Environment Protection Engineering

Vol. 41 2015 No. 4

DOI 10.5277/epe150412

PREMRUDEE KANCHANAPIYA[1], WARAPORN PINYO[1],
SAWANYA JAREEMIT[2], SUPHAPHAT KWONPONGSAGOON[2]

RECYCLING OF NON-METALLIC POWDER FROM PRINTED CIRCUIT BOARD WASTE AS A FILLER MATERIAL IN A FIBER REINFORCED POLYMER

Rapid growth in the electricity and electronics industry in Thailand has resulted in numerous problems with electrical waste management. Printed circuit board (PCB) components contain copper in an amount of approximately 10 wt. % and approximately 90 wt. % of non-conductive substrate made from fiberglass resin. In the recycling process, after copper is physically separated from PCB, only non-metallic powder (NMP) will be left; that needs to be properly disposed of and managed. Therefore, this study is a proposal of suitable choices for NMP management. The results showed that NMP can be disposed in hazardous waste landfill. Furthermore, NMP can be recycled as a component in fiber-reinforced polymer (FRP) of the following composition: coarse NMP 25%, fine NMP 25%, polyester 38.8%, hardener (Butanox type) 0.6%, catalyst (cobalt type) 0.6%, styrene monomer 10%. This FRP mixed with NMP can be properly processed into an artificial wall tile product in terms of mechanical properties, manufacturing processes and conditions of use.

1. INTRODUCTION

Printed circuit boards (PCB) are an essential basic component of nearly every type of electronic products. They contain two significant components such as metal component – copper, and non-metal component made from fiber glass resin, approximately 10 wt. % and 90 wt. %, respectively [1]. According to the previous study of Warapon [2], precious metals were separated by grinding PCB wastes into fine powder until copper particles were separated from non-metal powder (NMP) by using a vibration table. The copper particles were smelted for copper recovery while NMP was treated in inappropriate combustion or landfill due to deficient value and no options for recycling. The combustion is not the best method for NMP treatment because during the process toxic

[1]National Metal and Materials Technology Center, 114 Pathumthani, Thailand, corresponding author P. Kanchanapiya, e-mail: premrudk@mtec.or.th

substances are formed: polybrominated dibenzodioxins and dibenzofurans (PBDD/Fs) while landfill of NMP can lead to secondary pollution from heavy metals and brominated flame retardants (BFRs) leaching to the groundwater [3]. In addition, the treatment process of NMP by combustion and landfill will cause loss of resource utilization and the increase in disposal cost to recycling enterprises.

NMP is one type of fiber-reinforced polymer (FRP), consisting of thermosetting resin (phenolic resin) and glass fiber enhancing the strength of composite materials. So, NMP has the potential to be reused as a filler in FRP which can be applied for several products such as construction, furniture and modeling products, etc. [4, 5]. Moreover the main advantages of the FRP mixed with NMP are lower in cost and better mechanical strength than the conventional FRP mixed with inorganic filler (calcium carbonate or talcum) [6]. In order to reach the resource utilization of the NMF effectively and environmental soundly, the potential to reuse NMP as filler in FRP has been studied which can be formed into artificial wall tile by considering both possibilities in the field of mechanical properties and environmental impact.

2. MATERIALS

Preparation of non-metallic powder (NMP). Figure 1 shows the scheme of the process of preparation NMP from PCB scrap purchased from a PCB factory. NMP from PCB waste were prepared by roughly grinding PCB waste with a shear cutting machine and grinding into fine power with a rod mill to liberate copper particles from fiberglass resin particles. This fine powder was then sieved to separate coarse particles (above mesh 100 or larger than 150 μm) and fine particles (pass mesh 100 or smaller than 150 μm) apart. After the size screening, the compositions of fine and coarse particles were analyzed using an X-ray fluorescence (XRF) spectrometer. The result showed that the particles larger than 150 μm have high copper content with cost-efficiency for undergoing the copper separation process using a vibration table, while particles smaller than 150 μm have nearly 100% of non-metal without cost-efficiency for copper separation using a vibration table (these particles are called fine NMP). After particles larger than 150 μm had passed the copper separation process, the outcome consisted of two kinds of particles containing high copper ratios (approximately 90–95 wt. %, and approximately 2–3 wt. %) and of the part that was almost in 100% non-metallic (these particles are called coarse NMP). Figure 2 depicts the fine and coarse NMF powders used in this research.

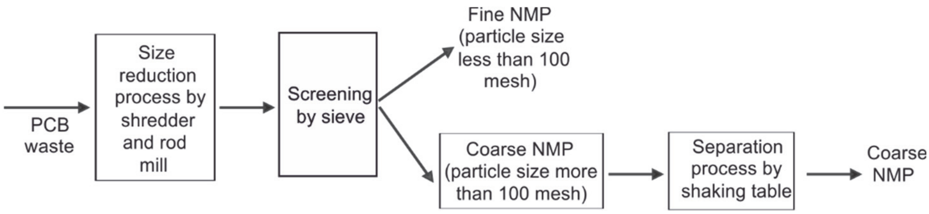

Fig. 1. Process of preparation for NMP

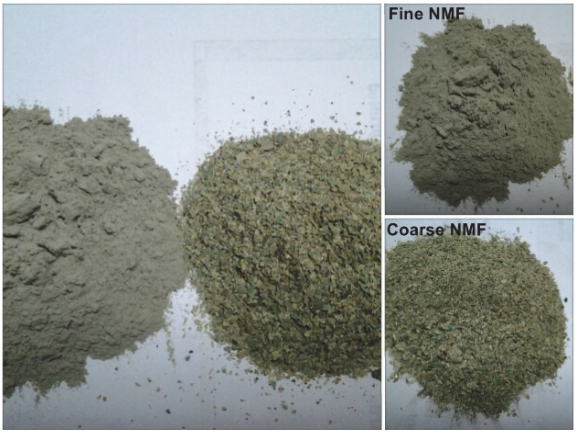

Fig. 2. Fine and coarse NMP

Preparation of fiber reinforced polymer (FRP). Generally, the composition of FRP consist of resin mixed with a monomer, accelerator, hardener and filler.

Table 1

Composition [wt. %] of samples of fiber reinforced plastic mixed with NMP

No.	Sample	Polyester resin	Cobalt accelerator	Styrene monomer	Hardener (butanox)	Filler NMP	
						Fine	Coarse
1	FRP_50F_20M	28.80	0.60	20.00	0.60	50.00	0
2	FRP_50F_10M	38.80	0.60	10.00	0.60	50.00	0
3	FRP _50F_5M	43.80	0.60	5.00	0.60	50.00	0
4	FRP _40F	48.80	0.60	10.00	0.60	40.00	0
5	FRP _50F	38.80	0.60	10.00	0.60	50.00	0
6	FRP _60F	28.80	0.60	10.00	0.60	60.00	0
7	FRP _40C	48.80	0.60	10.00	0.60	0	40.00
8	FRP _50C	38.80	0.60	10.00	0.60	0	50.00
9	FRP _60C	28.80	0.60	10.00	0.60	0	60.00
10	FRP 20F/20C	48.80	0.60	10.00	0.60	20.00	20.00
11	FRP 25F/25C	38.80	0.60	10.00	0.60	25.00	25.00
12	FRP 30F/30C	28.80	0.60	10.00	0.60	30.00	30.00

Most fillers in the market are calcium carbonate or talcum to be filled to increase the amount of materials and reduce the production cost. This research is to use NMP from PCB waste as filler substitution in FRP instead of calcium carbonate and talcum. In this experiment, NMP, polyester resin and styrene monomer were mixed to enable FRP components blending easily for convenient pouring into molds, hardeners helped the materials harden more quickly, and catalysts reacted with hardeners to ease solidifying. The materials used in this experiment were purchased from a fiberglass furniture factory. The ratios of the components used to create FRP are shown in Table 1. Experiments 1–3 were conducted to determine the right styrene monomer ratios. Experiments 4 to 6 were conducted to determine the properties of FRP with fine NMP components. Experiments 7–9 were conducted to determine the properties of FRM with coarse NMP components and experiments 10–12 were conducted to determine properties of FRM with both fine and coarse NMP.

3. TEST METHOD

The elemental composition of fine NMP and coarse NMP was determined using X-ray fluorescence (XRF) spectrometer after milling with a mortar. The NMP was heated in a muffle furnace at 900 °C for 1 day in order to volatilize the organic elements. Loss on ignition (LOI) was then determined by weighing. To determine the feasibility of NMP disposal by the landfilling method, the concentration of metals leached from NMP and FRP mixed with NMP was tested by ICP-AES according to the regulation of industry ministry: waste disposal method (2005) [7] and US EPA SW-846 [8]. Polybrominated biphenyls/polybrominated diphenyl ethers (PBBs/PBDEs) are listed in restricted hazardous materials in electrical equipment so the concentration of PBBs/PBDEs extracted from NMP and FRP mixed with NMP was tested by GC-MS based on US EPA 8270C and 3540C methods [9, 10]. The tensile, flexural and compressive strength of FRP samples (Table 1) were tested on an electronic universal testing machine at room temperature (25 °C) with a cross head speed of 50 mm/min and 2 mm/min according to ASTM D638, D790, and D695, respectively. Specimen dimensions for tensile, flexural and compressive strength were 165×20×3 mm, 125×13×3 mm and 25×25×6 mm, respectively. Izod impact strength is defined as the amount of energy absorbed in fracturing a specimen at high velocity. Izod impact test was performed on the FRP samples according to ASTM D 256 with the specimen dimensions of 63×13×3 mm. Rockwell B scale hardness (HRB) of FRP samples was determined by measuring the depth of penetration of a steel sphere of the diameter of 1.588 mm under load of 1 kN compared to the penetration made by a preload according to ASTM D 1525 with the specimen dimensions of 25×25×6 mm. The suitable mixture of FRP was used to form into artificial wall tile. The chemical properties such as thermal expansion, water absorption, chemical resistance and flammability of these tiles were tested according to ISO 10545-8: 1994, ISO 10545-3, ISO 10545-13 and UL 94 standards [15–18]. Thermal expansion was tested using a dilatometer to determine the coefficient of linear thermal expansion in mutually perpendicular directions with the specimen dimensions of 25×5×5 mm. Water absorption by immersion tests under boiling water was carried out in specimens of the age of 1 day. The chemical resistance for unglazed tiles (UGL) was tested towards potential chemical aggression that ceramic tiles need to withstand under the chemical attack of acids and alkalis at low concentration (L), and at high concentration (H). The code displayed in technical information, to indicate the chemical resistance class of an unglazed ceramic tile, is expressed for the three classification groups as follows: class UA/ULA/UHA: no visible effect, class UB/ULB/UHB: definite change in appearance, class UC/ULC/UHC: partial or complete loss of the original surface. The flammability of these tiles was tested for vertical burning test and horizontal burning test to define the flammability class according to UL 94 standards. The classification code for vertical and horizontal burning test are expressed for the five groups (V-0, V-1, V-2, 5VB, 5VA) and one group (HB), respectively[18].

In order to show the environmental impacts of FRP as a wall tile prototype, this study conducted simple life cycle assessment of the product using the Simapro 7 software [19] to calculate the overall cradle-to-gate emission associated with tile production process. Life cycle assessment (LCA) is generally considered very useful as a means of identifying environmental hot-spots in the product development stage. It allows comparisons with conventional products that may be replaced by new products, and helps to identify environmental tradeoffs. This study employed LCA in compliance with ISO 14040-14043 standards with SimaPro 7 software by selecting ReCiPe V1.06 method to evaluate mid-point impacts. Three types of tile product were studied, i.e. FRP mixed with NMP, ceramic tiles, and conventional FRP. The boundaries of the system studied include only raw materials for tile production.

4. RESULTS

4.1. PHYSICAL AND CHEMICAL PROPERTIES OF NMP

According to the analysis of the type and amount of the chemical composition of NMP by XRF as shown in Table 2, most of the NMP was found to contain Si, Ca, and Al particles which are a component of the fiberglass used in PCB boards and Br particles, which are a component of the fire retardants used in PCB. Cu is a component of the electrical conducting layer in PCB boards, found in small amounts of 1.5–2.5 wt. %; Cu in fine NMP was found in lower amounts than Cu in coarse NMP.

Table 2

Main constituents of fine and coarse NMP by the XRF method

Constituent	Coarse NMP	Fine NMP
SiO_2	29.48	30.11
CaO	11.6	14.6
Br	9.76	7.37
Al_2O_3	5.56	7.27
CuO	2.51	1.67
Fe_2O_3	1.13	3.48
ZnO	0.59	1.89
Others	1.46	2.97
Loss on ignition	37.92	30.64
Total	100	100

Table 3

Leaching properties of NMP

Constituent	Content [mg/dm^3]	
	NMP	STLC[a] [7]
Cr	<0.020	5
As	<0.078	5.0
Zn	18.3	250
Cd	<0.004	1.0
Ni	0.05	20
Cu	29.3	25
Pb	0.11	5.0
Ba	3.66	100
Hg	<0.014	0.2

[a]STLC – soluble.

To consider alternative methods for NMP management by landfill, the leaching and combustion properties of NMP were determined. Table 3 shows the result of leaching test of NMP by waste extraction test comparing with the soluble threshold limit concentration which is the regulation of the industry ministry [7]. The concentration of nearly every heavy metal was below the limitation for non-hazardous waste landfill in Thailand, except for the concentration of Cu. The leaching concentration of Cu was about 29.3 mg/dm^3, whereas the limitation standard was 25 mg/dm^3. This means that the disposal of NMP by landfill method needs to dispose NMP in hazardous waste landfill. However, the Cu leaching concentration of NMP was over the limitation, NMP could be reused as a filler material in FRP if the leaching properties of FRP sample is lower than the limit level. Thus the leaching properties of FRP sample were determined and discussed later. The concentration of PBBs/PBDEs extracted from NMP and FRP mixed with NMP was below the instrumental limit of detection, equal to 3 mg/dm^3 and also below the restriction of hazardous substances (RoHS) directive, equal to 1000 mg/dm^3 [20]. The RoHS directive for comparison was chosen because there are no limitation standards of PBBs/PBDEs for non-hazardous waste landfill in Thailand. RoHS directive restricts the use of six hazardous materials, including PBBs/PBDEs, in electrical equipment and it is closely related with WEEE (waste electrical and electronic equipment) directive which is legislation to control the problem of toxic e-waste. However, from the XRF results as shown in Table 2, the NMP was found to contain high bromine which may be a composition of brominated flame retardant (BFR) chemicals. From the literature review, it was found that the type of BFR used in printed circuit board is TBBPA (tetrabromobisphenol A) [21] which is not included in restricted substances of RoHS directive. This means that the disposal of FRP product by landfill method may be done safely in view of PBBs/PBDEs toxicity.

4.2. MECHANICAL PROPERTIES OF FRP SAMPLES MIXED WITH NMP

Figures 3–5 show the tensile strength, flexural strength, impact strength and hardness of FRP samples mixed with NMP at the ratios given in Table 1.

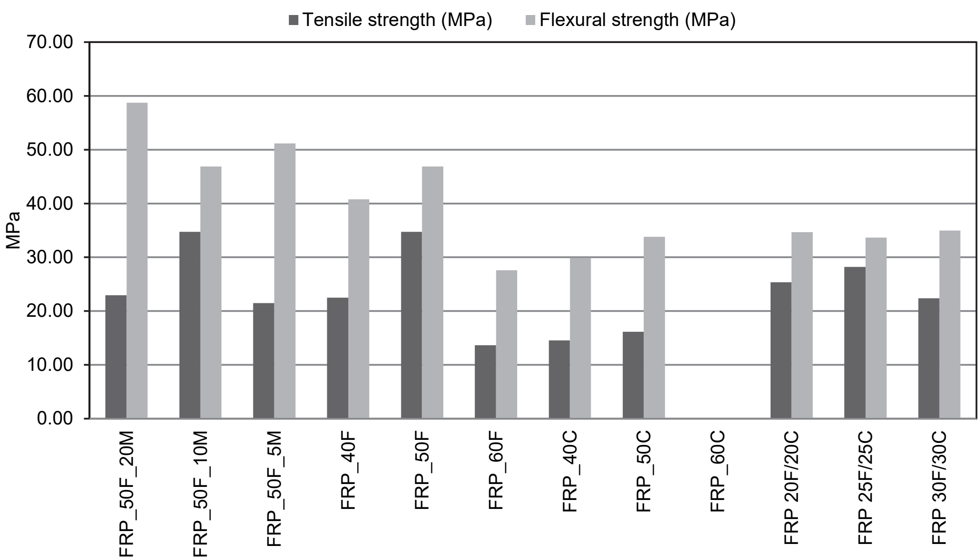

Fig. 3. Tensile and flexural strength of samples of fiber reinforced polymer mixed with NMP

When mixing fine NMP as a filler at 50 wt. %, and the monomer contents was 5 wt. %, 10 wt. % and 20 wt. %, we found that the texture of FRP mixed with 5 wt. % of the monomer was too sticky which made it difficult to mix and pour into the molds. The texture of the mixture with the monomer content of 10 wt. % and 20 wt. % could be successfully mixed and poured into the molds. However, once the FRP samples were dry, the samples mixed with 20 wt. % of the monomer bent backward and became more twisted than the FRP samples mixed with 10 wt. % of the monomer.

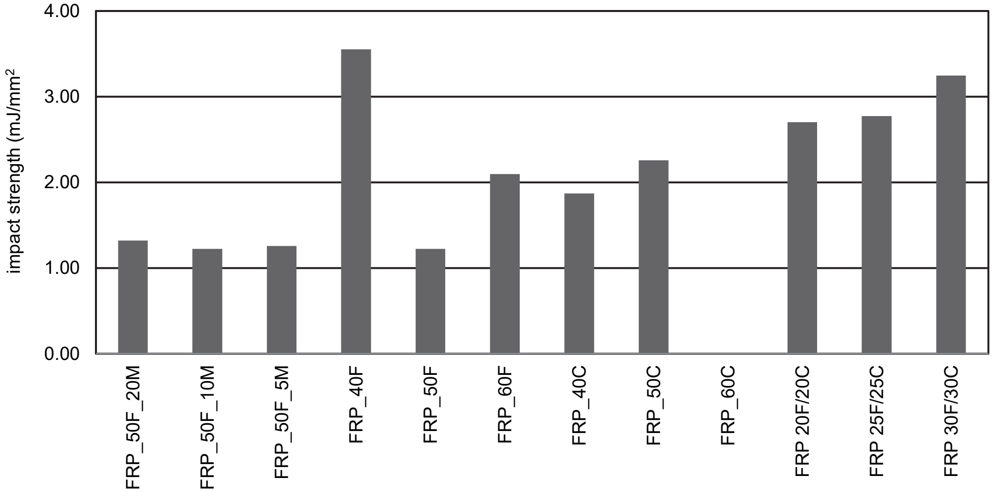

Fig. 4. Impact strength of fiber reinforced polymer mixed with NMP

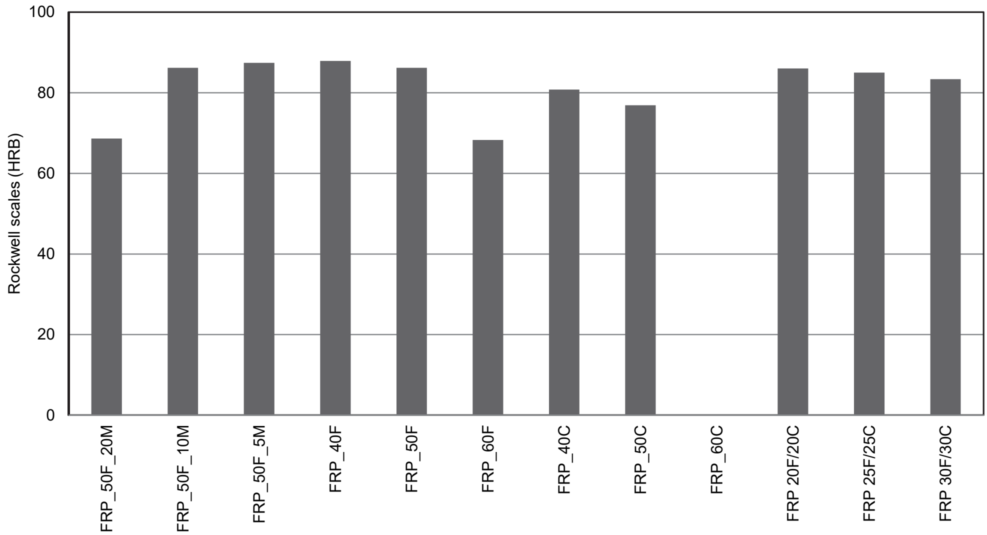

Fig. 5. Hardness of fiber reinforced polymer mixed with NMP

Considering the mechanical strengths, the FRP samples mixed with 10 wt. % of the monomer had the tensile strength of 34.71 MPa, which was the highest when compared with the samples mixed with 5 wt. % and 20 wt. % of the monomer. As for the flexural strength of the samples mixed with the monomer at the ratio of 10 wt. %, the value was found to be lower than for the samples mixed with monomer at the amounts of 5 wt. %, 20 wt. % at approximately 25 wt. % and 10 wt. %, respectively. The impact strength of the samples mixed with monomer at the ratios of 5 wt. %, 10 wt. % and 20 wt. %, equaled 1.32, 1.22 and 1.26 mJ/mm^2, respectively, which were similar values.

The values of the Rockwell B hardness of the samples mixed with monomer at the three ratios examined, were 68.65, 86.20 and 87.38 HRB, respectively. It is evident, therefore, that the samples mixed with a monomer ratio of 5 wt. % had the least strength when compared to the samples containing more monomer. Therefore, according to the consideration of the mechanical strengths and the shrinkage and bending types of the FRP samples, including the difficulty or ease of mixing and pouring into the molds, it becomes evident that the monomer ratio of 10 wt. % seems to be the right ratio for making FRP products. Therefore, applied 10 wt. % of the monomer in mixing FRP samples in order to find the suitable ratio for NMP used as an alternative filler to replace calcium or talcum.

The fine NMP ratio was changed to 40 wt. %, 50 wt. % and 60 wt. % when mixing with the 10 wt. %of the monomer. We found that the texture of the FRP mixed with 60% of fine NMP was too sticky and the mechanical strength of FRP samples was the lowest when compared with other samples. Samples containing 40 wt. % and 50 wt. % of fine NMP were mixed and poured easily and the FRP sample was neither overly shrunken nor bent. The samples mixed with fine NMP at 50 wt. % had the highest tensile strength and flexural strength at 34.71 and 46.89 MPa, respectively.

The coarse NMP ratio was changed to 40 wt. %, 50 wt. % and 60 wt. % when mixing with 10 wt. %. of the monomer. The texture of the FRP mixed with 60 wt. % of the coarse NMP was too friable, the particles failed to adhere to one another which made it impossible to mix and mold them into a shape. The samples mixed with coarse NMP at 50 wt. % had tensile strength and flexural strength equal to 16.12 and 33.81 MPa, which was higher than the samples mixed with coarse NMP at 40 wt. %. The sample mixed with fine NMP had higher mechanical strength than the samples mixed with coarse NMP at the same mixture ratio. This shows that the particles of fine NMP have better cohesion with better mechanical strength than the coarse NMP.

Samples containing 10 wt. % of the monomer mixed with both fine and coarse NMP at the ratios of 40–60 wt. % had similar mechanical strengths with tensile strengths of 25.34, 28.19, 22.35 MPa, flexural strength of 34.67, 33.66 and 34.97 MPa, and impact strength of 2.70, 2.77 and 3.25 mJ/mm^2. The samples with both coarse and fine NMP were mostly found to have higher mechanical strength values than the samples with only coarse or fine NMP. This shows that mixing coarse and fine NMP particles increased the density of the sample and coarse NMP were able to attach to one another better because fine NMP increased the space for cohesion, thereby improving mechanical strength. Nevertheless, the samples with 60 wt. % of NMP at a ratio of were found to have excessive viscosity and thickness, which was similar to the aforementioned samples with mixture ratios of 60%. The samples mixed with 50 wt. % of NMP were found to be able to add more NMP particles than the samples mixed with NMP at 40 wt. %. The hardness of all three samples containing both coarse and fine NMP was similar to one another at 80–90 Rockwell B scales (HRB) with higher mean values than of the samples mixed with only fine NMP or coarse NMP.

Therefore, according to consideration of mechanical strength with shrinkage and bending of the FRP samples including ease in mixing and pouring into molds and ability to recycle NMP waste, FRP samples using both fine and coarse NMP as fillers at half each with NMP ratios at 50% can be seen as an appropriate ratio for producing FRP products. Hence, the contents of the monomer at 10 wt. %, fine NMP at 25 wt. % and coarse NMP at 25 wt. % were selected to mix prototype artificial wall tiles from FRP.

Table 4

Mechanical properties of FRP mixed with fine NMP at 25 wt. %, coarse NMP at 25 wt. %, and similar products

Parameter	FRP sample	Artificial sandstone tile	Acrylic resin tile	Fiber cement	Std_glass fiber plastic[a]
Flexural strength, MPa	34–47	13–30	27.5	12–13	96.6
Flexural modulus, MPa	2500–3600	380–1500	6894	6000	3448
Compressive strength, MPa	118	12			

[a]Std – (soluble threshold limit) for glass fiber plastic: ASTM D 3841-98.

Table 4 shows the mechanical properties of FRP 25F/25C samples (using 10% of the styrene monomer, 25 wt. %, of fine NMP and 25 wt. % of coarse NMP, 38.8 wt. % of polyester resin, 0.6 wt. % of cobalt accelerator at 0.6 wt. % of the hardener) and similar materials. The FRP samples can be found to have worse overall mechanical properties than the acrylic resin, fiber cement and glass fiber plastic tiles [22, 23] while being better than those of artificial sandstone tiles commonly sold in Thailand's markets. Hence, there is feasibility in the production of this FRP material as artificial wall tiles to replace artificial sandstone tiles in Thailand.

4.3. THE POTENTIAL TO USE FRP FILLED WITH NMP AS ARTIFICIAL WALL TILE

In this research, we attempted to manufacture artificial wall tile from FRP filled with NMP because this product has the high demand and high value added for the construction material market. The artificial wall tile product was molded with the FRP mixtures. Other chemical properties such as thermal expansion, water absorption, chemical resistance, flammability and leaching tests of this product were tested as previously described.

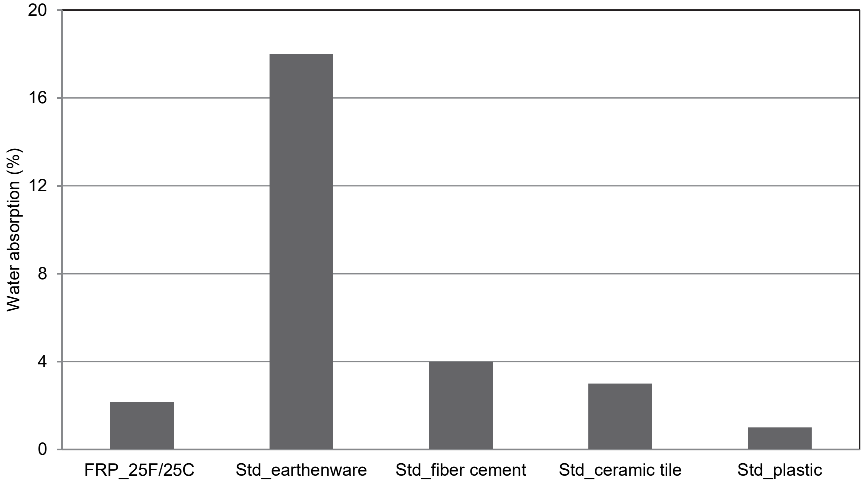

Fig. 6. Water absorption properties: Std_earthenware – TISI 613-2529, Std_fiber cement – ASTM C1185 – 08, Std_ceramic tile – ISO 10545-3:1995, Std_plastic – ASTM D 570

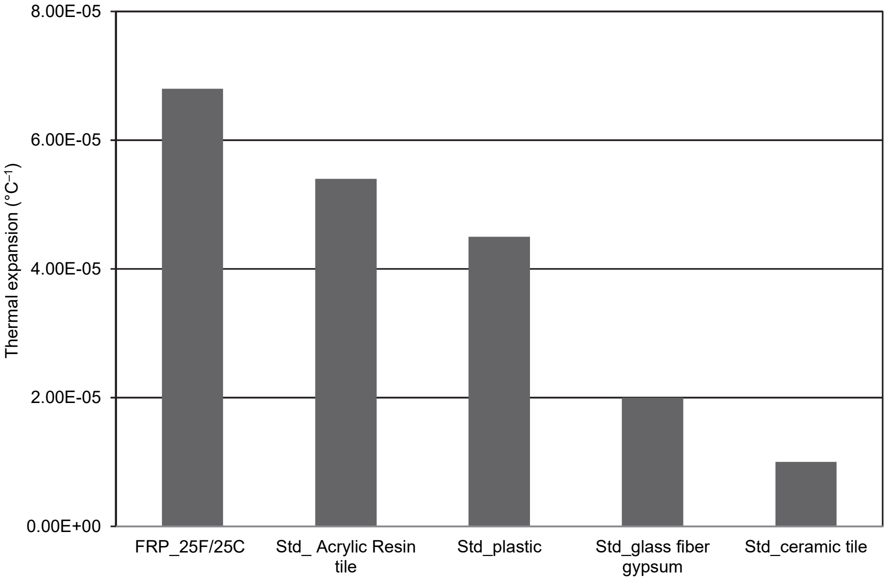

Fig. 7. Linear thermal expansion properties (*Std_plastic: ASTM D696, *Std_glass fiber gypsum: ASTMC 1355/C 1355M-96, *Std_ceramic tile: ISO 10545-8:1994)

According to water absorption and thermal expansion tests comparing the standards of other products as shown in Fig. 6 and Fig. 7, the water absorption of the artificial tile prototypes mixed with NMP was 2 wt. %, which was lower than that of earthenware tiles

(18 wt. %), ceramic tiles (3 wt. %) and fiber cement (4 wt. %), while higher than that of polyester-fiber reinforced plastic (1 wt. %). Thermal expansion of artificial tiles mixed with NMP was $6.8\cdot10^{-5}$ °C^{-1}, which was higher than that of ceramic tiles and polyester-fiber reinforced plastic tiles [22–26]. The sizes, shapes and colors of the FRP prototypes did not change after soaking and drying in sunlight for approximately three months.

The tile surfaces after chemical resistance testing with various types of acids had rust spots because of the use of copper particles in NMP as a filler (Fig. 8). The chemical resistance of these artificial tiles was in class UC/ULC/UHC. According to this data, this tile prototype should not be used for jobs with risks for chemical contact and its surface should be coated to protect rust spots.

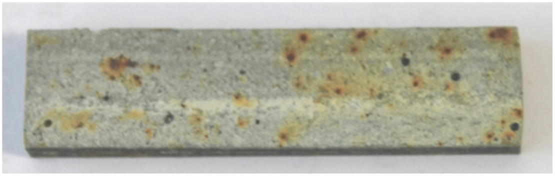

Fig. 8. Surface of FRP 25F/25C sample after chemical resistance testing

The flammability test is necessary as a specification for materials used for building decorations [27]. This study conducted flammability tests of FRP 25F/25C samples compared to conventional FRP using 50% talcum (TAL). Both types failed to pass the 20 mm vertical burning test while in the horizontal burning test (Table 5) the FRP 25 F/25C samples had better flammability properties than the TAL 50 sample at the lowest level of HB (slow burning on a horizontal specimen; burning rate lower 76 mm/min for thickness below 3 mm and burning stops before 100 mm). This result revealed that the bromine flame retardants in NMP can improve the flammability of FRP mixed with NMP to have better fire resistance as compared to FRP products using talcum as the filler. Nevertheless, in using this tile product for jobs requiring resistance to fire, flame retardants should be added to increase flammability property.

Table 5

Flammability testing of FRP mixed with NMP

Sample	Thickness [mm]	Burning rate [mm/min]	Flammability classification [18]
FRP 25F/25C-1	3.74	6.39	HB[a]
FRP 25F/25C-2	3.51	13.04	failed
FRP 25F/25C-3	3.63	7.38	HB[a]
TAL50-1	3.13	16.13	failed
TAL50-2	3.12	14.85	
TAL50-3	3.16	16.48	

[a]HB – specimens stop burning before the flame reaches the 100 mm mark.

Table 6 shows the result of the leaching test of FRP product by waste extraction compared with the soluble threshold limit concentration which is the regulation of the ministry of industry [7]. The concentration of Cu was 1.73 mg/dm^3 which is below the limitation for non-hazardous waste landfill in Thailand. This means that the disposal of FRP product by the landfill method can be done in non-hazardous waste landfill.

Table 6

Leaching properties of FRP mixed with NMP

Constituent	Content [mg/dm^3]	
	FRP 25F/25C	Limitation Std [7]
Cr	<0.020	5
As	<0.078	5
Zn	33.7	250
Cd	0.01	1
Ni	1.73	20
Cu	0.6	25
Pb	0.72	5
Ba	<0.014	100
Hg		0.2

Furthermore, in this study, preliminary test were made for the adhesive capabilities of the FRP product to cement walls. Grooves were made behind the artificial wall tile prototype before attaching to the cement walls by mortar and being left to dry in the sun for two months. The FRP tiles with grooves behind the tiles were able to attach to cement walls using ordinary mortar.

4.4. COMPARISON OF SIMPLE ENVIRONMENTAL IMPACT BETWEEN FRP PIECES AND MARKET PRODUCTS

In order to show the environmental impacts of FRP processed as wall tile products, simple life cycle assessment of the product has been conducted using the Simapro 7 software to calculate the environmental impacts [19]. The FRP 25F/25C samples were selected as representatives of the component ratios used in the assessment. As for the scope of the assessment, only the materials for FRP production were selected from software database to assess impacts. The study compared the impacts of the FRP mixed with NMP, ceramic tiles and conventional FRP.

The three highest values of environmental impacts of FRP mixed with NMP prototype were human toxicity, marine ecotoxicity and climate change, respectively (Fig. 9). Over 95% of these impacts came from polyester resin present in FRP. The impact of FRP using NMP as an ingredient is lower than the impact of conventional FRP by 50%

due to the lower polyester resin content. Furthermore, when compared to the impacts of ceramic tiles, the impacts of FRP using NMP as a component were still higher by 20%.

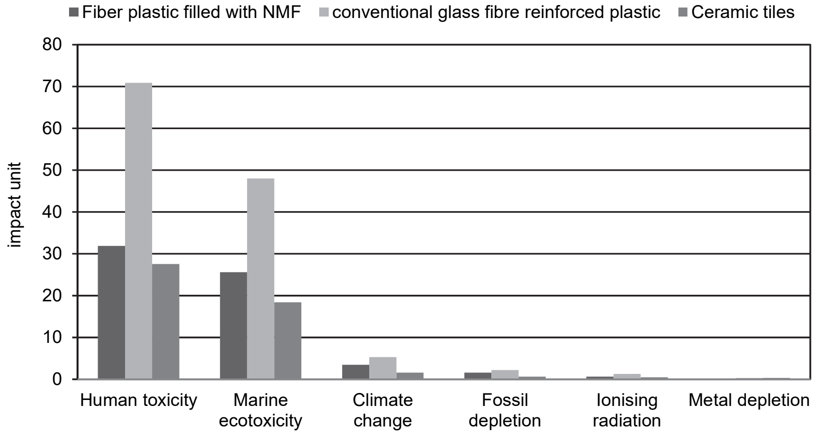

Fig. 9. Midpoint impact assessment of 1 m^3 tiles
with the SimaPro 7 software/ReCiPe Midpoint (E) V1.06 /World ReCiPe E

However, the environmental impacts from the calculation was a comparison of products of the same volume (1 m^3) and no considerations were given to other aspects such as usage life, weight and volume to the product's surface area, which influences the energy consumption in transportation and maintenance. If these factors are considered in addition to the impact assessment of wall tiles, FRP tile mixed with NMP may have lower impacts than the impacts of ceramic tile because FRP tile is more durable and has a longer usage life. Moreover, it is lighter than ceramic tiles which can save the energy for transportation.

5. CONCLUSION

The feasibility to dispose NMP by means of landfill, alternative fuels and filler material has been investigated. NMP was classified as a hazardous waste because it contains more copper than the standard for ordinary waste. Thus, if NMP is disposed of in a landfill, NMP has to be treated in secure landfill as a hazardous material. For the recycling NMP as a filler material in FRP, this research determined the suitable composition ratios of FRP material mixed with NMP. When the suitable ratios were obtained, the FRP material was processed into artificial wall tile products. According to the test results, the suitable ratios for producing FRP materials were 25 wt. % of coarse NMP, 25 wt. % of fine NMP, 38.8 wt. % of polyester, 0.6 wt. % of the hardener (butanox type), 0.6 wt. % of the catalyst (cobalt type) and 10% of the styrene monomer. According to the FRP mechanical strength testing results, the material can be molded or shaped into artificial wall tiles. However, its properties on flammability and chemical resistance were below ordinary ceramic wall tiles. These properties can be improved by including other additives. In addition, to ensure environmental safety and to concern the disposal of FRP after end-of-life product, leaching tests were conducted on various substances, including copper from FRP materials, and the values found meet the standard criteria of the Thailand's Ministry of Industry. Thus, this FRP material could be disposed of in ordinary landfill and had a lower risk for releasing hazardous substances into the environment.

REFERENCE

[1] GOOSEY M., KELLNER R., *A Scoping Study End-of-Life Printed Circuit Boards*, The Centre for Sustainable Design, UK, 2002.

[2] PINYO W., NUSOM Y., SAEHENG P., KANCHANAPIYA P., ANNANON K., *The Development of Resource Recovery Process from Industrial Waste*, The 4th International Workshop and Conference on Earth Resources Technology, Thailand, 2010.

[3] WATSON A., BRIDGEN K., SHINN M., COBBING M., *Toxic transformers. A review of the hazards of brominated and chlorinated substances in electrical and electronic equipment*, Greenpeace Research Laboratories Technical Note, University of Exeter, UK, 2010.

[4] PENG M., DONG X., GUANGHONG D., *Products Made from nonmetallic materials reclaimed from waste printed circuit boards*, Tsinghua Sci. Technol., 2007, 12 (3), 276.

[5] GUO J., RAO Q., XU Z., *Application of glass-nonmetals of waste printed circuit boards to produce phenolic moulding compound*, J. Hazard. Mater., 2008, 153, 728.

[6] JAREEMIT S., KANCHANAPIYA P., SAEHENG P., PINYO W., KWONPONGSAGOON S., *The recycling of non-metallic fraction from printed circuit board waste as reinforcing material in the artificial wall tile*, the International Conference on Green and Sustainable Innovation, Thailand, 2012.

[7] Thailand Industrial Ministry, *The regulation of Industrial Ministry: Waste disposal method*, 2005.

[8] US EPA, *Test methods for evaluating solid waste, physical/chemical methods, SW-846*, 1994.

[9] US EPA, *Method 8270C: Semivolatile organic compounds by gas chromatography/mass spectrometry (GC/MS)*, 1996.

[10] US EPA, *Method 3540C: Soxhlet extraction*, 1996.

[11] The American Society for Testing and Materials, *ASTM D638 Standard Test Method for Tensile Properties of Plastics*, 2008.

[12] The American Society for Testing and Materials, *ASTM D790 Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials*, 2007.

[13] The American Society for Testing and Materials, *ASTM D256 Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics*, 2006.

[14] The American Society for Testing and Materials, *ASTM D1525 Standard Test Method for Vicat Soft ening Temperature of Plastics*, 2007.

[15] The International Organization for Standardization, *ISO 10545-8:1994 Ceramic Tiles. Part 8: Determination of Linear Thermal Expansion*, 1994.

[16] The International Organization for Standardization, *ISO 10545-3:1995 Ceramic Tiles. Part 3: Determination of Water Absorption, Apparent Porosity, Apparent Relative Density And Bulk Density*, 1995.

[17] The International Organization for Standardization, *ISO 10545-13:1995 Ceramic Tiles. Part 13: Determination of Chemical Resistance*, 1995.

[18] Underwriters Laboratories of the USA, *UL 94 the Standard for Safety of Flammability of Plastic Materials for Parts in Devices and Appliances Testing*, 2013.

[19] PRé Consultants, *SimaPro LCA software*, the Netherlands, 2010.

[20] The European Parliament and of the Council, *Directive 2011/65/EU: The Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment*, 2011.

[21] European Chemicals Bureau, *Eu Risk Assessment Report: TBBP-A*, 2006.

[22] The American Society for Testing and Materials, *ASTM D 3841-97 Standard Specification for Glass Fiber Reinforced Polyester Plastic Panels*, 1997.

[23] The American Society for Testing and Materials, *ASTM C1185-08 Standard Test Methods for Sampling and Testing Non-Asbestos Fiber-Cement Flat Sheet, Roofing and Siding Shingles, and Clapboards*, 2008.

[24] The American Society for Testing and Materials, *ASTMC 1355/C 1355M-96 Standard Specification for Glass Fiber Reinforced Gypsum Composites*, 1996.

[25] Thai Industrial Standard, *TISI 613-2529 Standard for Glazed Ceramic Tiles for Internal Walls,* 1986.

[26] The American Society for Testing and Materials, *ASTM D570-98(2010)e1 Standard Test Method for Water Absorption of Plastics*, 2010.

[27] Department of Public Works and Town and Country Planning of Thailand, *8101-51 the Standard for Internal Building Materials*, 2008.