International Journal of GEOMATE, Dec., 2017, Vol. 13, Issue 40, pp. 1 - 8
Special Issue on Science, Engineering & Environment, ISSN: 2186-2990, Japan
DOI: https://doi.org/10.21660/2017.40.73599

A NEW COMPOSITE MADE FROM NON-METALLIC WASTE PRINTED CIRCUIT BOARDS: TABLE-TOP PRODUCT AS A PRACTICAL PROTOTYPE

Premrudee Kanchanapiya[1], Sawanya Jareemit[2] and *Suphaphat Kwonpongsagoon[2]

[1] National Metal and Materials Technology Center, National Science and Technology Development Agency, Ministry of Science and Technology, Pathumthani, Thailand
[2] Department of Sanitary Engineering, Faculty of Public Health, Mahidol University, Bangkok, Thailand; Center of Excellence on Environmental Health and Toxicology (EHT), Bangkok, Thailand

*Corresponding Author, Received: 4 May 2017, Revised: 13 May 2017, Accepted: 4 July 2017

ABSTRACT: This study aims to develop practical products that can be produced from non-metallic fraction (NMF) - a non-valuable waste from the copper recovery process of printed circuit board waste (PCBW) as a reinforcing material in glass fiber reinforced plastic (GFRP) furniture products. A table-top product was selected as the practical prototype. The results show that the new composite, called "NMF composite" can be used to replace the plywood layer or the glass fiber layer in table-top prototypes. The production process and physical properties of the new product, including weight changes, deflection and shrinkage, were studied. The advantage of the practical prototype production over the traditional GFRP production is that the processing time can be improved up to 32% because of no hand lay-up process involved. From the economic analysis and an environmental viewpoint, to promote the recycling of NMF as the filler material in FRP furniture product, government subsidy is necessary to motivate manufacturers to initiate the new product.

Keywords: Printed circuit board waste, Non-metallic fraction, Glass fiber reinforced plastic, Table-top surface

1. INTRODUCTION

The fast growth of cities and the rapid growth of the population are resulting in increasing waste, especially electrical and electronic waste (E-waste) or waste electrical and electronic equipment (WEEE). E-waste management was mentioned as one of the issues of most concern in the United Nations Conference on Sustainable Development 2012 (Rio+20). The reduction, reuse and recycling of E-waste as a resource is a challenge. The high value of the metals in electrical equipment and electronic devices is the driving force to recycle these E-wastes. The printed circuit board (PCB) is a basic component in electrical and electronic devices. A PCB contains approximately 30% metals and 70% non-metals [1-6]. The major economic driving force for recycling printed circuit board waste (PCBW) is the value of these metallic fractions, especially copper. Generally, after copper extraction through a physical process, the remaining part, which is the majority of the non-metal portion (non-metallic fraction: NMF) of the PCB consists of thermoset resins and reinforcing materials. NMF is usually disposed of, since it is not valuable and has no recycling potential [7-8]. NMF contains thermoset resin and fiber glass which, after blending with polyester resin, could establish a chemical bond and, after hardening, could be used as a substitute for materials with hardness and ductility properties [4, 9]. Fiber Reinforced Plastic (FRP) is one composite material. Its major composition is polymer matrix reinforced with fiber, which can be glass fiber or carbon fiber. Other constituents that may also be found are coupling agents, coatings, and fillers. Fillers are used with some polymeric matrices primarily to reduce costs and improve their dimensional stability [10-12]. In previous research [13-16], the composition formula for the recycling of NMF as a filler material in FRP was developed. The research determined suitable composition ratios of FRP material mixed with NMF. However, the development of practical products made from non-metallic PCB waste that can be marketed has not been initiated yet.

In Thailand, the FRP manufacturing industries use unsaturated polyester resin mixed with glass fiber and other additives to manufacture FRP. FRP is widely used as a laminate structure in several products, for example, construction materials, furniture and home decorative products, boat products, vehicle equipment, industrial machinery and pipes, liquid tanks etc. [17, 18]. In this research, the table-top product in the furniture group was selected as an initial prototype to promote the value-added product application of recycled NMF as a filler material in FRP. In general, the FRP table-top is made of polyester and glass fiber to increase the strength, placing a plywood layer inside to increase the thickness and to make it look attractive and more expensive. To serve the product functions especially of strength and thickness, it is possible to use NMF as a filler material instead of the plywood and glass fiber layer. Thus, this research evaluated the production of a table-top using the new NMF composite material to replace both fiberglass and plywood. The main issues evaluated include the raw material, production equipment, production process and physical properties of the product. Furthermore, this research considered economic aspects in terms of the production cost for the FRP product filled with NMF compared to the traditional FRP product.

2. MATERIALS AND METHODS

2.1 Material layers of traditional product and prototype product

2.1.1 Traditional product

Generally, traditional GFRP table-top products (abbreviated as Trad.1) consist of 5 layers as shown in Table 1. The top layer is a gel coat which makes the table surface glossy. The second is a laminated layer of polyester resin and glass fiber which has the function of providing high strength. Because the thickness of the laminated layer is only 1 mm, other material is used to increase the thickness of the product in order to easily join the top part and legs of the table with screws and to look good. As a result, the plywood which is the third layer is often used to increase the thickness of the product. In addition, the rigid structure of the plywood can reinforce the product's strength. The fourth layer is again a glass fiber laminated layer which is the same as the second layer described above. The last layer is optional. It can be a gel coat or putty layer.

2.1.2 Prototype product

The first option (abbreviated as New V.1) to use NMF from PCBW in the table-top product uses NMF as a secondary material instead of the plywood layer, as shown in Table 1. Since NMF is a powder, it is mixed well with polyester resin, styrene monomer, and hardener to make a NMF mixture liquid and then poured into a mold to make a composite casting. The NMF composite is used to increase the thickness of the table-top and to replace the plywood layer. The second option (abbreviated as New V.2) to use NMF from PCBW in the table-top product uses NMF from PCBW as a secondary material instead of the glass fiber and the plywood layer, as shown in Table 1. The NMF powder again has to be mixed with polyester resin, styrene monomer, and hardener to make a NMF composite casting as in the first option. The NMF layer in this option has the function of reinforcing the strength of the product instead of glass fiber, and to increase the thickness of the product instead of using plywood.

2.2 Material composition and data collection

The composition formula used for the recycled NMF as a filler material in FRP follows the research by Kanchanapiya [13, 16] as shown in Table 2. The materials used to produce the traditional FRP table-top product comprise polyester resin, MEKPO (hardener), glass fiber, and plywood. The approximate amounts of materials used for the production of a 1x1 m^2 traditional FRP table-top with 1 cm thickness are summarized in Table 3.

Table 1 Material layers of the traditional and optional table-top products

Material layers inside the table top product

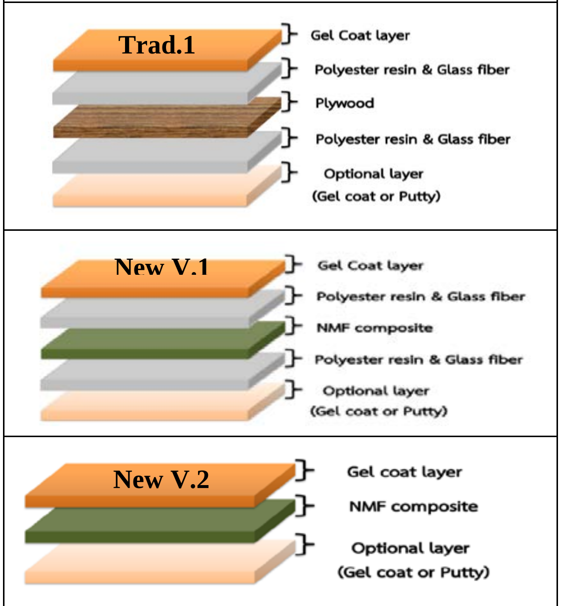

Table 2 Material composition of NMF mixture

Ingredients	Content (%)	Cost ($/kg)
Polyester resin	39.4	2.5
Styrene monomer	10	2.1
Methyl Ethyl Ketone Peroxide (MEKPO)	0.6	5.3
Coarse NMF (>100 mesh)	25	0.0
Fine NMF(<100 mesh)	25	0.0

To assess the three types of table-tops including traditional, new V.1 and new V.2 product (see details in section 2), items such as raw materials, process equipment, process time and physical product properties are evaluated as shown in Table 4. The square shape produced was 30x30 cm^2 with 1 cm thickness for all types of table-top to compare the overall production. Moreover, to find the effect of the shape and size of the table-tops on the dimensional stability, which is the main problem with FRP products, three different shapes and sizes including square (30x30 cm^2), rectangular (30x60 cm^2) and circular (30 cm diameter) were produced for the New V.2 product.

Table 3 Amounts of raw materials used for production of a 1x1 m^2 Trad.1 with 1 cm thickness

Ingredients	Amount (kg)	Cost value	Cost unit
Polyester resin	2.9	2.5	$/kg
Methyl Ethyl Ketone Peroxide (MEKPO)	0.045	5.3	
Glass fiber	0.9	3.5	
Plywood (1 cm thickness)	12	5.3	$/$m^2$

Table 4 Data collection

Evaluation item	Data collection
Raw material	type, weight, cost
Equipment	type, cost
Production process	process step, process time, setting time
Physical product property	density, strength, dimensional stability
Economic	material cost, labor cost

It is necessary to measure the deflection and shrinkage of the table-top product because this is the first property requirement from customers. However, there is no table-top standard in Thailand to limit the deflection and shrinkage value. Most FRP factories measure the deflection and shrinkage of the product by visual inspection after release from the mold. In this research, the deflection and shrinkage of the New V.2 table-top were studied for three shapes including square (30x30 cm^2), rectangular (30x60 cm^2) and circular (dia. 30 cm) with 1 cm thickness. After the mold was released, the table-top samples were placed on the smooth floor as a whole piece (to reduce the deflection effect from self-weight) without loading at room temperature in the open air. To calculate the deflection and shrinkage, the height (H), width (W) and length (L) of the surface from the reference level (see Figure 1) against times starting from mold release to 60 days were measured. The shrinkage is the difference between the original width and length (horizontal plane) of the table-top and those after duration time t, while the deflection is the difference in height. The measuring points along the perimeter were at intervals of 10 cm. The shrinkage is the average values in both the width and length directions.

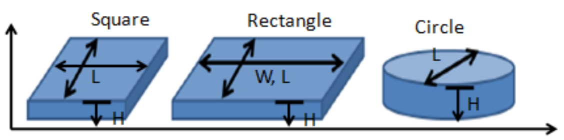

Fig. 1 Measured dimensions of table-top surface to calculate deflection and shrinkage

The deflection and shrinkage is calculated by Eq. (1).

$$\text{Deflection}_t\ (\%) \text{or Shrinkage}_t\ (\%) = \frac{|D_t - D_0|}{D_0} \times 100 \quad (1)$$

D_0 = the initial dimension after mold release (cm.)
D_t = the dimension at time t (cm.)
t = the measuring time (day)

3. RESULTS AND DISCUSSION

3.1 Raw materials

The percentage of raw materials used in these products is shown in Figure 2. Acetone and water were used as consumable materials to clean the equipment in the process. The results show that the highest weight percentage of raw material used in the traditional FRP product is plywood, in contrast with New V.1 product where the highest percentage of raw material is polyester resin. In the New V.2 product, the percentage of NMF from PCBW is the highest amount compared with other raw materials. In the comparison of the amount of polyester resin used for production in these three products, the highest amount is in the New V.1 product, followed by the New V.2 and the traditional FRP product. According to the production process of the New V.1 product, polyester resin is used to make both the FRP laminated layer and the NMF composite layer. So it is obvious that the percentage of polyester resin used for the New V.1 production is the highest compared with the New V.2 and traditional FRP products. Styrene monomer is used only for the casting process of NMF composite, so it is not present in the traditional GFRP product. The density of each product was calculated from the total weight as shown in Figure 2 and the values are 1585, 2412 and 2092 kg/m^3 for the Trad.1, New V.1 and New V.2, respectively. This result shows that the density of the New V.1 and New V.2 products is higher than the density of the Trad.1 product by about 52% and 32%, respectively.

3.2 Production of the table-top product

3.2.1 Comparison of production process

Figure 3 shows the production process and processing time of each type of table-top. The production process of a Trad.1 product started with spraying a gel coat on an open mold surface. Next, the second layer was made by rolling on the layer of the glass fiber and polyester resin using the hand lay-up technique. Then the plywood was put on the laminated second layer to increase the thickness. After that, the fourth layer was made by rolling on the layer of laminated structure (glass fiber and polyester resin) in the same way as the second layer. The curing stage of the composite occurred at room temperature. When the FRP composite was completely cured, the product was removed from the mold. Then, the last layer was made to cover the FRP laminated structure. The final step was surface cleaning and polishing of the product in order to make it smooth and shiny.

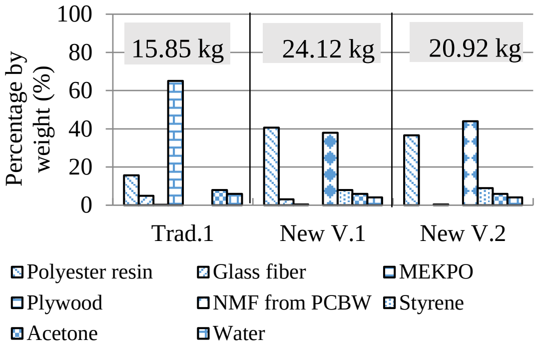

Fig. 2 Weight percentage of raw materials used to manufacture three types of table-top, size 1x1 m^2 with 1 cm thickness

The production process of the New V.1 table-top is similar to the production process of the traditional FRP product as shown in Figure 3. The product still had the glass fiber layer but the difference was that the plywood layer was replaced by the NMF composite layer. This layer was prepared by mixing and casting the NMF mixture in an open mold. The production process of the New V.2 table-top was quite different from the production process of the traditional FRP product. The product had neither glass fiber nor plywood layers, so the rolling process by the hand lay-up technique was not required. After spraying the gel coat on the open mold surface, the NMF mixture was stirred continuously and poured over the gel coat layer to cast the NMF composite for replacing the glass fiber and plywood layer. The curing stage of the NMF composite occurred at room temperature and after complete curing the product was removed from the mold. Unlike traditional production, the production of New V.2 does not require the process of rolling and trimming the excess glass fiber edge. The final step was surface cleaning and polishing.

3.2.2 Comparison of processing time

The processing time of each type of table-top product was counted and shown in Figure 3. For Trad.1, the overall production process took 47 minutes. As the first step, it took 6 minutes for preparing and spraying the gel coat on the mold surface. After waiting 20 minutes to cure the gel coat, the next step is to make the first layer of FRP laminated by the hand lay-up technique, then adding the plywood, and finally making the second layer of FRP laminate. These last three steps after curing of the gel coat took 21 minutes.

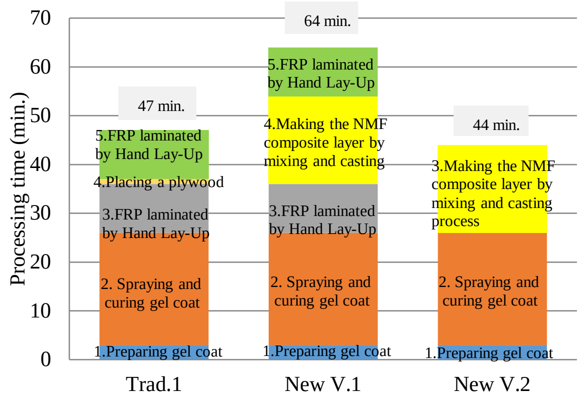

Fig. 3 Production process and processing time of each type of table-top

For the New V.1 product, the overall production process took around 64 minutes. The first to third steps were the same as for the Trad.1 product and took around 36 minutes. The mixing and pouring of the NMF mixture to make the NMF composite took 18 minutes. Finally, making the second layer of FRP laminate took about 10 minutes, the same as the Trad.1 product. For the New V.2 product, the overall production process took around 44 minutes. The first step was about 6 minutes for preparing and spraying the gel coat on the mold surface. After waiting around 20 minutes to cure the gel coat, the next process was started to make the NMF composite and took around 18 minutes, which is the same as for the New V.1 product.

3.2.3 Processing time improvement

According to the processing time of New V.1 and New V.2, their production processes can be improved in order to reduce the processing time of the products, as shown in Figure 4. Normally, the polyester resin will convert from a liquid mixture of chemicals to a solid material after adding the hardener, so it is possible to prepare the bulk of the NMF mixture in a separate process to reduce the free time in production. For the New V.1 and New V.2 products, the production process can be improved as suggested in Figure 4. While the workers are waiting for curing of the gel coat, they can mix the NMF powder with polyester resin and styrene monomer, without hardener. After making the first layer of FRP laminate, the hardener is added to the NMF mixture (NMF + polyester resin + styrene monomer). The mixture is stirred homogeneously and then poured into the mold. This improved production process can reduce the processing time by around 12 minutes. The total processing time can be improved from 64 minutes to 52 minutes for the New V.1 product and from 44 minutes to 32 minutes for the New V.2 product. Comparing these processing times with Trad.1, it can be seen that the processing time of the improved production process of the New V.2 is the lowest.

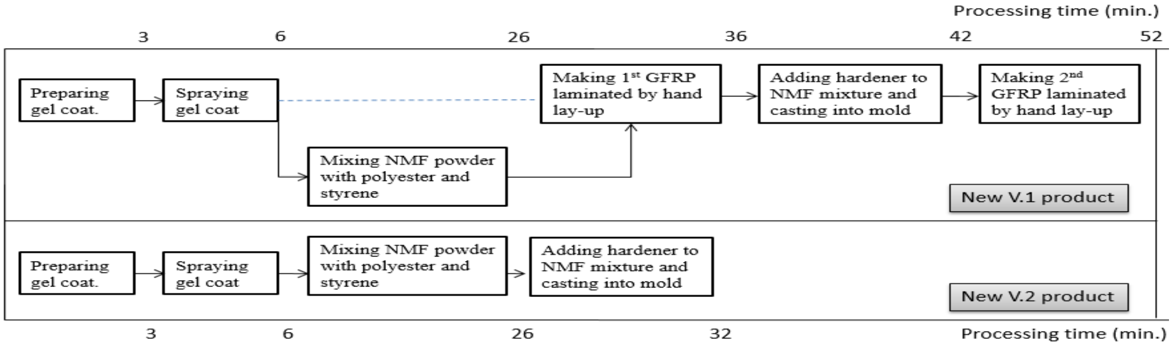

Fig. 4 The suggestion to decrease the processing time of the new V.1 and V.2 product.

Table 5 Production equipment for table top products

Equipment	Function	Trad.1	New V.1	New V.2
Open FRP mold	Shaping the table top product	✓	✓	✓
Sprayer	Spraying the color or gelcoat on the mold surface	✓	✓	✓
Fiberglass roller	Distributing the resin within a lamination	✓	✓	-
Grinder and Sander	Cleaning and polishing the product surface in order to make it smooth and shiny.	✓	✓	✓
Chemical stirrer	Blending the NMF mixture	-	✓	✓
Surface plate	Setting the main horizontal reference plane during casting	-	✓	✓

3.2.4 Production equipment

The equipment used in each production process is summarized in Table 5. For the traditional FRP product using the hand lay-up technique, the main equipment was the open FRP mold, sprayer and fiberglass roller, grinder and sander. For casting the NMF mixture of the New V.1 and V.2 products, a chemical stirrer and surface plate were the additional equipment. The stirrer was used to completely blend the NMF mixture, while the surface plate was used to set the main horizontal reference plane when pouring the NMF mixture into the open mold. There was no need to use the fiberglass roller for New V.2 because it had no polyester or glass fiber layer.

When comparing the New V.1 and New V.2 products in terms of raw materials, processing time and equipment, it is found that the resources used to produce the New V.2 product are lower than those used for the New V.1 product. So the New V.2 was selected for further study of the product properties, especially the dimensional stability.

3.3 Physical properties of the New V.2 product

3.3.1 Weight change and product strength testing

The weight of NMF composite samples (square, rectangular and circular) was measured against the times, beginning from mold release to 45 days. The results show that the range of weight change is very small, at 0.03–0.18%. It can be inferred that the weight of all samples is unlikely to change. There is no strength testing standard for GFRP table-top products in Thailand, so the flexural strength of NMF composite (with the value of 33.7×10^5 kg/m^2) as studied by Kanchanapiya [13,16] was used for comparison with the minimum weight loading of the terrazzo table (with the value of 150 kg/m^2) announced in Thai Community Product Standard [19]. The comparison shows that the strength of the New V.1 and V.2 products is likely to pass the standard of the terrazzo table.

3.3.2 Deflection versus shape and size

The percentage of deflection plotted against time for each sample is shown in Figure 5. The results show that the deflection of the square shape is the lowest, followed by the circular and rectangular shapes, with the ranges of 0.19–0.63%, 0.44–1.13% and 0.31–1.50%, respectively. At 60 days, the deflection of all product shapes continued steadily and it decreased to about 0.3–0.4% of the initial dimension after mold release. Moreover, it can be seen that the longer the curing time, the less the deflection of all samples. These deflection ranges are necessary for the tolerance of the product assembly. To study the effect of product size on the deflection, two sizes of New V.2 table-top, including 30x30 cm^2 and 60x60 cm^2 squares with 1 cm thickness, were selected to produce and measure the deflection in the same way as above. The results show that the deflection of the (30x30 cm^2) square with the range of 0.19–0.63 % is lower than the deflection of the (60x60 cm^2) square, with the range of 2.08–3.02%. It can be seen that the deflection of the bigger square is greater than the smaller one. The comparison of the deflection of the corners and sides of the square and rectangular shapes is shown in Figure 6. From the figure, at 30 days the highest deflection of the square shape at the corner is equal to 2.24% while at the side it is equal to 0.68%. Thus the deflection at the corner of the square is greater than the deflection at the side. For the rectangle, the deflection of the width is about 3.5–6% while the deflection of the length and corner are about 0.5–1.2% and 0.2–4%. Thus the deflection at the width has the highest value compared with the deflection value of the length and corner.

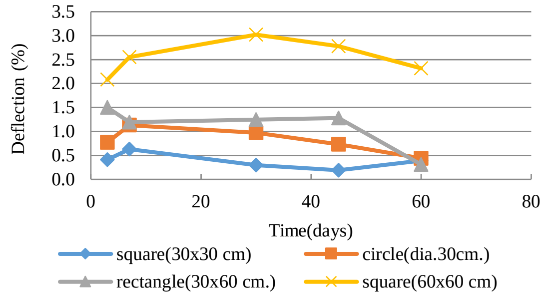

Fig. 5 Percentage of deflection versus time for square, rectangular and circular shapes

In order to reduce the deflection of the large table-top products, the compression on the table-top surface after mold release was assessed by setting a 5 kg force on the surface of the 60x60 m^2 table-top products for three days. The results show that the deflection of the product with the 5 kg weight pressing at the corner and side was 2.57 % and 0.23%, while the average deflection of the product without the weight was 7.01% and 0.99%, respectively. The deflection can be decreased by about 63% and 77% for the corner and side, respectively. Thus, it is seen that compression can significantly reduce the deflection of the product.

3.3.3 Shrinkage versus shape and size

The percentage of shrinkage plotted against time for each sample is shown in Figure 7. The results show that the maximum shrinkage was about 0.65 %, which is lower than the maximum deflection of 3.0%. The shrinkage of the circular shape is the lowest, in the range of 0.04–0.13% while the shrinkage of the square and rectangular shape is similar, with the range of 0.27–0.64% and 0.20–0.66%, respectively. Comparing the shrinkage of the small square (30x30 cm^2) and the big square (60x60 cm^2), it is found that the shrinkage of the small square at 0.50% is higher than the big square at 0.41%. At 45 days, the shrinkage of most products seems to be stable and it is slightly lower at 60 days. This data suggests the allowable variation for the size of the square and rectangular shape table-tops. In other words, the tolerance of shrinkage for the square and rectangular shapes is higher than the shrinkage tolerance of the circular shape.

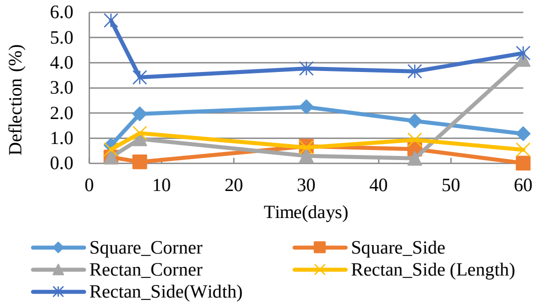

Fig. 6 Comparison of deflection at corner and side of square and rectangular shapes

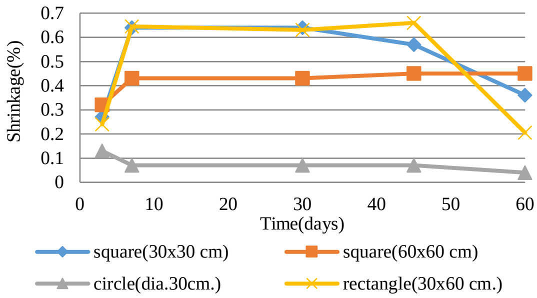

Fig. 7 Percentage of shrinkage versus time for square, rectangular and circular shapes

3.4 Simplified economic analysis

The production cost of the Trad.1, New V.1 and New V.2 products was calculated including only the raw material and labor cost. The fixed cost, overhead cost, transportation cost and others were excluded. Tables 2 and 3 show the cost of the raw materials used in FRP furniture manufacturing in Thailand. The cost of NMF from PCBW was assumed to be zero. For the labor cost, the minimum wage according to the Ministry of Labor in Thailand was about 1.25 \$/hr [6]. The improved processing time of each table-top product refers to Figure 4 as mentioned above. The production cost of each 1 cm thick table-top product was evaluated in \$/m^2 by using Equations (2)–(4) and the results are reported in Table 6.

$$\textbf{Production cost}\left(\frac{\$}{\mathbf{m^2}}\right) = \textbf{Raw material cost} + \textbf{Labor cost} \quad (2)$$

$$\textbf{Raw mat. cost}\left(\frac{\$}{\mathbf{m^2}}\right) = \sum \textbf{amountof mat.}\left(\frac{\mathbf{kg}}{\mathbf{m^2}}\right) \times \textbf{cost of mat.}\left(\frac{\$}{\mathbf{kg}}\right) \quad (3)$$

$$\textbf{Labor cost}\ \left(\frac{\$}{\mathrm{m}^2}\right) = \textbf{processing time}\ \left(\frac{\mathrm{hr}}{\mathrm{m}^2}\right) \times \textbf{wage}\left(\frac{\$}{\mathrm{hr}}\right) \qquad (4)$$

Table 6 Production cost of table-top product

Product type	Production cost ($/m²)	Raw material cost($/m²)	Labor cost($/m²)
Trad.1	17.00	16.03	0.97
New V.1	36.85	35.77	1.08
New V.2	27.44	26.77	0.67

The results indicated that the production cost of the New V.1 product equal to 36.85 ($/m²) is the highest, followed by the New V.2 and the Trad.1 product, equal to 27.44 and 17.00 ($/m²), respectively. The production costs of the New V.1 and New V.2 products are higher than the Trad.1 product, at around 116% and 61%, respectively because of the higher raw material cost. Looking at the labor cost of the New V.2 and the Trad.1 products (Table 6), the values are similar although the processing time of the New V.2 is around 47% lower than the Trad. 1. This is due to much lower wages in Thailand as mentioned above. The high material cost of the New V.1 and New V.2 products mostly depends on the amount of polyester resin used in the process. From Figure 2, the amount of polyester used for New V.1, New V.2 and Trad.1 production was 10.81, 8.56 and 2.90 kg/m², respectively. Most of the polyester resin in the New V.1 and New V.2 products was used for making the NMF mixture layer instead of the plywood layer. The cost of NMF mixture with 1 cm thickness is about 27 $/m², while the cost of plywood with 1 cm thickness is about 5.3 $/m². Thus, for the same table- top thickness, the New V.1 and the New V.2 products have higher material costs than the Trad.1 product. To reduce the material cost of the New V.1 and New V.2 products, it is possible to decrease the thickness of the NMF layer while maintaining acceptable strength. From this economic analysis and an environmental viewpoint, it can be inferred that the promotion of the recycling of NMF as a filler material in FRP furniture products still requires a subsidy from somewhere (i.e. government) to motivate manufacturers to initiate the new NMF production.

4. CONCLUSION

Due to the incomplete initiation of the recycling of NMF as a filler material in FRP in the previous study by Kanchanapiya [13, 16], this study aims to further develop practical table-top products that can be produced from NMF and to evaluate the best product option. NMF composite was used as one layer in two new table-top prototypes called New V.1 and New V.2. In the New V.1, the NMF composite replaced the plywood layer to increase the thickness of the table-top, while in the New V.2, it replaced both the glass fiber layer and the plywood layer.

The production process of the New V.1, is similar to that of the Trad.1 product except for the additional process of casting the NMF layer. The production process of the New V.2 is quite different from the production process of the Trad.1 because the rolling process by the hand lay-up technique is no longer required. The mixing and casting process of the NMF mixture is the main production process of the New V.2. The processing time of the New V.1 at 64 minutes is higher than the Trad.1 by about 36%, while the processing time of the New V.2 at 44 minutes is lower than the Trad.1 by about 7%. To improve the processing time of products, it is suggested to prepare the bulk of the NMF mixture in a separate process to reduce the free time in the production line. In this way, the total processing time can be reduced from 64 minutes to 52 minutes for the New V.1 and from 44 minutes to 32 minutes for the New V.2. Comparing these processing times with the Trad.1 product, it can be seen that the processing time for the improved production process of the New V.2 is the lowest.

The physical properties including weight change, deflection and shrinkage of the New V.2 product were measured. The results showed that the weight of all samples is unlikely to change, with the range of 0.03–0.18% by weight. The deflection of the square shape is the lowest followed by the circular and rectangular shapes, with ranges of 0.19–0.63%, 0.44–1.13% and 0.31–1.50%, respectively. Moreover, from the data of deflection versus curing time, it can be seen that the longer the curing time, the less the deflection of all samples. These deflection ranges are necessary for the tolerance of the product assembly. To reduce the deflection of the large table-top products, a 5 kg force compression on the table-top surface after mold release was tested. The results showed that the deflection of the product can be decreased by about 63% and 77% for the corner and side, respectively. The maximum shrinkage is about 0.65%, which is lower than the maximum deflection with the value of 3.0%. At 45 days, the shrinkage of most products seems to be stable. Of the three shapes tested in this research, the circular shape shows the least shrinkage.

The production costs of the New V.1 and New V.2 products are higher than the Trad.1 product by around 116% and 61%, respectively because of the higher raw material cost, especially the polyester resin used for making the NMF mixture layer instead of plywood. To reduce the material cost of the New V.1 and New V.2 products, it is proposed to reduce the thickness of the NMF layer while maintaining acceptable strength. From this economic analysis, it is shown that to promote the recycling of NMF as the filler material in FRP furniture products, a subsidy to motivate manufacturers to initiate this new product is necessary.

List of acronyms

NMF = Non-Metallic Fraction
GFRP = Glass Fiber Reinforced Plastic
E-Waste = Electronic Waste
WEEE = Waste of Electrical and Electronic Equipment
PCB = Printed Circuit Board
PCBW = Printed Circuit Board Waste
FRP = Fiber Reinforced Plastic

5. ACKNOWLEDGEMENTS

This research work was supported in part by a grant from the Center of Excellence on Environmental Health and Toxicology, Science & Technology Postgraduate Education and Research Development Office (PERDO), Ministry of Education. Moreover, this study was supported for publication by the China Medical Board (CMB), Faculty of Public Health, Mahidol University, Bangkok, Thailand.

6. REFERENCES

[1] Hall, W.J. and Williams, P.T., "Separation and recovery of materials from scrap printed circuit boards", Resources, Conservation and Recycling, Vol. 51(3), 2007, pp. 691-709.
[2] Hadi, P., Xu, M., Lin, C.S.K., Hui, C-W. and McKay, G., "Waste printed circuit board recycling techniques and product utilization", J. of Hazard.Mater., Vol. 283(0), 2015, pp. 234-243.
[3] Guo, J., Guo, J. and Xu, Z. "Recycling of non-metallic fractions from waste printed circuit boards: A review", J. of Hazard. Mater., Vol. 168(2–3), 2009, pp. 567-590.
[4] Zheng, Y., Shen, Z., Ma, S., Cai, C., Zhao, X., Xing, Y., "A novel approach to recycling of glass fibers from nonmetal materials of waste printed circuit boards", J. of Hazard. Mater., Vol. 170 (2–3), 2009, pp. 978-982.
[5] Huang, K., Guo, J. and Xu, Z., "Recycling of waste printed circuit boards: A review of current technologies and treatment status in China", J. of Hazard. Mater., Vol. 164(2–3), 2009, pp. 399-408.
[6] Marques, A.C., Cabrera, M.J,-M. and de Fraga, M.C., "A review of the recycling of non-metallic fractions of PCBs", SpringerPlus, Vol. 2, 2013, pp. 521-531.
[7] Kwonpongsagoon, S., Jareemit, S., Kanchanapiya, P., "Environmental impacts of recycled nonmetallic fraction from waste printed circuit board", Int. J. of GEOMATE, Vol. 12 (34), 2017, pp. 8-14.
[8] Tesanan, S., Kwonpongsagoon, S., Kanchanapiya, P., "Solidification/stabilization of nonvaluable residue from waste printed circuit board assembly", Int. J. of GEOMATE, Vol. 11 (24), 2016, pp. 2307-2313.
[9] Mou, P., Xiang, D., Duan, G., "Products Made from Nonmetallic Materials Reclaimed from Waste Printed Circuit Boards", Tsinghua Science & Technology, Vol. 12(3), 2007, pp. 276-283.
[10] Mallick, P.K., Materials: Fiber-Reinforced Composites (3rd ed.). CRC, 2007, pp. 18-136.
[11] Zheng, Y., Shen, Z., Cai, C., Ma, S., Xing, Y., "The reuse of nonmetals recycled from waste printed circuit boards as reinforcing fillers in the polypropylene composites", J. of Hazard. Mater., Vol. 163(2–3), 2009, pp. 600-606.
[12] Wang, X., Guo, Y., Liu, J., Qiao, Q., Liang, J., "PVC-based composite material containing recycled non-metallic printed circuit board (PCB) powders". J. of Env. Manage., Vol. 91(12), 2010, pp. 2505-2510.
[13] Kanchanapiya, P., Pinyo, W., Jareemit, S. Kwonpongsagoon, S., "The recycling of non-metallic powder from printed circuit board waste as filler material in fiber reinforced polymer", Environmental Protection Engineering, 2015, pp. 151-166.
[14] Pinyo, W., Nusom, Y., Saeheng, P., Kanchanapiya, P. and Annanon, K., "Resource Recovery Process from Industrial Waste", in Proc. 4th International Workshop and Conference on Earth Resources Technology, 2010, pp. 1-10.
[15] Jareemit, S., Kanchanapiya, P., Saeheng, P., Pinyo, W. and Kwonpongsagoon, S., "The recycling of non-metallic fraction from printed circuit board waste as reinforcing material in the artificial wall tile", in Proc. 3rd International Con. on Green and Sustainable Innovation, 2012, pp. 485-492.
[16] Kanchanapiya, P. et al., "Fiber Glass material composition with reinforced fiberglass from printed circuit board waste. Petty Patent of Thailand". No. 8341, 2013, pp. 1-2.
[17] Liampiphat, P., F.R.P. (seven ed.). Bangkok: Samphanpanit, 2008, pp. 1-283.
[18] Mou, P., Xiang, D., Duan, G., "Products Made from Nonmetallic Materials Reclaimed from Waste Printed Circuit Boards", Tsinghua Science & Technology, Vol.1 2 (3), 2007, pp. 276-283.
[19] Thai Industrial Standards Institute, "Thai Community Product Standard (TCPS): tcps948/2548", 2005, pp. 1-5.