Effectiveness of Palm Oil Fuel Ash as Micro-Filler in Polymer Concrete

Jahangir Mirza[1], Nur Hafizah Abd Khalid[1*], Mohd Warid Hussin[1], Mohammad Ismail[2], Mohamed A. Ismail[3], Mahmood Md. Tahir[1], Azman Mohamed[4], Farhayu Ariffin[1]

1 Institute for Smart Infrastructure and Innovative Construction (ISIIC), Universiti Teknologi Malaysia, 81310 Johor, Malaysia

2 Department of Structure and Materials, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Johor, Malaysia

3 School of Architecture and Architectural Engineering, College of Engineering Sciences, Hanyang University ERICA Campus. South Korea

4 Department of Geotechnics and Transportation, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Johor, Malaysia

*fiza_johor2003@yahoo.com.sg

ABSTRACT

This paper presents the potential of utilizing an agricultural waste known as palm oil fuel ash (POFA) as micro-filler in polymer concrete (PC). Being a plant with open cellulose structure, such potential has gone untapped due to its tendency to take up excessive resin during the mixing process. This study has invested its filler characterization by first segregating the POFA fillers into fine (ground POFA, GPOFA) and coarse (unground POFA, UPOFA) fillers. GPOFA was paired with calcium carbonate while UPOFA was with silica sand for comparisons. Filler characteristics were studied under microstructural examination; particle size analyzer and morphology. Twenty design mixes of polymer blended and polymer concrete were casted for flowability and compression tests, respectively. Further investigations were carried out after two categories of fillers were incorporated with different filler contents. Test data showed that filler had changed its physical features significantly after surface modification. Also, the finer fillers gave superior filling ability and compressive strength. This study concluded that POFA can be potentially transformed into effective PC filler following some physical modifications and mixing with the appropriate design mix.

Keywords: palm oil fuel ash, micro-filler, polymer concrete

1. INTRODUCTION

Sustainable issues of concrete structures have motivated researchers to boost new innovative applications [1-3]; such as, polymer concrete (PC) in construction industry. PC is produced from polymer resin, which acts as the only concrete binder; dry inert granular aggregate; and filler. Since it does not contain cementing materials and water, its hardening follows the polymerization process when additives, catalysts, or accelerators are added. Generally, PC with filler has better mechanical properties due to its effective dispersal in mixture and ability to induce denser concrete mixture packing, though the type of filling materials (natural, granulated, or synthetic) also plays a pivotal role in affecting the composite characteristics [4].The characteristics of PC incorporated with filler are governed by several factors such as the type of filler and binder, the size and shape, and also the amount of binder used [5]. Filler fills the gaps between larger particles to enhance the mechanical properties of PC. Several researchers such as Atzeni *et al*[6]. have proven that the addition of fly ash as filler in epoxy mortar has enhanced their specimens' mechanical properties more than conventional quartz flour filler due to greater fineness. This has been supported by Gorninski *et al.*[7], Bhutta *et al.*[8], Noor *et al.*[9], Mirza *et al.*[10]. The authors concluded that, the higher the fly ash filler content, the denser the PC packing. The general explanation is that very fine filler reduces the total pore volume and average pore size [11].It has also been suggested that denser concrete with fine fillers undergoes delayed diffusion of aggressive agents [7,12].

The objective of this paper is to give an insight into the potential incorporation of POFA as micro-filler into PC, gauged through microstructure and strength examination. The study covers two microstructure characteristics comparisons in between: (i) ground POFA (GPOFA) and calcium carbonate as fine fillers and (ii) unground filler (UPOFA) and silica sand as coarse fillers. The outcomes of these comparisons are supported by further investigating the filling ability of filler

and the compressive strength of PC combined under appropriate mix design. It is hope that the findings of this work will assist both researchers and engineers in the field of PC with agricultural waste used as micro-filler, in future.

2. EXPERIMENTAL

2.1. Materials

Polyester resins used in polymer concrete are commonly unsaturated Isophthalic polyester resins [13]. In this study, polyester additive with 0.5% of promoter of cobalt naphthenate (CoNp) and 1% of cross linker of methyl ethyl ketone peroxide (MEKP) by resin weight were added into the polymer binder formulation [14].

Oven-dried and crushed coarse aggregates and river fine aggregates were used and the moisture content was kept consistently below 0.1% for both. The size of coarse aggregate in this study was limited to10-12 mm only; smaller single sizes of coarse aggregate are preferred to give high compressive strength, as suggested by Rashid and Mansur[11].

Palm Oil Fuel Ash (POFA) was ground and the particles that had passed through 45 μm sieve were used as filler in polymer concrete. This was done based on the researchers' preference to use waste resources as an alternative innovative filler [11, 15, 17]. Incorporating filler with low binder content in this study is possible to obtain high strength polymer concrete. In this study, the fillers which passed through 45μm sieve were determined as fine filler, while those that passed through 300 μm sieve were used as coarse filler. Therefore, both GPOFA and calcium carbonate were paired as fine filler while UPOFA and silica sand were paired as coarse fillers.

2.2. Microstructural Examination

The size distribution of all fillers was investigated using a particle size analyzer to identify the changes in size before and after the grinding process. This was carried out using the wetting method where the particles were dispersed using distilled water to avoid agglomerated condition.

Morphology test was conducted to examine the filler surface under field emission scanning electron microscopy (FESEM) with 1000 times magnification. All specimens were coated beforehand so that significant morphology image could be captured.

2.3. Mix Proportions

The mix proportions of twenty PC with different fillers are given in Table 1. In this study, Isophthalic resin was used as binder of PC. 12% by weight of resin was mixed with methyl ethyl ketone peroxide (MEKP) as a catalyzer (hardener) and cobalt naphthenate (CoNp) as the initiator. All fillers that occupied the PC spaces varied from 8% to 16% by weight of filler. To achieve the strength of PC inert granular material, fine and coarse aggregates were used. The coarse aggregate content was fixed at 30% by weight of total PC. The PC without any filler was designated as the control specimen. The general sample notation is as follows:

Iso-GPOFA : Isophthalic PC with ground POFA
Iso-$CaCO_3$: Isophthalic PC with calcium carbonate
Iso-UPOFA : Isophthalic PC with unground POFA
Iso- Sand : Isophthalic PC with silica sand

2.4. Specimen Preparation

The dry PC mix consisting of inert granular aggregates and filler was prepared before the wet mix. The wet mix had additional polyester binder mixed together with its initiator, and promoter. Then, the wet mix was poured into the dry mix and immediately mixed together using concrete

mixer. Releasing agent was applied onto the mold surface for easy de-molding. The fresh concrete was then poured into the mold and compacted using vibrating table for 20 seconds. The specimens were subjected to post-curing through oven-heating at 50^{o}C for six hours. All specimens were strictly prepared according to JIS A 1181 [18].

Table 1: Mix Proportion of Polymer Concrete

Mix proportion (kg/m^3)				
Polymer concrete type	Polyester binder	Filler	FA*	CA*
Iso-GPOFA, Iso-UPOFA,	132[a]	78	1240	750
		97	1190	
		116	1141	
		136	1091	
		155	1042	
Iso-$CaCO_3$	132[a]	216	1240	750
		270	1190	
		324	1141	
		378	1091	
		432	1042	
Iso-Sand	132[a]	126	1240	750
		158	1190	
		190	1141	
		221	1091	
		253	1042	

[a] polyester binder was mixed with 1% MEKP, 0.5% CoNp
*FA= Fine aggregate, CA=coarse aggregate

2.5. Flowability Test

After mixing the PC to measure its workability, flowability test was conducted as per JIS R 5201 [19]. The filing ability of actively-mobilized materials was governed by the flow spread. In this study, the actively-mobilized materials were the polymer binder and filler, which were used to fill in the gaps of inert materials. Both materials were blended at various filler content and no compaction was applied during the test. The blended polymer was poured into v-funnel slump cone (the inside diameter of v-funnel cone is 70 mm and 100 mm while the height is 50 mm) and immediately uplifted once the cone was full. The flow spread diameter was measured five times in every test after the flow spread ceased. This method has been employed since PC is sticky and has zero slumps (zero slumps lost).

2.5. Compression Test

The cured specimens were tested for compressive strength according to JIS A 1181 [18] where 110 cubical specimens (100 mm x 100 mm)including control specimens (without any filler) were prepared. Compression test was carried out using a compression machine with a capacity of 200 kN at a loading rate of 1.2 MPa/s. Effect of filler content was investigated at this point.

3. RESULTS AND DISSCUSSION

3.1. Microstructural Examination

The particle size distribution curves of various fillers are shown in Figure 1. The distribution showed that all fillers had well-graded fine and coarse micro-filler. More than 90% had passed through 45 µm sieve and approximately 80% had passed through 300 µm sieve. The mean fine filler sizes of GPOFA and calcium carbonate were 14.21 µm and 6.24 µm, respectively, while those of UPOFA and silica sand were 86 µm and 177 µm, respectively. The mean size of fillers in this study was their original size, but smaller size was obtained after POFA grinding (see morphology image). UPOFA and silica sand were deemed as coarse micro-fillers, since Bakar *et al.* [20] also classified fillers with not more than 18 µm in original mean size as coarse.

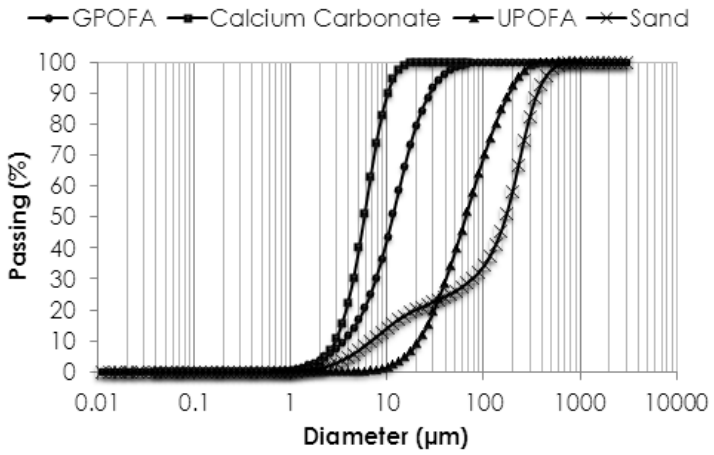
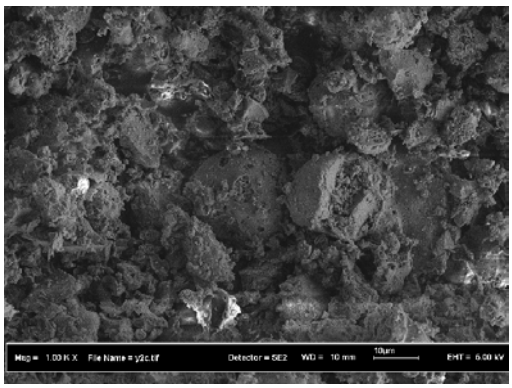
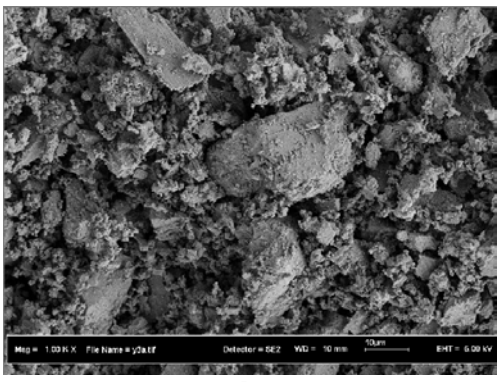


Figure 1: Particle Size Distribution of Fine and Coarse Fillers

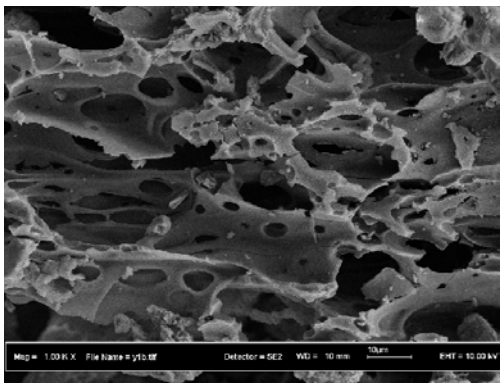
The morphology images of all fillers are shown in Figure 2. Generally speaking, no pores were spotted under FESEM with 1000 times magnification except UPOFA, but a more porous cellular structure similar to that found by Noorvand *et al.* [18] using SEM. The pores' opening size, which was between 8.3 µm and 17 µm, was expected to affect the workability of fresh PC since it would mean a higher tendency to absorb liquid resin [21, 22]. It was also expected to increase the amount of voids and capillaries, thus reducing the density of packed structure [23, 24]. The existing UPOFA opening pore size was identical to those of naturally cellulose based plant. However, after the physical grinding process, the open cellulose structure collapsed (see Figure 2a). This demonstrated a higher potential of GPOFA in becoming a PC's filler than UPOFA.



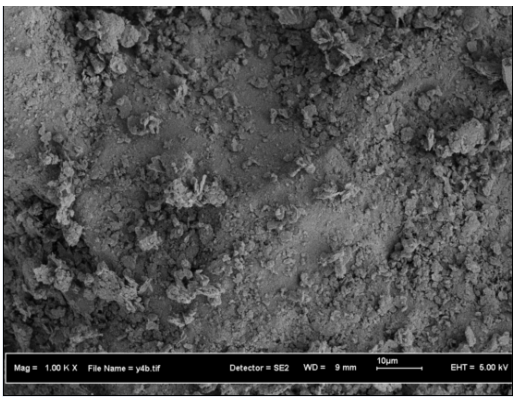
(a)



(b)



(c)



(d)

Figure 2: Morphology Image at 1000 Times Magnification of Fine Filler (a) GPOFA (b) Calcium Carbonate and Coarse Filler (c) UPOFA (d) Silica Sand

3.2. Flowability

Figures 3 and 4 present the flow spread diameter of blended polymer (polyester resin incorporating only fillers) as obtained in the flowability test. Higher flow spread diameter indicates higher flow and filling abilities and vice versa. The results demonstrated that, the overall flowability of various blended polymers had gradually decreased when filler content was increased. For blended Iso-polymer (16% filler content), reduction of about 6 %, 26 %, 23 %, and 21 % respectively had been found in Iso-GPOFA, Iso-$CaCO_3$, Iso-UPOFA, and Iso- sand when compared to neat polymer (without filler). The decrease in the flowability of blended polymer with GPOFA was the highest, attributable to the grinding of POFA. Additionally, the finer GPOFA had produced more actively-mobilized filler than UPOFA, since its performance was better. The inferior performance of UPOFA was attributed to its natural open cellulose structure (see Figure 2c) that acted as a sponge to absorb excessive polyester resin. Similar finding was observed by Bignozzi *et al.* [24]. Consequently, it can be concluded that POFA has to undergo physical modification to enhance its filler performance, a conclusion that has also been reached by Memon *et al.* [25].

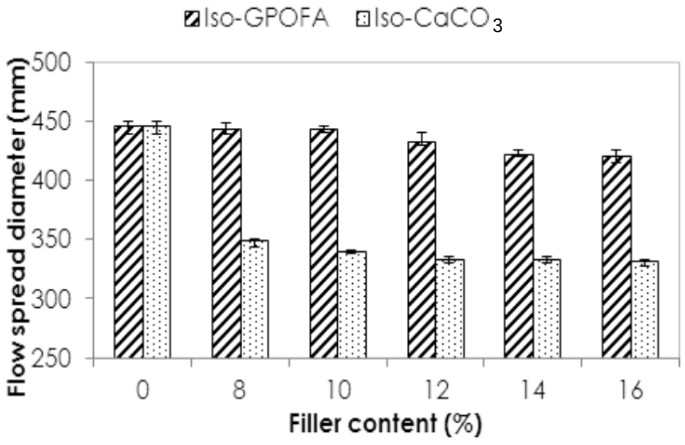


Figure 3: Flow spread diameter of Isophthalic polyester resin incorporating fine filler

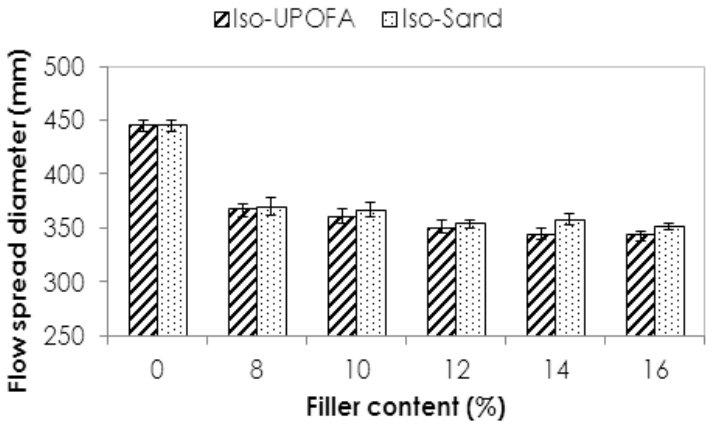


Figure 4: Flow spread diameter of Isophthalic polyester resin incorporating coarse filler

3.2. Compressive Strength

The compressive strength of PCs with different type of filler and filler content are shown in Figures 5 and 6. Figure 5 shows that PC with calcium carbonate filler has superior compressive strength as compared to PC with GPOFA and PC with fine micro filler at 10 % of filler content. This is believed to be caused by the high fineness of fillers which has tremendously increased the surface area. In this case, PC with GPOFA was expected to perform similar to PC with calcium carbonate in obtaining high compressive strength. The highest compressive strength of PC with GPOFA was achieved with 14% filler content. The inference was made that the filler had satisfactorily filled the spaces between inert granular materials. Moreover, the results demonstrated that an increment in GPOFA content elevated the compressive strength of PC. On the other hand, UPOFA gave lower compressive strength as expected due to excessive absorption of liquid resin by the open cellulose-pores structure, which had also been documented by Haidar *et al.* [22] and Bignozzi *et al.*[24].

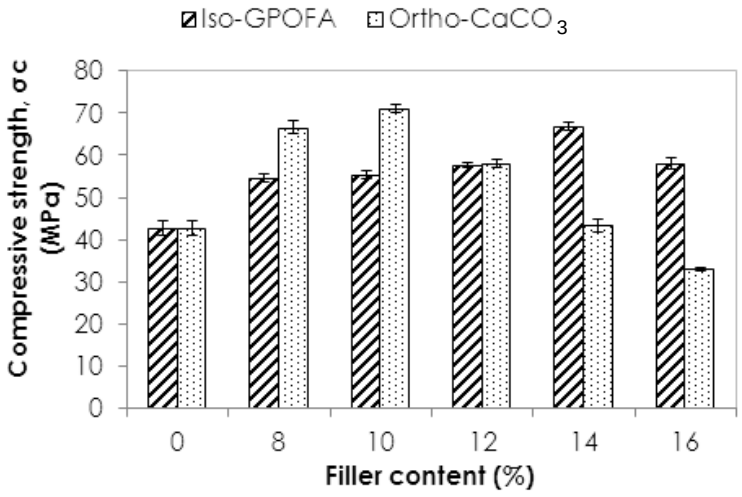


Figure 5: Compressive Strength of Isophthalic Polyester Concrete Incorporating Fine Filler

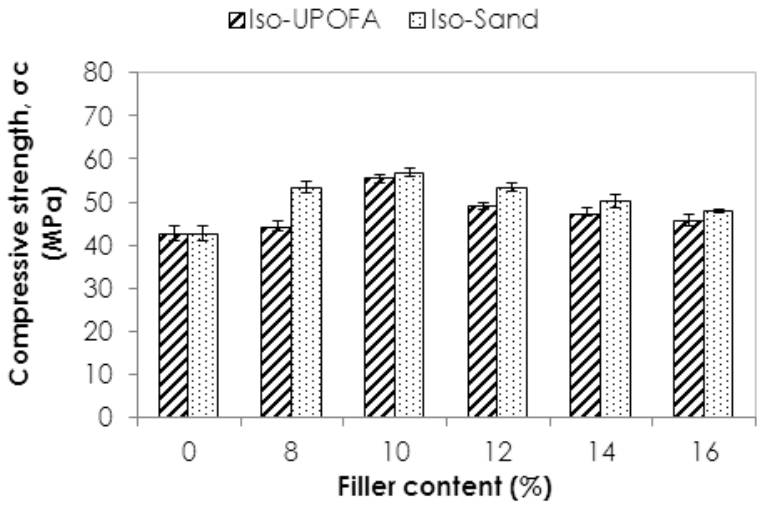


Figure 6: Compressive Strength of Isophthalic polyester Concrete Incorporating Coarse Filler

CONCLUSIONS

This paper had described the potential of POFA agricultural waste as filler in polymer concrete. The following conclusions have been drawn from the present study:

1. The original cellulose-pores structure of POFA had collapsed and sufficient micro fine filler of POFA was achieved after grinding.
2. Ground POFA (GPOFA) had increased the flowability of blended polymer and enhanced filing ability in PC. Therefore, the potential of GPOFA as PC filler is markedly better than unground POFA (UPOFA).
3. Appropriate mix design with ground POFA gives good filling ability and superior PC compressive strength.
4. POFA can be utilized and effectively used as green micro-filler in PC after being subjected to physical surface modification.

REFERENCES

(1) Kueh A.B.H., She W.W., Shek P.N., Tan C.S., Tahir M.M. 2011. Maximum Local Thermal Effects Carpet Plot for Symmetric Laminated Composite Plates. Advanced Materials Research. 250-253:3748-3751.

(2) Talebi E., Tahir M.M., Zahmatkesh F, Yasreen A., Mirza J. 2014. Thermal Behavior of Cylindrical Buckling Restrained Braces at Elevated Temperatures. The Scientific World Journal. 2014:2014.

(3) Lee Y.H., Tan C.S., Mohammad Sh., Tahir M.M., Shek P.N. 2014. Review on Cold-Formed Steel Connections The Scientific World Journal. 2014:2014.

(4) Ateş, E., and Barnes, S. 2012. The Effect of Elevated Temperature Curing Treatment on the Compression Strength of Composites with Polyester Resin Matrix and Quartz Filler. Materials and Design. 34:435–443.

(5) Roger, N. R., and Hancock, M. 2003. General Principles Guiding Selection and Use of Particulate Materials. In . R.N. Rothon (Ed.), Particulate-Filled Polymer Composites. United Kingdom: Rapra Technology Limited.

(6) Atzeni, C., Massidda, L., and Sanna, U. 1990. Mechanical Properties of Epoxy Mortars with Fly Ash as Filler. Cement and Concrete Composites.12(1):3–8.

(7) Gorninski, J. P., Dal Molin, D. C., and Kazmierczak, C. S. 2007. Strength Degradation of Polymer Concrete in Acidic Environments. Cement and Concrete Composites. 29(8):637–645.

(8) Bhutta MAR, Hassanah N; Ariffin NF; Hussin MW; Md Tahir M; Mirza J. 2013. Properties of porous concrete from waste crushed concrete (recycled aggregate). Construction and Building Materials. 47:1243-1248.
(9) Md Noor N., Yahaya N., Abdullah A., Md. Tahir M., Sing L.K. 2012. Microbiologically Influenced Corrosion of X-70 Carbon Steel by Desulfovibrio Vulgaris. Advanced Science Letters. 13:312-316.
(10) Mirza J., Saleh K., Langevin M.A., Mirza S., Bhutta M.A.R., Md. Tahir M.2013. Properties of Microfine Cement Grouts at 4 C, 10 C and 20 C, Construction and Building Materials. 47:1145-1153.
(11) Rashid, M. A., and Mansur, M. A. 2009. Considerations in Producing High Strength Concrete. Journal of Civil Engineering. 37(1):53–63.
(12) Usman, J., Sam, A. M., and Sumadi, S. R. 2014. Strength and Porosity of Cement Mortar Blended with Metakaolin. Advanced Materials Research. (838-841):142–147.
(13) San-José, J. T., Vegas, I, and Ferreira, A. 2005. Reinforced Polymer Concrete: Physical Properties of the Matrix and Static/Dynamic Bond Behaviour. Cement and Concrete Composites. 27: 934–944.
(14) Hafizah, N. A.K., Bhutta, M. A. R., Jamaludin, M. Y. , Warid, M. H., Rahman, M. S., Yunus, I., Azman, M. 2014. Journal of Advanced Concrete Technology. 12: 167-177.
(15) Fowler, D. 1999. Polymers in Concrete: A Vision for the 21st Century. Cement and Concrete Composites. 21(5-6): 449–452.
(16) Reis, J. M. L. 2011. Effect of Aging on the Fracture Mechanics of Unsaturated Polyester based on Recycled PET Polymer Concrete. Materials Science and Engineering: A. 528: 3007–3009.
(17) Bamaga, S. O., Hussin, M. W., Ismail, M. A. 2013. Palm Oil Fuel Ash: Promising Supplementary Cementing Materials. KSCE Journal of Civil Engineering. 17: 1708-1713.
(18) JIS A 1181. 2005. Test Methods for Polymer Concrete. Japan: Japanese Industrial Standard.
(19) JIS R 5201. 1997. Physical Testing Method for Cement. Japan: Japanese Industrial Standard.
(20) Bakar, B. H. A., Ramadhansyah, P. J., and Azmi, M. J. M. 2011. Effect of Rice Husk Ash Fineness on the Chemical and Physical Properties of Concrete. Magazine of Concrete Research. 63(5): 313–320.
(21) Noorvand, H., Abdullah, A., Ali, A., Demirboga, R., Noorvand, H., and Farzadnia, N. 2013. Physical and Chemical Characteristics of Unground Palm Oil Fuel Ash Cement Mortars with Nanosilica. Construction and Building Materials. 48: 1104–1113.
(22) Haidar, M., Ghorbel, E., and Toutanji, H. 2011. Optimization of the Formulation of Micro-Polymer Concretes. Construction and Building Materials. 25(4): 1632–1644.
(23) Mahjoub, R., Yatim, J. M., Sam, A. R. M., and Hashemi, S. H. 2014. Tensile Properties of Kenaf Fiber due to Various Conditions of Chemical Fiber Surface Modifications. Construction and Building Materials, 2014(55): 103–113.
(24) Bignozzi, M., Saccani, A. and Sandrolini, F. 2000. New Polymer Mortars Containing Polymeric Wastes. Part 1. Microstructure and mechanical properties. Composites Part A: Applied Science and Manufacturing. 31(2):97–106.
(25) Memon, N. A., Sumadi, S. R., and Ramli, M. 2007. Performance of High Wokability Slag-Cement Mortar for Ferrocement. Building and Environment. 42(7): 2710–2717.