Research Article

Effect of elevated temperatures on properties of sustainable concrete composites incorporating waste metalized plastic fibres

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Abstract

The utilisation of industrial waste in the production of sustainable construction materials has attracted much attention recently due to the saving of vital places for landfills, low-cost of waste materials and also an improvement in the concrete properties. Exposing concrete structures to elevated temperatures causes progressive failure of the macro- and micro-structures of cement paste and, therefore, severe deterioration and damages in the load-bearing capacity. This study explored the effect of waste metalized plastic (WMP) fibres and palm oil fuel ash (POFA) on the performance of concrete exposed to high temperatures of 200, 400, 600 and 800 °C. Four concrete mixes comprising 0 and 0.5% WMP fibres, and 0 and 20% POFA content were cast. Properties studied include mass loss, compressive strength, and ultrasonic pulse velocity. The results showed that the adding of WMP fibre to the concrete mixes significantly improves the concrete performance at elevated temperatures with the lower rate of strength loss along with eliminating the explosive spalling behaviour as compared to those of plain concrete mixes. Furthermore, in comparing the results of compressive strength losses at a high temperature of 800 °C, strength losses were lower for specimens containing 0.5% WMP fibres than those of plain specimens. Moreover, green concrete decreases waste materials, the diminution of harmful impacts on the environment, and leads to sustainable and green cement and concrete industries.

Keywords Concrete composites · High temperatures · Waste metalized plastic fibre · Palm oil fuel ash · Residual properties

1 Introduction

From the sustainability point of view, reduction in the utilisation of non-renewable raw materials is a critical factor in sustainable construction. Sustainability helps the environment by minimising the waste materials and the reduction of raw materials consumption [1, 2]. With the generation of massive amounts of wastes, several types of non-biodegradable wastes such as plastics will remain in the environment for hundreds, perhaps thousands of years [3–5]. The production of various sorts and forms of plastic has grown massively worldwide. The overall production of plastic in different forms increased up to about 300 million tons in 2014 [6], and approximately half of these plastics are used once only, which initiated critically to generate and dispose of the massive amount of waste plastics [7, 8]. Therefore, efficient management of several types of solid waste initiation is getting more consideration to ensure sustainability in construction and concrete industries.

The majority of waste plastics are capable of being recycled and reprocess chemically or thermally, but not all types of plastic waste are appropriate for this category

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[9]. Waste metalized plastic (WMP) films are one type of waste plastics generated and send to landfills all around the world. WMP films are a polymeric base coated with a thin layer of aluminium which are consumed mainly in food packaging productions. Amongst all waste plastics, waste metalized plastics are inappropriate for reusing and reprocessing [10, 11]. As there is no proper technique for reprocessing of such an extensive quantity of plastic wastes, WMP films are sent to landfill and then incinerated. Accordingly, sustainable and reliable approaches to disposal that substitute the current methods have become vital. Palm oil fuel ash is another type of waste generated by the burning of palm oil husk and palm kernel shells in palm oil mills as fuel. Amongst the countries that produce palm oil products, Malaysia is the second producer, and nearly 4 million tons of palm oil fuel ash were produced and wasted in 2010. This waste material is now categorised as pozzolanic ash with adequate characteristics that can be recycled and used in concrete by enhancing the strength and durability of concretes [12, 13].

Concrete is the most consumed construction materials globally. In concrete structures, fire is one of the most destructive causes of failure [14, 15]. Fire may cause entirely the collapse of the structure with a single case of exposure, making it complicated to take necessary actions while a risk or the resulting destruction is initially perceived. The performance of concrete structures exposed to high temperatures is generally related to the distribution of stresses, surface micro-cracking, crack formation and spalling [16, 17]. Concrete structures are exposed to fire throughout its service life for an extensive period. Variation in moisture content, dehydration of cement and binder paste, thermal expansion and crack formation, increase in porosity, conversion of pores pressure, spalling due to high pore pressures, and reduction in strength are the most significant influences of elevated temperatures on concrete components [18–20].

The addition of short fibre is the most widely recognised technique to prevent concrete spalling at elevated temperatures [21, 22]. The fibres can provide a significant contribution to concrete structures by prevention crack formation through their bridging action. Therefore, short fibres were added to the concrete mixtures mainly to enhance the concrete toughness, flexural and tensile strengths, energy absorption as well as impact resistance. Moreover, uniformly distribution of short fibres in concrete has revealed adequate properties with enhancement in the fire resistance capacity of concrete [23, 24].

In the last decades, in response to the continuous search for sustainable, durable, and ductile structures, the search for technologies that permit the consumption of solid wastes in construction has attracted attention. Regarding what was stated, several researchers have investigated the effects of the various plastic wastes on the properties of different types of concrete. The most popular waste plastics used to reinforce concrete are polyethylene terephthalate (PET) waste bottle [25–27], polyethylene (PE) waste bag [28], polyvinyl alcohol (PVA) fibre [29], and waste polypropylene (PP) fibre [30, 31]. Based on their findings, most of the waste plastics are capable of being employed as a fibrous material 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 an essential source of littering of wastes, have not been used in the fibres form in concrete yet.

Several investigations have been performed on how to prevent and control the explosive spalling of structures exposed to fire. Sanchayan and Foster [32], Kalifa et al. [33], and Mohammadhosseini et al. [34] are amongst others who have studied the behaviour of concrete containing hybrid steel and PVA fibres, waste carpet fibres, and micro PP fibres, respectively, at elevated temperatures and reported similar explosive behaviour of concrete. It has been found that the application of short fibres particularly PP fibres in concrete significantly decrease the amount of concrete spalling at high temperatures. In addition, it was stated that the mechanical properties of concrete reduced with a rise in temperature. According to Hiremath and Yaragal [22], at high temperatures, polymeric based short fibres melt and their bed ways formed passages through which the moist vapour pressures and gasses built-up inside matrix as temperature upsurge are liberated. This liberation of the vapour and pore pressures considerably diminishes the spalling propensity of concrete components exposed to fire.

To date, there is no study on the behaviour of concretes comprising WMP fibre and POFA at high temperatures. Therefore, given the local availability and ease of access of the metalized plastic wastes and POFA in particularly in Malaysia, comprehensive experimental work was carried out in the Universiti of Teknologi Malaysia to investigate the potential of these waste materials and advantages of manufacturing sustainable concrete and its performance at elevated temperatures. This research aimed to examine the interactive effects of WMP fibres and POFA on the mechanical properties of concrete specimens exposed to elevated temperatures as well as understanding the contribution of WMP fibre in the reduction of concrete spalling. In this work, an evaluation was made among the residual cube compressive strength and ultrasonic pulse velocity (UPV) of conventional concrete and concrete reinforced with WMP fibres after exposure to temperatures of 200, 400, 600 and 800 °C.

2 Experimental program

2.1 Materials

In this research, the type I ordinary Portland cement (OPC) 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 minimised and then the ash was kept in the furnace at the temperature of 100 ± 5 °C to evaporate the moisture and sieved. Subsequently, the particles passed through a sieve of size 150 µm were ground for two hours 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, based on ASTM C618-2015 specifications. Table 1 displays the chemical and physical properties of Portland cement and palm oil fuel ash used in this study.

Fine aggregates used in this study were local river sand passed through a sieve of size 4.75 mm, with a specific gravity of 2.6, water absorption of 0.70%, and fineness modulus of 2.3. Coarse aggregates of 10 mm maximum size, having a specific gravity of 2.7 and water absorption of 0.5% were consumed. In this study, the metalized plastics were collected from local food packaging wastes, for instance, coffee, snack foods, candies and kept and remained in the water for 24 h to eliminate any dirt and impurities. The polypropylene sort of metalized plastics was used with aluminium metallization treatment. The WMP films were then shredded into fibre form with a constant width of 2 mm and 20 mm in length, as revealed in Fig. 1. The essential engineering properties of typical WMP fibres used are given in Table 2.

2.2 Mix proportions

In this study, total four mix proportions were designed, namely OPC-based (B1, B3) and POFA-based (B7, B9), which contain 0% (B1, B7) and 0.5% (B3, B9) of WMP fibres.

Table 1 Chemical compositions and physical properties of Portland cement and palm oil fuel ash

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

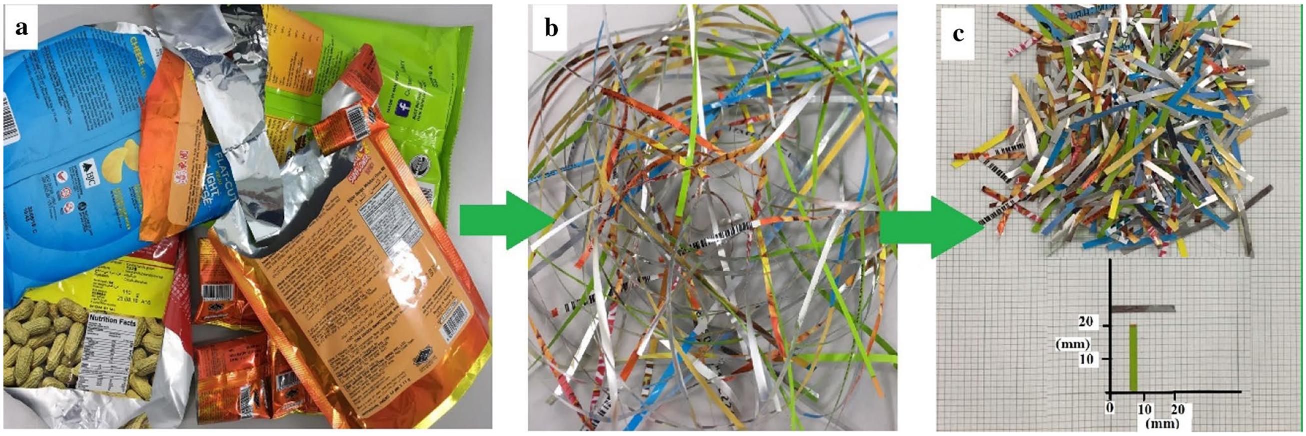


Fig. 1 **a** Metalized plastic waste; **b** fabricated films; **c** WMP fibres with 20 mm length

Table 2 Engineering properties of used WMP fibres

Resin category	Plastic type	Size (W * L) (mm)	Thickness (mm)	Reaction with water	Melting point (°C)	Density range (kg/m^3)	Elongation (%)	Tensile strength (MPa)
Polypropylene	LDPE	2 * 20	0.07	Hydrophobic	180	0.915–0.945	8–10	600

Table 3 Properties of different mix compositions

Mix	Cement (kg/m^3)	POFA (kg/m^3)	Water (kg/m^3)	Fine agg. (kg/m^3)	Coarse agg.(kg/m^3)	V_f (%)	Slump (mm)	VeBe (s)
B1	445	–	215	830	860	–	190	2.5
B3	445	–	215	830	860	0.50	80	6.7
B7	356	89	215	830	860	–	170	3.4
B9	356	89	215	830	860	0.50	50	7.3

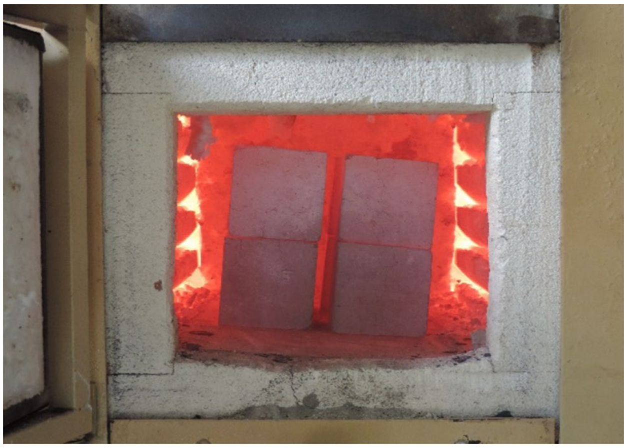


Fig. 2 An electrically controlled furnace contains concrete specimens

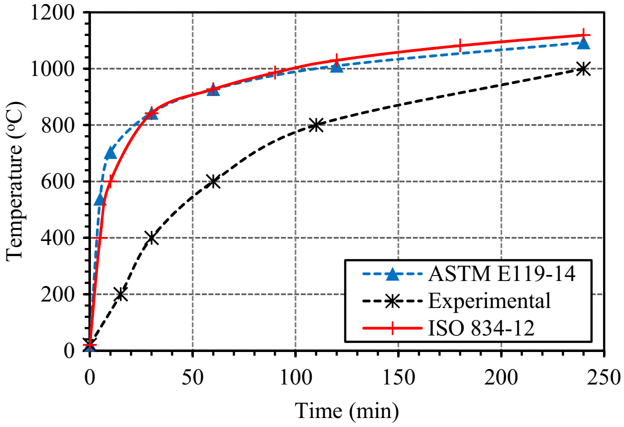


Fig. 3 The time–temperature graph of the furnace and existing standards

The POFA-based mixes were prepared, whereby OPC was substituted by 20% POFA. The details of the mix proportions are mentioned in Table 3.

2.3 Specimen preparation and test method

Cube concrete samples of 100-mm size were made according to BS EN 12390-2, 3:2009. After 24 h, the concrete cubes were then demoulded and immersed in the water for 90 days. Subsequently, the cubes were taken out from the water tank and dried at room temperature while the mass of the specimens was monitored up to a constant weight. Before the thermal exposure test, the initial mass of all concrete specimens was recorded, and the specimens were then assessed for a non-destructive test of UPV according to the ASTM C597-09 specifications. The concrete cubes were then positioned inside a furnace, as revealed in Fig. 2, whose inner temperature was raised from ambient temperature to 200, 400, 600, and 800 °C at a constant rate of 10 °C/min. For each range of temperatures, the peak temperature was retained for 1 h to attain thermal equilibrium at the inside of the concrete cubes. Figure 3 demonstrates the time–temperature graph of the used furnace, which is comparable to those standard trends specified by ASTM E119 and ISO 834.

After 1 h heating, the furnace was turned off and the thermally conserved specimens were cooled by both water and air. The concrete cubes were permitted to cool slowly by the air in the laboratory at the ambient temperature for the air-cooled group, whereas the water-cooled set samples were cooled down by spraying water to reflect fire-combating action. The residual mass as an indication of the amount of loss, residual UPV, and compressive strengths were then noted for all samples.

3 Results and analysis

3.1 Visual assessment and mass losses

Variations on the surface of the heated concrete specimens included colour changes, crack formation and spalling are revealed in Fig. 4. It can be seen that no considerable explosive spalling was detected in the concrete specimens comprising WMP fibres exposed to fire. The observations reinforced the conception that WMP fibres are capable of preventing the spalling of concrete specimens at high temperatures. The inner pore pressures build-up owing to the vaporisation of bound and free waters at elevated temperatures is one of the primary

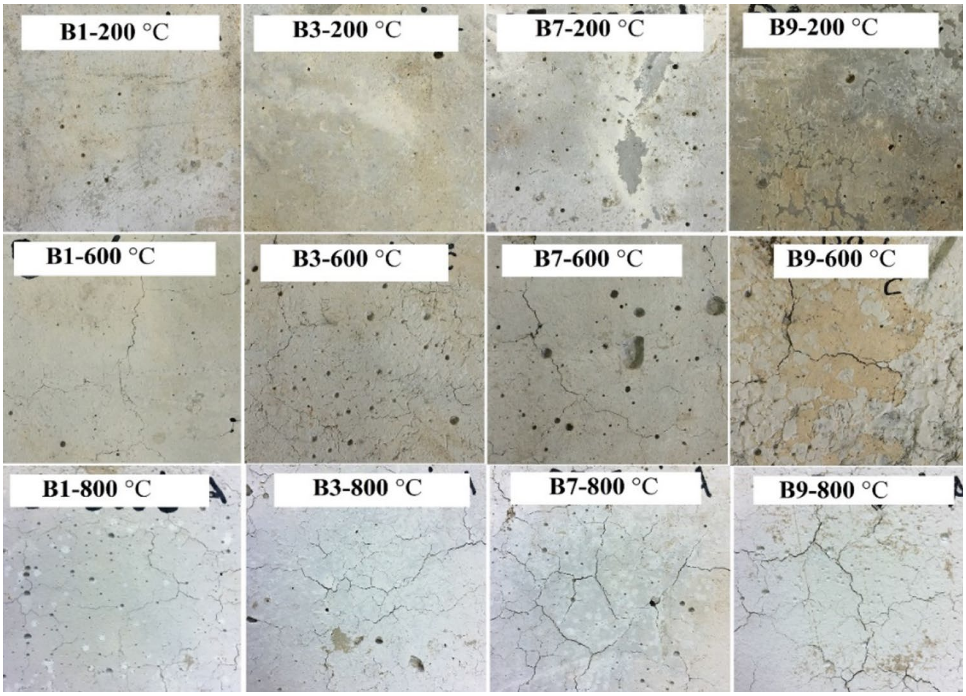


Fig. 4 Surfaces of thermal exposed concrete specimens at various temperatures

causes of concrete spalling. Therefore, in the absence of short fibre in the plain concrete mixes, the inner pressures were not liberated and consequently caused in explosive spalling of the surface of specimens [18].

As above mentioned, the prevention of spalling in the specimens containing WMP fibres might be owing to the low melting point of used fibres. According to the findings reported by Sanchayan and Foster [32] and Noumowe [18], plastic and PP fibres melt at nearly 150–190 °C whereas spalling of concrete happens beyond 200 °C. After melting, the fibres are fully or partially absorb by the matrix and create a channel on the bed of the fibre which works as a passageway for generated vapours. Consequently, the created channels form a network alongside the concrete matrix, which then allows the passage of gases towards outside and as a result, the reduction in pore pressures and spalling of concrete.

For mass loss evaluation, before the thermal exposure, the mass of the unheated specimens was recorded as control mass. After specimens exposed to high temperatures and cooled either by water-cooling or air cooling methods, the residual mass was measured for all concrete cubes. The weight losses are expressed as a percentage of the unheated control mass to the residual mass after exposure to the temperatures of 200, 400, 600 and 800 °C, as shown in Fig. 5. It can be observed that at various temperatures, the mass losses of the specimens comprising WMP fibres and POFA tended to increase.

The impacts of high temperatures on concrete specimens can be divided into three different stages related to the obtained residual mass at elevated temperatures. The first stage, at the temperatures, ranged from 27 to 200 °C, the minor mass loss was detected in all concrete specimens owed to the vanishing of free water. As the melting point of used WMP fibre is at roughly 180 °C, in this range of temperature, only the outer fibres in the specimens were melted and did not notably affect the internal fibres. In the second stage, where the range of temperatures laid between 200 and 400 °C, a significant mass losses were recorded where all of the fibres completely melted in addition to the evaporation of capillary and calcium silicate hydrate (C–S–H) gel waters. The last stage which is at 400 °C and above, a moderately slow rate of mass loss was observed. From the obtained results, it can be seen that the rate of mass loss was significantly slighter for the specimens cooled by water as compared to those cooled by air.

It can be observed from Fig. 5 that the maximum mass losses were recorded for concrete mixture with 0.5% WMP fibres and 20% POFA as 10.35% and 9.43% for air-cooled and water-cooled, respectively. The comparatively higher mass losses in POFA content mixes might be owing to the more water content absorbed by POFA [35]. Besides, the lower mass loss of specimens cooled by water might be attributed to the absorption of water by the surface of the specimen throughout the cooling process by spraying water. Theoretically, the losses in the mass of concrete exposed to fire can be owing to the decomposition of calcium hydroxide $Ca(OH)_2$ as well as calcareous fine and coarse aggregates, sloughing off of the specimen surfaces and release of carbon

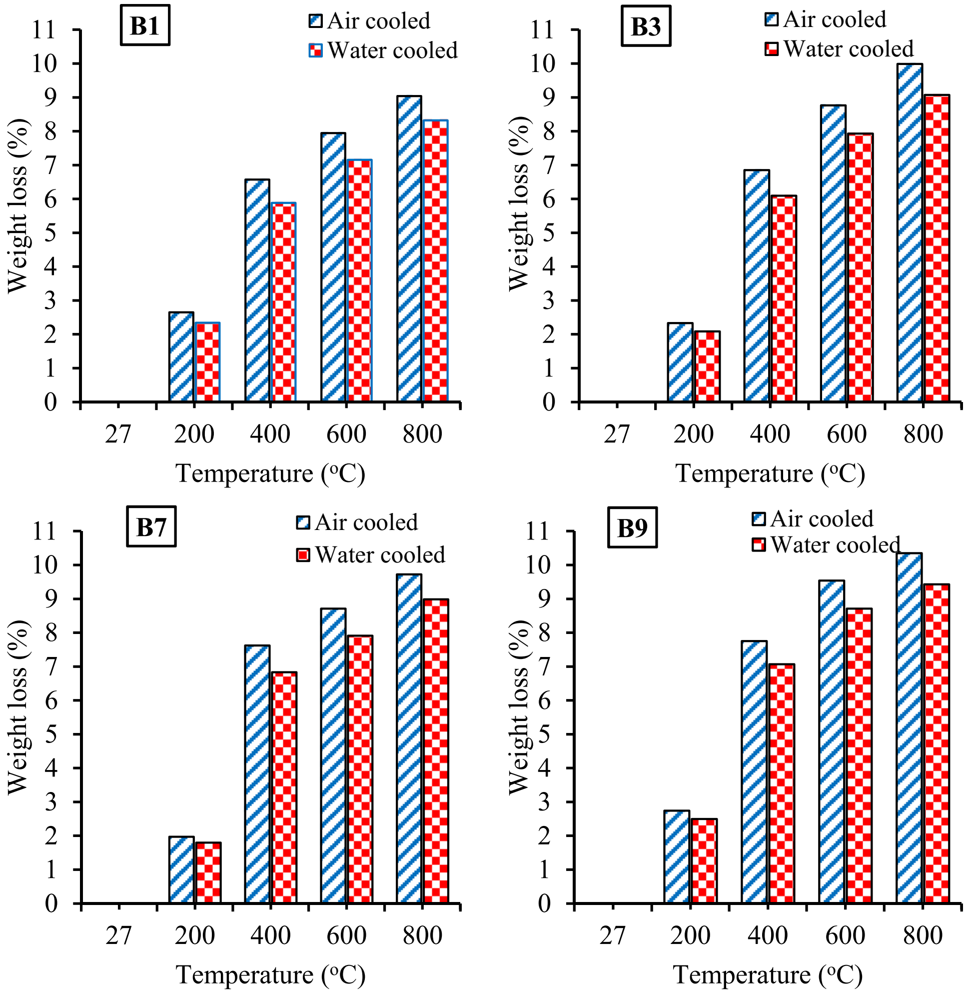


Fig. 5 Mass loss of concrete specimens at various temperatures

dioxide [24]. The loss in mass consequently altered the mechanical performance and caused spalling in concrete. Mohammadhosseini et al. [19] also observed the loss in the matrices binding of FRC because of the dehydration of moisture in the C–S–H gels in addition to the decomposition of $Ca(OH)_2$.

Figure 6 demonstrates the correlations between the results of mass losses of concrete mixes containing WMP

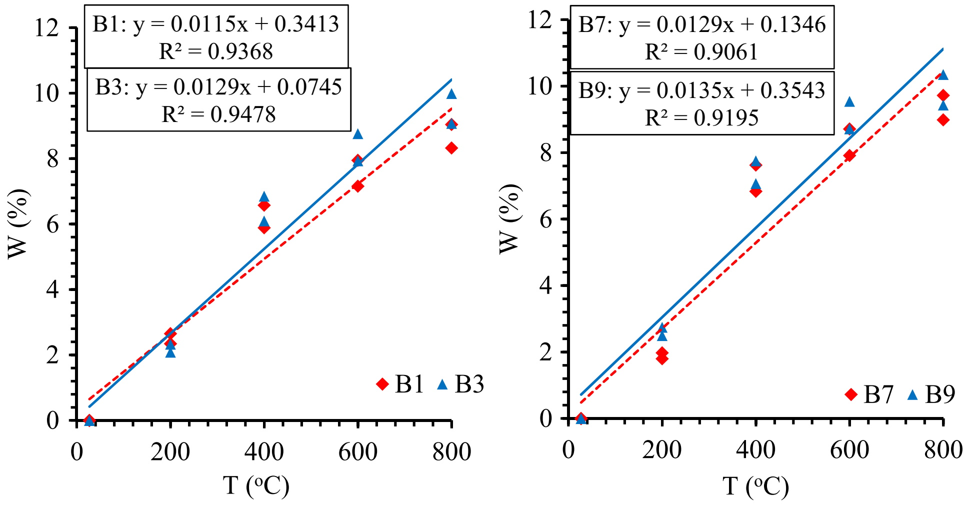


Fig. 6 Mass loss versus temperatures

fibres and POFA at different temperatures. In this regard, a linear regression method resultant in Eqs. (1)–(4), and having a coefficient of determination (R^2) was applied. It can be seen that the obtained R^2 values are ranged from 0.906 to 0.947 for all concrete specimens. This range of R^2 values represents good confidence in the relationship for both cooling systems.

$$B1 : w^T/w^A = 0.0115T + 0.3413 \quad (R^2 = 0.9368) \tag{1}$$

$$B3 : w^T/w^A = 0.0129T + 0.0745 \quad (R^2 = 0.9478) \tag{2}$$

$$B7 : w^T/w^A = 0.0129T + 0.1346 \quad (R^2 = 0.9061) \tag{3}$$

$$B9 : w^T/w^A = 0.0135T + 0.3543 \quad (R^2 = 0.9195) \tag{4}$$

where w^A is the mass of specimens at the ambient temperature, T signifies the exposure temperatures (°C) and w^T indicates the residual mass of specimens at T.

3.2 Ultrasonic pulse velocity

A non-destructive test of ultrasonic pulse velocity (UPV) was used to measure the quality and consistency of concrete, as well as the investigation of the existing cracks and pores. The variation in the UPV of unheated specimens and those heated up to 800 °C are demonstrated in Fig. 7. From the obtained results, it can be observed that the WMP fibre produced no significant influences on the UPV of the unheated specimens. However, comparatively lower values were recorded at high temperatures for all mixes. For instance, the values of 4567 m/s and 4558 m/s were recorded at room temperature for the OPC mixes comprising 0 and 0.5% WMP fibres, respectively. The values of 4545 m/s and 4530 m/s were similarly noted for POFA mixes containing the same fibres content. Based on the obtained UPV values and compared with those stated by Neville and Brooks [36, 37], the concrete specimens are considered as excellent quality.

The UPV values ranged from 3850 to 4500 m/s were recorded at the temperatures up to 400 °C for OPC and POFA concrete specimens comprising WMP fibres for both cooling regimes, which categorised as good quality concrete. Nevertheless, the UPV values for all concrete specimens were significantly dropped at the temperatures of 600 and 800 °C. The drop in the UPV values of concrete specimens exposed to fire might be owed to the evaporation of moisture content as well as the melting of the WMP fibres. It, therefore, caused a higher volume of voids and the creation of channels along the bed of the melted fibre. Theoretically, lower UPV values at elevated temperatures is also a result of the deterioration of microstructures of the concrete [31]. The abovementioned form of UPV reduction beyond 450 °C, can also be owing to the degradation of C–S–H gels, which raises the size and amount of voids in the specimens [35].

3.3 Compressive strength and correlations

Figure 8 presents the results of the compressive strength of concrete comprising WMP fibre and POFA at the ambient temperature and exposed to elevated temperatures of up to 800 °C for air- and water-cooled systems. It can be seen that the addition of 0.5% WMP fibres reduced the compressive strength of concrete at the ambient temperature by 7.5% as related to that of the control mixture. Moreover, the compressive strength of plain POFA-based concrete was found to be about 3% higher than that of the control OPC-based concrete mix. The rise in strength of POFA-based concretes theorised to be due to the

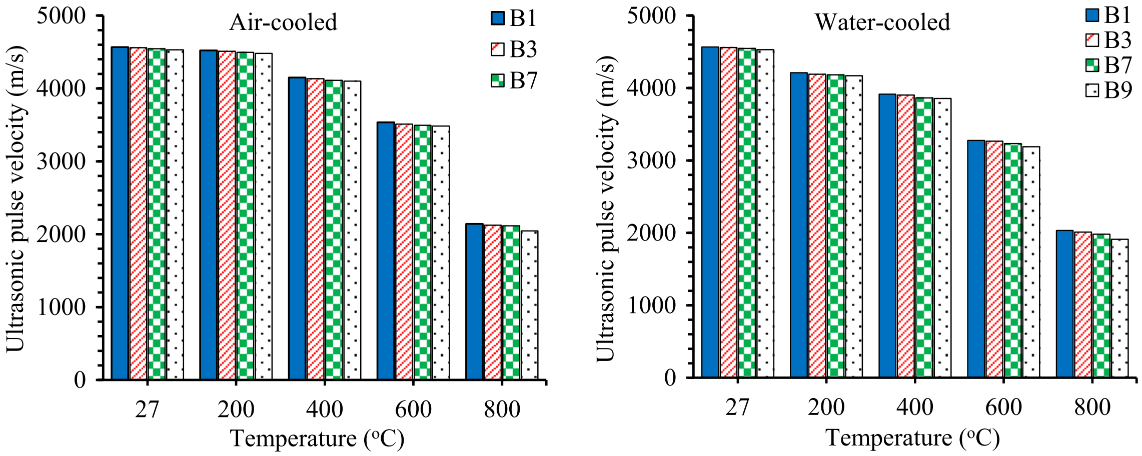


Fig. 7 UPV values of the concrete mixes at elevated temperatures

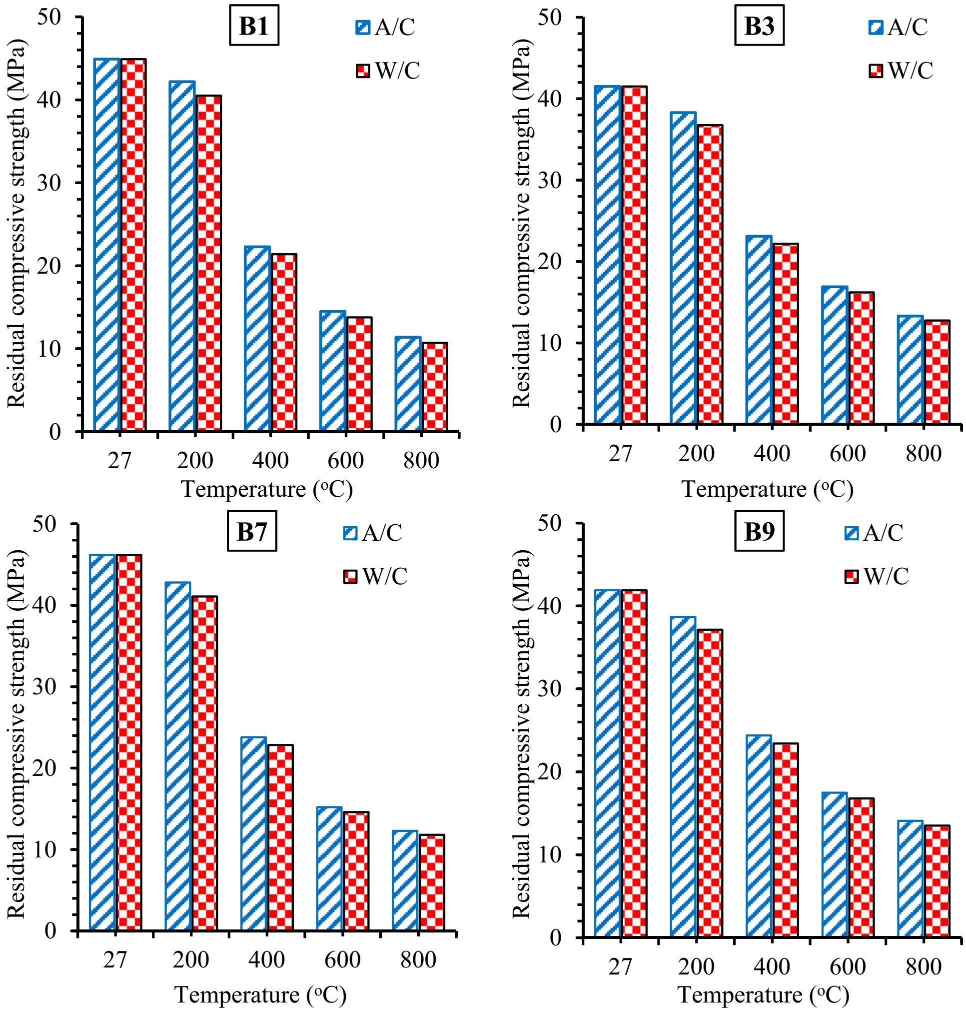


Fig. 8 The compressive strength of concrete mixes exposed to elevated temperature

enhanced pozzolanic reaction of POFA at longer curing ages, as the specimens were cured in water for 90 days.

After exposure to the temperature of 200 °C and cooling down the specimens by water spray and air, the reduction of compressive strength values was ranged between 9 and 11% for all four mixes, as associated with those values obtained for unheated specimens. The loss of compressive strength in this range of temperature is mainly owed to the vanishing of free waters existed in the concrete. It can also be observed that the strength losses were found to be higher in the specimens cooled by water. The important effect of free water in the concrete exposed to high temperatures was recognised by previous researchers [18]. The strength loss was not significant up to 200 °C, due to the partial evaporation of free waters. Nevertheless, the compressive strength decreased sharply at the temperature of 400 °C, owed to the full vanishing of waters.

As mentioned earlier, WMP fibre melts at temperatures amongst 170 and 190 °C. Therefore, these melted WMP fibres fill the voids as they are in liquid form and consequently resulted in improved performance of concrete. The positive influences of WMP fibre on the residual strength of mixes were noticeably revealed at high temperatures. Moreover, at 400 °C and beyond, the strength loss for all mixes became steady with the rise in temperature. This gradual strength loss was perceived in both cooling systems. The consistent drop in strength values might be a consequence of the full melting of WMP fibre in addition to the gradual vaporisation of bound waters as a result of the dehydration and disintegration of C–S–H gels and decomposition of $Ca(OH)_2$, which take place in concrete at temperatures more than 400 °C [22].

The residual compressive strength values of concrete reinforced with WMP fibre was considerably higher than those of plain concretes without any WMP fibres at the temperatures of 600 and 800 °C. These higher residual strength values were owing to the existence of the WMP fibre that caused the decrease of concrete spalling. By adding short and discontinuous fibres to the concrete mix, the uneven propagation of macro and micro-cracks reduced notably at elevated temperature and therefore sustained a ductile performance [23]. The WMP fibres were found to be able to sustain adequate stress to repress crack and redistribute the stress along the adjacent matrix. It has also been observed that the concrete specimens reinforced with WMP fibres had better ductility, higher energy absorption and uniform distribution of cracks, in addition to the slower rate of strength loss as related to those of plain concrete specimens.

Compressive strength and UPV values of WMP fibre reinforced concrete mixes, obtained from experimental tests for unheated and those exposed to elevated temperatures, are related together via empirical relations. These correlations were developed by using regression analysis for both water and air cooling systems. Figure 9 demonstrates the empirical equations developed amongst the compressive strengths and UPV values of the air-cooled specimens. Concerning the presented results, a linear regression method was found, considering R^2 values of higher than 0.70 for all mixes, which meant good confidence for the relations [38, 39]. Concerning the developed equations of (5)–(8), the obtained R^2 values of B3 and B9 are higher than specimens of B1 and B7. It indicates that the adding of 0.5% WMP fibres is caused to achieve a higher rate of efficiency in improving the compressive strength and UPV of concrete mixes exposed to fire.

$$B1 : f_{rcuA} = 0.0129V_A - 21.778 \quad (R^2 = 0.6925) \tag{5}$$

$$B3 : f_{rcuA} = 0.0107V_A - 13.6 \quad (R^2 = 0.7237) \tag{6}$$

$$B7 : f_{rcuA} = 0.0131V_A - 20.905 \quad (R^2 = 0.7063) \tag{7}$$

$$B9 : f_{rcuA} = 0.0103V_A - 11.225 \quad (R^2 = 0.7284) \tag{8}$$

where f_{rcuA} signifies the air-cooled compressive strength of specimens at different temperatures and V_A is the UPV values.

Moreover, the relation between the residual compressive strength and the UPV of the water-cooled samples is drawn in Fig. 10. With reference to the developed equations of (9)–(12), similar to the air-cooled specimens, a linear regression relation was found with R^2 values of higher than 0.7 for all specimens.

$$B1 : f_{rcuW} = 0.0135V_W - 22.406 \quad (R^2 = 0.7457) \tag{9}$$

$$B3 : f_{rcuW} = 0.0111V_W - 13.915 \quad (R^2 = 0.7675) \tag{10}$$

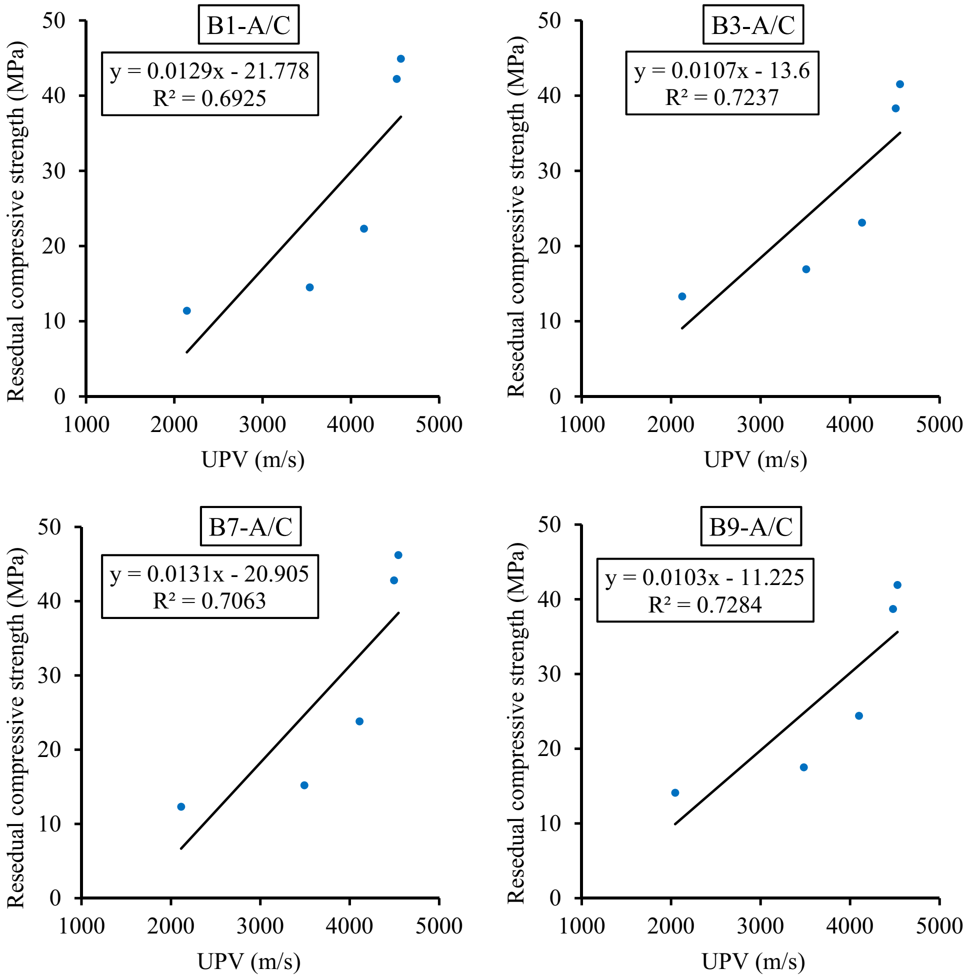
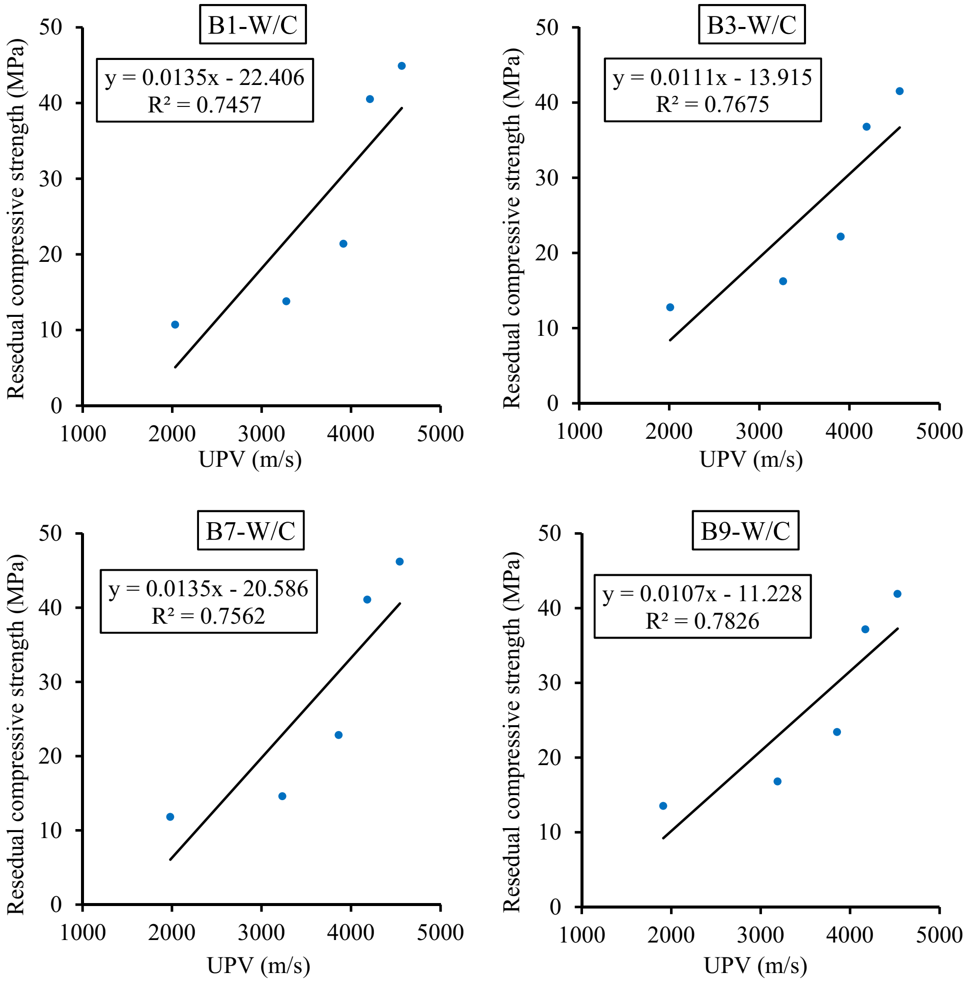


Fig. 9 Residual compressive strength versus UPV of air-cooled specimens

Fig. 10 Residual compressive strength versus UPV values of water-cooled specimens



$$B7:\ f_{rcuW} = 0.0135V_W - 20.586 \quad (R^2 = 0.7562) \tag{11}$$

$$B9:\ f_{rcuW} = 0.0107V_W - 11.228 \quad (R^2 = 0.7826) \tag{12}$$

where f_{rcuW} signifies the water-cooled compressive strength of specimens at different temperatures and V_W is the UPV values.

The outcomes of this study confirm the findings by Mastali et al. [40] on the existence of a good correlation amongst the UPV and residual compressive strength values of concrete reinforced with PP fibres. Based on the outcomes, it can also be observed that the best performance in terms of residual properties was found for concrete specimens reinforced with WMP fibres in both OPC and POFA mixes. Besides, the relationships in the current study revealed that the UPV measurement and the obtained values could be used in the assessment of the concrete properties at high temperatures, such as compressive strength more quickly and effectively.

4 Conclusions

In the present study, the mechanical properties of sustainable concrete containing WMP fibres and POFA exposed to high temperatures were explored. The following conclusions can be made based on the examination and investigational results:

- The concrete specimens containing WMP fibres showed a higher percentage of mass loss at elevated temperatures than those of plain concrete specimens. The maximum mass losses for both air- and water-cooled specimens were approximately 9.3% for OPC and 10% for POFA mixes.
- The specimens reinforced with WMP fibres shown better ductility performance than plain concrete specimens owed to the bridging action of the WMP fibres. A good quality concrete with the UPV values between

3850 and 4500 m/s was detected at the ambient temperature. Nevertheless, after exposure to the fire, the UPV values of all specimens dropped sharply.

- The compressive strength reduced slightly with the adding of WMP fibres at normal conditions. Despite the higher mass loss in the specimens containing WMP fibres, the overall compressive strength of mixes reinforced with WMP fibre was not extensively influenced by up to 400 °C. The reduction in compressive strength values, nevertheless, was more noticeable at the temperatures of 600 °C and beyond.
- The production of eco-friendly concrete by adding WMP fibres and POFA is highly potential to be developed with adequate capacity in resistance to elevated temperatures for both structural and non-structural applications.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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