.29 J.m. The synthetic adhesive PMDI resin gave an average between at 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 between at 12.52 to 13.82 $N.mm^{-2}$ and 14.16 to 14.95 $N.mm^{-2}$. The binder of PMDI resin, had a value between at 15.05 to 15.68 $N.mm^{-2}$ respectively. 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).

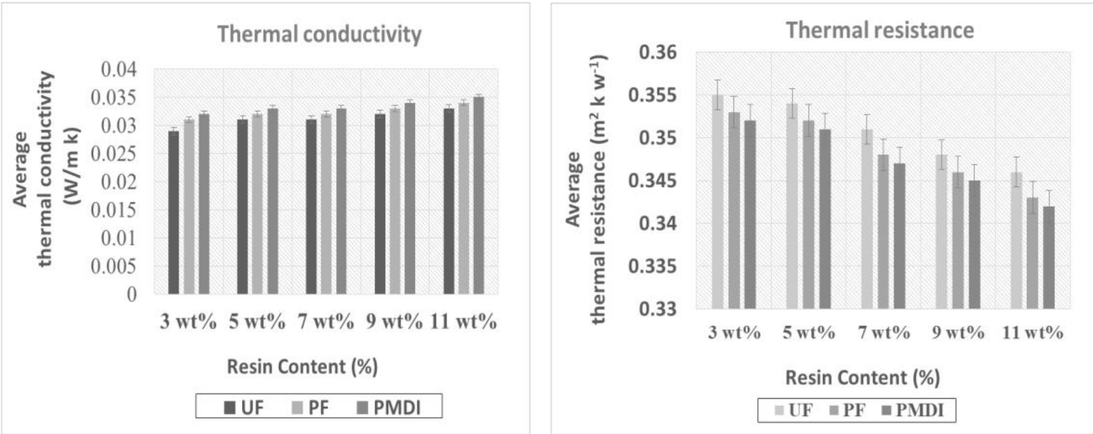


(a) (b)

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 between at 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 between at 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% of UF, PF resin were tested this gives a solar reflectance at a wave length of 350–2,500 nm. This gave an average solar reflectance value between at 21.18 to 24.18% and 21.24 to 25.18%, A roofing material with PMDI binder resin, gave a solar reflectance between 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.

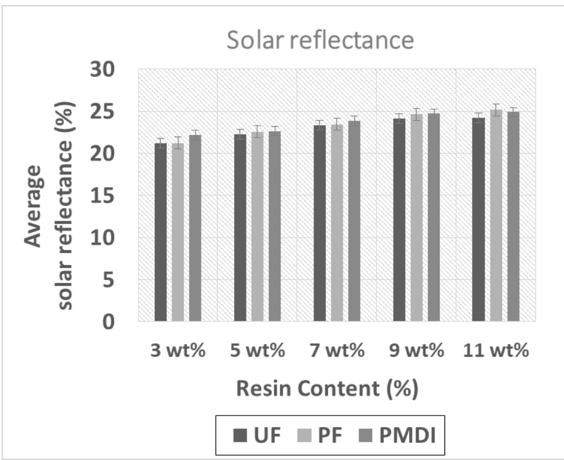


Figure 9. Effect of resin types and content solar reflectance at wavelength 350–2,500 nm

($p > 0.05$)

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}. Testing of the physical and mechanical properties according to JIS A 5908-2003, ASTM D 256-2006a, TIS 535-2556, ASTM D1037-12 and the thermal properties ASTM C177-2010, ASTM E 891-87(solar reflectance). 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 with low density and 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, PMDI was 24.91%, PF of 25.18% and UF of 24.18% reflectivity. The results of analysis of variance carried out showed that the type of resin content used had a significant influence on the physical mechanical and thermal properties of the roofing sheet materials with a $p> 0.05$. It is a roofing tile material that reduces thermal conductivity and is a 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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