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Green concrete composites production comprising metalized plastic waste fibers and palm oil fuel ash

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ABSTRACT

Amongst the potential solutions to a cleaner environment is to minimize the consumption of non-biodegradable materials and to reduce wastes. The generation and disposal of waste plastics cause severe impacts on the environment. The utilization of solid waste in the sustainable constructions has concerned much attention due to the lower cost of wastes along with saving a necessary place of landfills. In this paper, the feasibility of metalized plastic waste (MPW) fibers and palm oil fuel ash (POFA) in the production of concrete composites was investigated by assessing the mechanical properties and ultrasonic pulse velocity. Six concrete mixes containing MPW fibers varying from 0 to 1.25% with a length of 20 mm were made of ordinary Portland cement (OPC). A different six concrete mixtures with the same fiber content were made, where 20% POFA substituted OPC. The results show that MPW fibers, together with POFA reduced the workability of concretes. It has also been found that by adding MPW fibers to the concrete mixtures, the compressive strength decreased for both OPC and POFA mixes at the early ages. Though at the curing period of 91 days, the mixes contain POFA attained compressive strength higher than those of OPC mixes. The mixture of MPW fibers and POFA subsequently enhanced the tensile and flexural strengths, thereby increasing the ductility. The study revealed that the MPW fibers are potential to be used in sustainable concrete by improving the mechanical properties.

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1. Introduction

In the past 50 years, the production of various sorts and forms of plastic has grown massively worldwide. Plastics have considerably caused the generation of massive amounts of waste. Different types of plastics are widely used in all fields, mostly in food packaging industries. As stated by Gu and Ozbakkaloglu [1], and Sharma and Bansal [2], the overall production of plastic in different forms increased up to about 300 million tons in 2014. Of these, nearly half of the produced plastics are used once only, which initiated critically to generate and dispose of the massive amount of plastic waste. Consequently, insufficient management and mishandling of these wastes direct to harmful impacts, for instance, human health risks, animal life hazards, soil pollutions, as well as water and air contaminations on the environment. Nevertheless, the majority of these plastic wastes are capable of being recycled and reprocess chemically or thermally, but not all types of plastic waste are appropriate for this category [3]. Metalized plastic waste (MPW) films are one of the plastic waste generated and send to landfills all around the world. MPW films are polymeric base and coated with a thin layer of aluminum, which consumed mainly in food packaging productions. Amongst all plastic wastes, metalized plastic wastes are inappropriate for reusing and reprocessing [4,5]. As there is no proper technique for reprocessing of such an extensive quantity of plastic wastes, they send to landfill and then incineration [6]. Accordingly, sustainable and reliable approaches to disposal that substitute the current methods have become vital.

Concrete is the most extensively used construction materials all over the world. The concrete composite comprises cement binders, coarse and fine aggregates, in addition to the short fibers that are uniformly distributed in the mixture. Different types of short fibers, either metallic or polymeric, virgin or waste, are commonly used to improve the concrete ductility [7]. Generally, the common

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fibers used to reinforce the concrete are steel and glass fibers, polypropylene (PP) and nylon fibers, natural fibers, as well as the waste fibers [8,9]. In the last decades, in response to the continuous detection of sustainable, durable, and ductile structures, the search for technologies that permit the consumption of solid wastes in construction has attracted attention. In regards to the said matters, several researchers have investigated the effects of the various plastic wastes on the properties of different types of concrete [10,11]. Based on their findings, most of the plastic waste are capable of being employed as fibers in the production of sustainable concretes in order to prevent the micro-cracks formation and, thus, enhance the durability of concrete. Nevertheless, the waste metalized plastics, which are a significant source of littering of wastes, have not been used in the fibers form in concrete yet. The use of wastes from agricultural products can also aid in providing the constructions more sustainable and environmentally friendly. The utilization of agricultural wastes such as ashes in the construction materials for their excellent performance has been recommended [12,13]. Moreover, palm oil fuel ash (POFA) is an agricultural waste which considered pozzolanic material. POFA is obtained from the burn up the palm oil husk and palm kernel shells in palm oil mill as fuel. Amongst the countries produce palm oil products, Malaysia is the second producer [14]. As said by Alsubari et al. [15], in Malaysia only, nearly 5 million tons of palm oil fuel ash were generated and wasted in 2010. This waste material is now categorized as pozzolanic ash with adequate characteristics that can be recycled in the concrete industries by enhancing the strength and durability properties of different types of concrete [16]. Taking into account the availability of the plastic waste and the pozzolanic nature of POFA, extensive research work was carried out in the Department of Structure and Materials of the Universiti Teknologi Malaysia to explore the potential benefits of producing sustainable building materials. The purpose of this study was to utilize palm oil fuel ash as a supplementary cementitious material in concrete reinforced with WMP fibers at volume fractions of 0% to 1.25%. The fresh and hardened state properties such as workability, compressive strength, ultrasonic pulse velocity (UPV), tensile and flexural strengths were examined and compared with those of OPC without any fibers.

2. Materials and test methods

In this research, type I ordinary Portland cement was consumed in accordance with ASTM C 150–2007. The palm oil fuel ash was also collected from a palm oil mill located in Johor, Malaysia. Before the ash can be used as a cement replacement, larger particles were removed, and the carbon content was minimized, and then the ash was kept in the furnace at the temperature of 100 ± 5 °C to evaporate the moisture. Subsequently, the ashes were sieved, and particles passed through a sieve of size 150 μm were ground in a modified Los Angeles abrasion machine. Finally, the very fine POFA was collected, which conforms to the requirements of BS 3892: Part 1–1992. The obtained POFA can be considered as class C and F, according to the ASTM C618-2015 specifications. Table 1 displays the chemical and physical properties of Portland cement and palm oil fuel ash used in this study. The fine aggregate used in this study was uncrushed river sand with the upper limit of 4.75 mm, a specific gravity of 2.6, 0.70% water absorption, and fineness modulus of 2.3. Coarse aggregates with the upper limit of 10 mm, a specific gravity of 2.7, and water absorption of 0.5% were consumed. Also, to improve the flowability of fresh concrete, superplasticizer at a dosage of 1.0% was used. Also, the polypropylene type metalized plastic wastes from food packaging were collected and cleaned to avoid any impurities. The films then tore into fibers form at a constant width of 2 mm and 20 mm in length, as revealed in Fig. 1. Table 2 presents the common properties of MPW fibers used in this study. The various contents of used materials in the concrete mix compositions are displayed in Table 3. Overall, twelve concrete batches with various percentages of fiber content were prepared for compressive strength, tensile and flexural strengths. The first batch named B1 as a control mix was cast without any fibers and POFA. Along with all mixtures, six of them were OPC mixes containing MPW fibers of 0%, 0.25%, 0.50%, 0.75%, 1.0%, and 1.25% namely B1–B6. An additional six mixes were cast with POFA substituting OPC by 20% for the similar fibers dosages, i.e., B7-B12.

Concrete mixes were examined for the slump test according to BS EN 12350–2: 2009 and VeBe time test in accordance with BS EN 12350-3: 2009. The ultrasonic pulse velocity (UPV) test was carried out on the cube specimens used for the compressive test following ASTM C597-09. To evaluate the cube compressive strength, cubic samples of size 100 mm were prepared, cast, and tested following BS EN 12390-2, 3: 2009 recommendations. Cylindrical specimens piloted the tensile strength and modulus of elasticity tests with a dimension of 100 mm × 200 mm based on the ASTM C496-11 and ASTM C469-14, respectively. Besides, the flexural strength test was also conducted based on the BS EN 12390-5: 2009, using prism samples with sizes of 100 mm × 100 mm × 500 mm.

3. Results and discussion

3.1. Workability

In order to investigate the effects of the MPW fibers on the consistency of concrete, the slump test and VeBe time test were conducted. The results of the workability tests are displayed in Fig. 2 (a, b). It can be observed that the workability of concrete mixes considerably reduced by the adding of MPW fibers. From Fig. 2 (a), it can be observed that the slump of the control mix was noted as 190 mm. With the inclusion of MPW fibers by 0.25%, 0.5%, 0.75%, 1%, and 1.25%, the slump values dropped to 120, 80, 65, 40, and 30 mm, respectively. Moreover, due to the higher surface area of POFA than OPC, the matrix absorbs more amount of water and thus, make the mixture stiffer and resulted in lower workability [17]. From the results given in Fig. 2(b), it can be observed that in mixes with 20% POFA, the VeBe time raised to 16 sec as compared to that of 190 mm and 15.3 sec for OPC plain concrete. A similar tendency like that of OPC mixes was observed for POFA mixes reinforced with MPW fibers. It has been found that the inclusion of WMP fiber in the mixtures caused in the decrease of slump values and an increase of VeBe times. The addition of WMP fibers affects the viscosity of the matrix. The inclusion of fibers at higher dosage also interrupts the consistency of the mixture, which was directed to the balling effect of concrete components and WMP fibers [18].

Table 1
Physical properties and chemical composition of OPC and POFA.

Material	Physical properties			Chemical composition (%)							
	Specific gravity	Blaine fineness	Soundness	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	SO_3	LOI
OPC	3.15	3990	1.0	20.4	5.2	4.19	62.4	1.55	0.005	2.11	2.36
POFA	2.42	4930	2.0	62.6	4.65	8.12	5.7	3.52	9.05	1.16	6.25

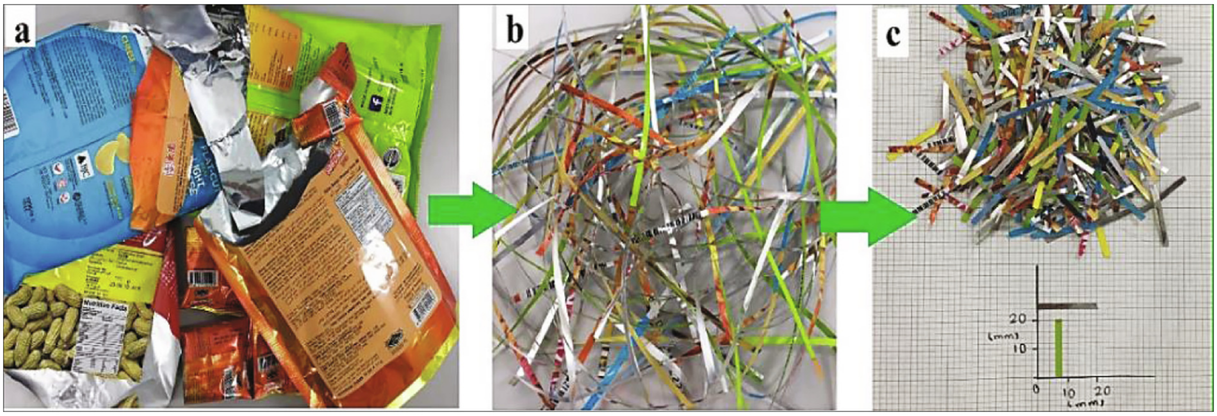

Fig. 1. (a) Waste metalized plastics; (b) Fabricated MPW fibers; (c) MPW fibers with 20 mm length.

Table 2
Properties of MPW fibers.

Resin type	Plastic type	Size (W*L) (mm)	Density range (kg/m^3)	Thickness (mm)	Tensile strength (MPa)	Elongation (%)
Polypropylene	LDPE*	2*20	0.915–0.945	0.07	600	8–10

* Low-density polyethylene.

Table 3
Concrete mix proportions.

Mix	Cement (kg/m^3)	POFA (kg/m^3)	Water (kg/m^3)	Fine Agg. (kg/m^3)	Coarse Agg. (kg/m^3)	Fiber volume fraction (V_f %)
B1	445	–	215	830	860	0.0
B2	445	–	215	830	860	0.25
B3	445	–	215	830	860	0.50
B4	445	–	215	830	860	0.75
B5	445	–	215	830	860	1.0
B6	445	–	215	830	860	1.25
B7	356	89	215	830	860	0.0
B8	356	89	215	830	860	0.25
B9	356	89	215	830	860	0.50
B10	356	89	215	830	860	0.75
B11	356	89	215	830	860	1.0
B12	356	89	215	830	860	1.25

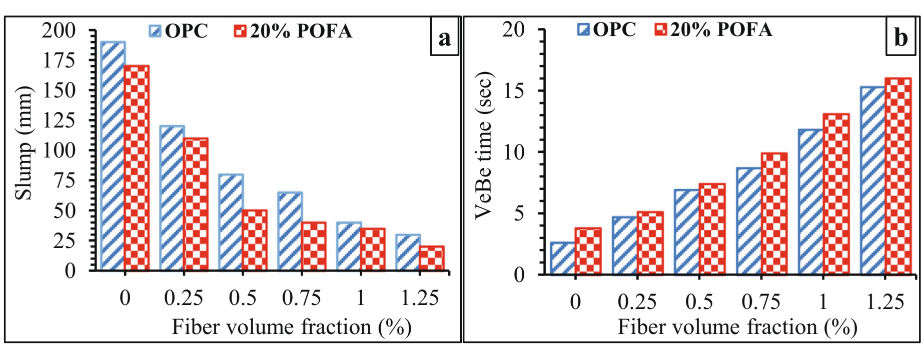

Fig. 2. Influences of MPW fibers on (a) slump and (b) VeBe time of concrete mixtures.

3.2. Compressive strength

The obtained compressive strength of concrete specimens is illustrated in Fig. 3. Results show that the inclusion of MPW fibers reduced the compressive strength of concrete. Comparing the 28 days compressive strength values of the plain concrete mixture, the inclusion of WMP fibers at dosage of 0.25%, 0.5%, 0.75%, 1% and 1.25% reduced the cube compressive strength by 6.1%, 7.53%, 11.14%, 18% and 21.25%, respectively. In plain concrete mixtures without fibers and containing 20% POFA, further decreases in compressive strength of 13.5% at 7 days and 10.2% at 28 days curing were observed related to that of the OPC-based concrete mixture. However, at the curing period of 91 days, concrete mixes containing MPW fibers and POFA achieved higher compressive strength values than those of OPC fiber reinforced concrete mixes. It is known that at the longer curing periods, the existence of POFA enhanced the strength of concrete due to the pozzolanic behavior of POFA, in addition to the formation of additional calcium silicate

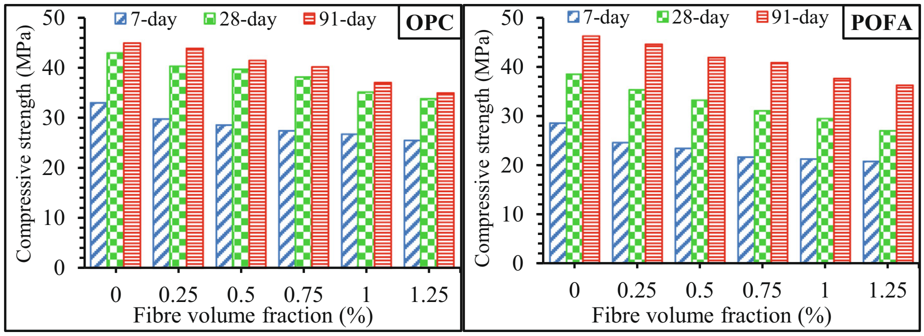

Fig. 3. Variation in the compressive strength of concrete mixes reinforced with MPW fibers.

hydrate (C-S-H) gel during the hydration process and densify the matrix.

In order to show a clear image of the role of POFA and the hydration process on the strength development of concrete, the scanning electron micrograph (SEM) test was done on the specimens at the age of 91 days. It can be observed from Fig. 4 that the development of C-S-H gels is more significant in the POFA-based specimen. The SEM image shows that the C-S-H gels are more uniformly spared in the POFA content specimens. The uniform distribution of C-S-H is owed to the consumption of a higher amount of calcium hydroxide by the pozzolanic action of POFA during the hydration, which caused in the formation of additional C-S-H gels and therefore resulted in higher strength of concrete [9].

3.3. Splitting tensile strength

The results of the tensile strength test on concrete specimens containing MPW fibers are presented in Fig. 5. By adding MPW fibers and increasing fiber dosages, the tensile strength of concrete significantly improved as compared to that of control concrete mix. The addition of MPW fibers at different volume fractions to the POFA-based concrete mixes resulted in the development of tensile strength. Reinforcement of plain concrete with MPW fibers resulted to enhance of 12.0%, 18.9%, 16.9%, 13.4% and 8.0% the tensile strength of specimens with fiber content of 0.25%, 0.5%, 0.75%, 1% and 1.25%, respectively, at the curing period of 91 days as compared to that of control mix. Although, for the POFA content mixes at the curing period of 91 days and fiber dosages of 0.25%, 0.5%, 0.75%, 1% and 1.25%, the tensile strength increased by 13.1%, 22.3%, 18.0%, 14.9%, and 11.4%, respectively, as associated with that of control mix. The development in the tensile strength might be owed to the larger interaction surface area among fibers and the cement paste. While the load is applying on the specimens and splitting occurred, MPW fibers connecting the split sections. Subsequently, persistent the stresses on the split zones and interruption the sudden failure of concrete. MPW fibers increased the resistance of concrete specimens against the indirect tension and enhanced the strain capacity of the concrete and then, consequences in higher tensile strength values [5].

3.4. Flexural strength

The measured values of flexural strength of specimens reinforced with MPW fibers are demonstrated in Fig. 6. It can be detected that the adding and increasing fiber volume fractions lead to enhancement in flexural strength. The maximum flexural strength was recorded as 5.95 MPa for POFA-based specimens containing 0.5% MPW fibers at the age of 91 days. The said improvement in the POFA mixes is owed to the higher pozzolanic activity of POFA at longer curing ages as well as the creation of extra C-S-H gels [18]. Bridging action of MPW fibers deals more resistance to crack formation in the tension area of the beams and, consequently, develops the flexural strength of concrete. At the tension zone, the fibers arrest the cracks through the bridging action and prevent the propagation of cracks while applying the loads.

3.5. Ultrasonic pulse velocity

The recorded ultrasonic pulse velocity (UPV) values of specimens reinforced with MPW fibers are indicated in Fig. 7. Results show that the inclusion of MPW fibers does not significantly affect the UPV values, particularly at the early ages. While at longer curing periods, the UPV values increased with the addition of fibers. The UPV values of between 4272 m/s and 4349 m/s were recorded at the ages of 28 and 91 days for plain concrete mixes. Based on the obtained UPV values and specifications stated by Neville and Brooks [19], concrete mixes are considered as a good quality concrete. The addition of MPW fibers leads to higher UPV values at longer curing periods. For example, the recorded UPV values for mixes containing 0.25% and 0.5% at 91 days are 4367 m/s and

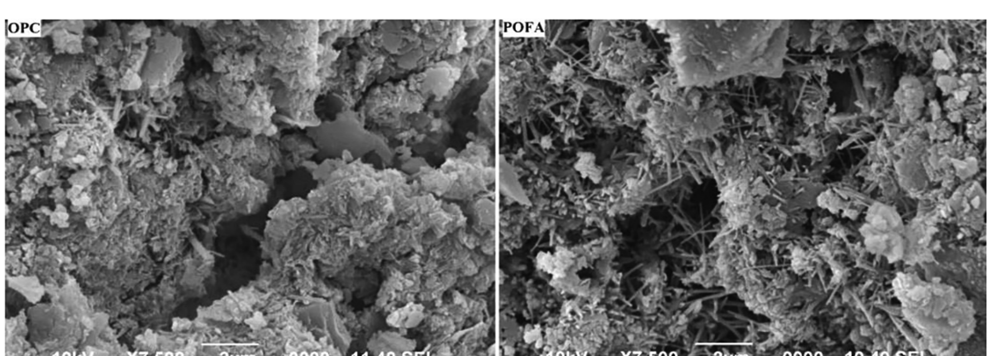

Fig. 4. SEM of hydration products in OPC and POFA concrete specimens.

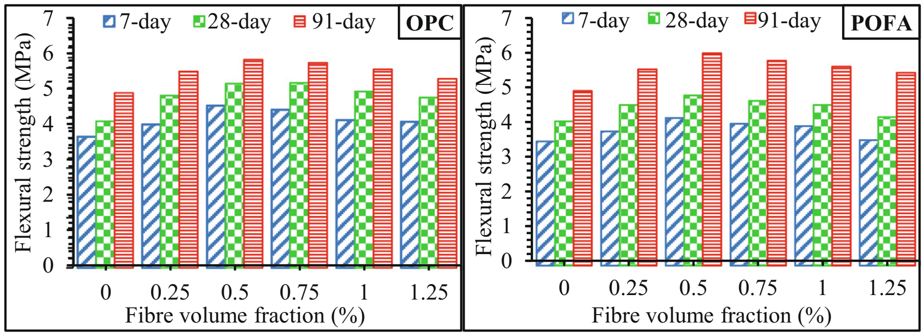

Fig. 5. Effects of MPW fibers on the tensile strength of concrete composites.

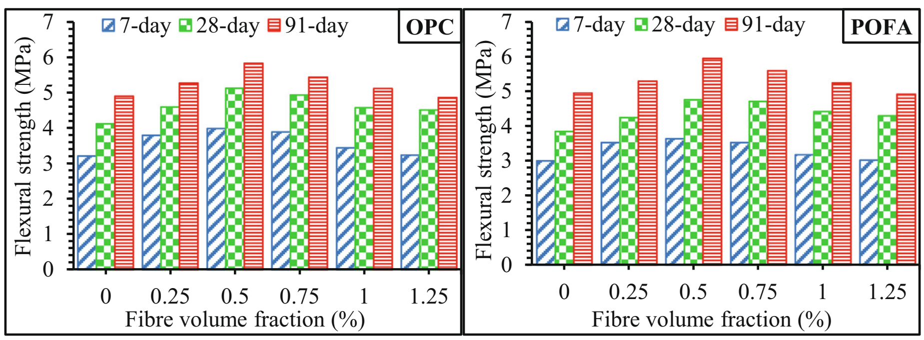

Fig. 6. Effects of MPW fibers on the flexural strength of concrete composites.

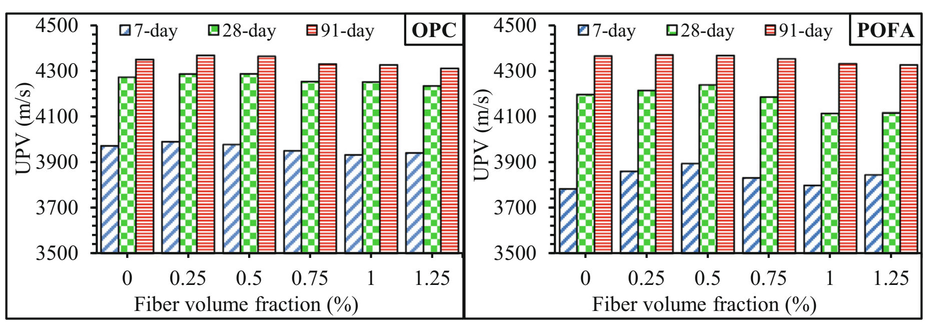

Fig. 7. UPV values of different concrete mixes.

4363 m/s, respectively, which are higher than those obtained for plain concrete mix. However, a reduction was found in the UPV of concrete containing fibers content beyond 0.75%. It is well-known that the drop in UPV of concrete can be owed to the existence of cavities and micro-cracks, which diminish the consistency of the matrices with high volume fractions of fiber [20–22]. Moreover, the increase in UPV values of the POFA-based specimens was more significant, mostly at the longer curing ages. UPV values of 4300 m/s and beyond were recorded, which categorized the concrete as good quality concrete [23]. The higher UPV values of POFA specimens could be owed to the development of extra C-S-H gels by the pozzolanic action of POFA, which fills the pores and make the concrete denser [24–26].

4. Conclusions

In the present study, the physico-mechanical properties of sustainable concrete composites were explored. The following results were concluded based on the examination and investigational results. By adding MPW fibers into concrete mixes, concrete was harsher, and the workability decreased. At the early ages, cube compressive strength diminished slightly with the adding of MPW fibers and POFA. However, for POFA mixes, the compressive strength was higher than that of OPC mixes at the age of 91 days. Unlike diminution in compressive strength, remarkable enhancements in both tensile and flexural strengths of all concrete specimens were noted. All specimens containing MPW fibers obtained higher tensile and flexural strength values than those of plain concrete mixes. The inclusion of MPW fibers in concrete specimens revealed better ductility performance due to the linking action of fibers. Furthermore, the obtained UPV values of 3700 to 4400 m/s for mixes containing MPW fibers and POFA at all ages were characterized as good quality concrete. The production of eco-friendly concrete by adding MPW fibers and POFA is highly potential to be industrialized with the satisfactory performance for both structural and non-structural applications.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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