Journal of Engineering and Applied Sciences 13 (11): 3985-3996, 2018
ISSN: 1816-949X

The Effects of Adding Waste Pet Fibers on the Some Mechanical Properties of Cement Mortar under Exposure to Elevated Temperature

[2]Suaad Nasir, [2]Bevian Ismail Al-Hadithi and [1]Abdulkader Ismail Al-Hadithi
[1]Department of Dams and Water Resources Engineering, College of Engineering, University of Anabr, Ramadi, Anbar, Iraq
[2]Department of Construction and Building, University of Technology, Baghdad, Iraq

Abstract: This research addresses the impact of rising temperatures on properties of reinforced cement mortar with Waste Plastic Fibers (WPF) resulting from cutting the bottles used to save soft drinks. These kinds of fibers were added as volumetric ratios of 0.5, 1, 1.5 and 2% as the reference mix was used for comparison. Each group of cement mortar specimens was heated to a wanted temperature and kept at that temperature for about 1 h before being gradually cooled to room temperature and then they were tested. Compressive strength and flexural strength tests were conducted at room temperature on some samples as others examined after exposing to elevated temperatures by electric ovens where temperatures were 100, 200, 400 and 700°C. The results show a noticeable decrease in both compressive strength and modulus of rupture values after exposure to temperature higher than 400°C of plain cement mortar and WPFM. Cement mortar samples which were heated to 200°C maintained their original color and no apparent visual discoloration occurred in the mortar whereas the specimens which were heated to elevated temperature equal to 400°C black spots appear on the top surfaces of both mortar cubes and prisms due to burning of PET fibers.

Key words: PET, elevated temprature, waste plastic fibers, fiber reinforced mortar, waste plastic fibers, flexural strength

INTRODUCTION

Due to the massive amounts of plastic waste that is dumped annually in the environment, given the seriousness of such waste to the environment, causing long term contamination of up to hundreds of years (Anonymous, 2005; Ismail and Al-Hashmi, 2008; Salem *et al*., 2009; Guerrero *et al*., 2013; Iucolano *et al*., 2013; Wu *et al*., 2013; Liguori *et al*., 2014; Tam and Tam, 2006). A considerable proportion of industrial products, tissues and goods made of plastics are generally discarded soon after being produced (e.g., PET beverage bottles, food packages) causing huge amounts of plastic post-consumer waste (Panyakapo and Panyakapo, 2008; Salem *et al*., 2009; Iadav, 2008). The production of this type of waste will continue to increase in the future. In fact, it has been estimated that the annual production of plastic waste doubles every 10 years (Choi *et al*., 2005).

Adding of waste plastic to concrete as an attempt to enhance concrete quality with the benefit of reducing the danger of waste degradation was conducted by many researchers (Hannawi *et al*., 2012; Salman, 2015; Saikia and de Brito, 2012; Batayneh *et al*., 2007). Many researchers all over the world had done some researches on this subject by adding waste plastic resulting from cutting beverage bottles as fibers for reinforced concrete and cement mortar (Al-Hadithi, 2008, 2013; Foti, 2011; Pandya and Purohit, 2014; Fadhil and Yaseen, 2015). The other studies were conducted to take advantage of this waste and converted to harmful and beneficial material to the environment by using PET waste as aggregate (Foti, 2011; Al-Hadithi, 2013; Pandya and Purohit, 2014; Fadhil and Yaseen, 2015; Al-Hadithi and Hilal, 2016; Hannawi *et al*., 2010; Mesbah and Buyle-Bodin, 1999; Remadnia *et al*., 2009; Marzouk *et al*., 2007; Safi *et al*., 2013; Verdolotti *et al*., 2014).

Fire is one of the most serious risks that leads to big problems to structures. Fire accidents may occur at any time in buildings and an unpredictable event (Muthadhi and Kothandaraman, 2014). With the increasing building activities, more interests have been given in studying the behaviour of concrete at a high temperature mainly resulting from fire (Awal and Shehu, 2015). Elevated temperature and exposure to fire one of the most issues caused serious problems in deterioration

Corresponding Author: Abdulkader Ismail Al-Hadithi, Department of Dams and Water Resources Engineering, College of Engineering, University of Anabr, Ramadi, Anbar, Iraq

of concrete and mortar strength. Exposure to elevated temperature as in the case of accidental fires is known to deteriorate concrete properties by the initiation of thermal cracks and developing of these cracks and the previously existed cracks in concrete members which leads to a decrease in concrete strength and causes additional deterioration in concrete members. Therefore, this study was dealing with finding the capability of steel fiber to improve concrete characteristics at high temperature exposure (Al-Owaisy, 2006).

Fire resistance is can be defined as the property of a material or assembly to resist the fire or to protect the material from fire as applied to elements of the building, it is differentiated by the ability to impound a fire or to continue to perform a given structural function or both (Defined in ASTM E176) (Anonymous, 1982).

The advantages of concrete in a fire are two-fold. It is: incombustible (e.g., when compared with a material like wood) and a good insulating material possessing a low thermal diffusivity (e.g., when compared with a material like steel). However, there are two problems of concrete in fire. These are: deterioration in mechanical properties as temperature rises which caused by physico-chemical changes in the material during heating and explosive spalling then leads to loss of material, reduced in section size and exposure of the reinforcing steel to excessive temperatures. Thus, the insulating and load bearing functions of the concrete member could be compromised. (Shakir and Jasim, 2009).

One of the most important dangers facing buildings is the exposure to elevated temperatures. There are many ways of exposing concrete structural members to elevated temperatures. Accidental fire can be classified as one of the most common kinds of exposure for buildings. The other way of high temperature exposure can be found in some industrial installations using concrete in locations exposed to continuous elevated temperatures such as the walls of furnace, industrial chimneys, floors under boilers, the kiln and pressure vessels of the nuclear-reactor (Nikolai, 1971).

The effects of elevated temperature on the concrete mechanical properties have been investigated, since, the 1940's (Diederichs and Schneider, 1981; Malhotra, 1956). These studies examined the behavior of mortar, cement paste, concrete specimens and reinforced concrete members exposed to high temperature. The results of these studies constituted the technical basis for the provisions and recommendations for determining concrete strength of elevated temperature in many codes (Akoz *et al*., 1995).

Previous studies Abrams (1971), Weigler and Fischer (1972), Harada *et al*. (1972) and Mohamedbhai (1986) refer to that the deterioration in mechanical properties of concrete at high temperatures. The residual value of strength depends on many factors like: temperature level, heating duration, the way of re-cooling, type of aggregate and ratio of cement/aggregate.

It is a fact that, the concrete in tension is weak and has a brittle behavior. For this reason, steel reinforcement added as continuous reinforcement to increase ductility and strength. This addition makes the concrete to be more homogeneous and isotropic. When the concrete cracks, the randomly oriented fibers start working, arrest crack formation and propagation. There are many types of fibers such as steel fibers, glass fibers, polypropylene fiber, carbon fibers, …, etc. (Romualdi and Batson, 1983; Anonymous, 1982).

Many researches and studies have been noticed to provide experimental results about the using fibers on the properties of concrete at elevated temperature (Purkiss, 1984; Faiyadh and Al-Ausi, 1986, 1989).

Polypropylene (PP) fibers and steel fibers have been used to decrease spalling and cracking and to enhance the residual strength (Nishida and Yamazaki, 1995; Kalifa *et al*., 2001). But minimal or even negative effects of PP fibers on the residual performance of the heated concrete were also observed (Chan *et al*., 2000).

Chen and Liu (2004) studied the residual strengths of High-Strength Concrete (HSC) and Hybrid-Fiber-Reinforced High-Strength Concrete (HFRHSC) when exposed to elevated temperatures. The results showed that normal HSC is prone to spalling after exposure to high temperatures and its first spalling occurs when the temperature approaches 400°C whereas the HSC reinforced with high melting point fibers, the first spalling occurs when the temperature reaches to approximately 800°C while there is no spalling appears during exposing to high temperatures for HSC reinforced by Polypropylene (PP) fiber with a low melting point.

Noumowe (2005) in his study of High Strength Concrete (HSC) reinforced with polypropylene fibers subjected to elevated temperatures showed that this kind of fibers has significant contribution to the spalling resistance. This study develops some signifigance data on the mechanical properties and microstructure of high strength concrete contains polypropylene fibers and exposed to elevated temperature up to 200°C. When polypropylene reinforced with polypropylene fibers, high strength concrete is heated up to 170°C, fibers readily melt and volatilise, creating additional porosity and small channels inside the concrete. TGs and DSC analysis showed the temperature ranges of the decomposition reactions in the high strength concrete. Scanninig electron microscope analysis showed supplementary pores and small channels created in the concrete due to fibers melting. Mechanical tests showed small changes in compressive strength, modulus of elasticity and splitting tensile strength that could be due to polypropylene fibers melting. Many important scientific facts resulted from that study like When a cementitious material such as concrete is being heated several chemical and physical phenomena occur in the temperature range between 100 and 900°C. Several physical phenomena occurred in the temperature range between 100 and 250°C: vaporization of water in the cementitious matrix (110°C), CSH dehydration, fibre shrinkage and melting (170°C). The following transformations can be identified, water evaporation at 110°C, fibre melting at about 170°C, first stage of CSH dehydration at 170°C and a peak is seen near 480°C in all the curves. The results shwoed also that, Quartz transformation from a rhomboedric shape to hexagonal shape at 573°C whereas at about 870°C a large peak can be seen. It is mainly due to decomposition of calcium carbonate and CSH phases.

An experimental program is carried out by Kim *et al*. (2014) to study the residual characteristics of organic and inorganic resins for structural modulate using Carbon Fiber Reinforced Polymer (CFRP) composites exposed to thermal stress states. An experimental program is carried out by three-phase to study the behavior of the inorganic resin, CFRP composites and resin-concrete interface at high temperatures ranging from 25-200°C. The inorganic properties confirm strong depending on the time of curing and are influenced by the temperature degree of exposure. CFRP composites show a decrements in both of strength and modulus with an increasing temperature due to the degradation of bond between both of fibers and resin. Thermal stability of the inorganic resin was better than that of organic resin, whereas the inorganic resin illustrates a lower strength than the organic resin because of insufficient stress transfers. The composites have failed abruptly, regardless of resin types. The resins interfacial fracture energy is reduced with the rising of temperature degree, including the deterioration in the morphology of the interface between the concrete substrate and the resin.

Correia *et al*. (2014) conducted an experimental study about the effects of elevated temperatures on the residual mechanical properties of concrete containing Plastic Waste Aggregates (PWAs). Many concrete mixes were prepared with a reference concrete mix made with Natural Aggregates (NAs). Waste plastic was added with replacement of two ratios of natural aggregate which were 7.5 and 15% by three types of Polyethylene Terephthalate (PET) Plastic Waste Aggregate (CPWA). Specimens were exposed to temperatures of 600 and 800°C for a period of 1 h, after being heated in accordance with the ISO 834, time-temperature curve. Compressive, splitting tensile strengths, elastic modulus, Ultrasonic Pulse Velocity (UPV), surface hardness and water absorption by immersion were tested after cooling down to ambient temperature and then these results were compared with the reference values obtained prior to fire exposure. For the replacement ratios used in these experiments, the maximum temperatures reached in reference mix were lower than those measured in CPWA due to the higher porosity increase in temperature of the former type of concrete that facilitated the propagation of heat inside concrete and the exothermic thermal decomposition of Plastic Aggregates (PA) which generated additional heat. After exposure to elevated temperatures, the degradation of both of compressive strength and elastic modulus of CPWA was higher than that of reference mix, particularly for the highest replacement ratio as a consequence of the higher porosity increase experienced by CPWA. The reduction of residual splitting tensile strength value of CPWA was found to be similar to that of reference mix, possibly because the addition of PWA led to lower internal stresses due to thermal gradients and allowed an easier dispersion of gases tied (confined) in pores, thus reducing crack development in the matrix. The magnitude of the degradation of concretes residual mechanical properties can be attributed to the type of PWAs and the replacement ratio.

From studies and researches mentioned above no studies or experimental works have been noticed to provide experimental data represent the effect of fibers make from waste plastic PET on the properties of concrete or cement mortar at high temperature, so because of that, it becomes an important issue to make studies on the effect of elevated temperature on the properties of WPFs reinforced concrete or cement mortar using WPFs resulting from cutting beverage PET bottles. In this study an investigation is perform on the effect of elevated temperature on both of compressive strength and modulus of rupture of cement mortar contains different volumetric fiber percentages.

MATERIALS AND METHODS

Cement: The cement that had been used in this research was Ordinary Portland Cement which is commercially known (LAFARGE UCC). Table 1 and 2 show the chemical composition and physical properties, respectively which conform to Iraqi Standard Specification No. 5/1984 (Anonymous, 1984a).

Fine aggregate: Natural fine aggregate from the Al-Ukhaidher region was used in this study. Figure 1 shows the grading of sand which was within zone three. The absorption, sulfate content, fineness modules and specific gravity for the used sand are 1, 0.5, 2.8 and 2.6, respectively. The used sand was compatible with the requirements of Iraqi standard specification No. 45/1984 (Anonymous, 1984b).

Water: The water used for both mixing and curing was potable water from the water-supply network system (tap water).

Table 1: Chemical composition for ordinary portland cement*

Oxides	Ordinary portland cement	Limits of Iraqi standard specification No. 5/1984 (%)
Chemical composition		
CaO	62.40	-
SiO_2	21.85	-
Al_2O_3	4.76	-
Fe_2O_3	3.41	-
MgO	2.35	≤5.0
SO_3	1.45	≤2.8
Na_2O	0.38	-
K_2O	0.35	-
LOI	1.60	≤4.0
IR	0.60	≤1.5
LSF	0.85	0.66-1.02
Main compounds (Bogue's equations)		
C_3S	46.98	-
C_2S	27.20	-
C_3A	6.84	-
C_4AF	10.38	-

Table 2: Physical properties of ordinary portland cement*

Physical properties	Ordinary portland cement	Limits of Iraqi specification No. 5/1984
Soundness by autoclave (%)	0.35	≤0.8
Fineness (Blaine method) (cm^2/gm)	3150	≤2300
Setting time (Vicat's method)		
Initial setting time (h:min)	2:55	≤45 min
Final setting time (h:min)	5:10	≤10 h
Compressive strength at		
3 days (MPa)	17.3	≤15
7 days (MPa)	24.5	≤23

*Chemical and physical tests are made by the National Center for Geological Survey and Mines

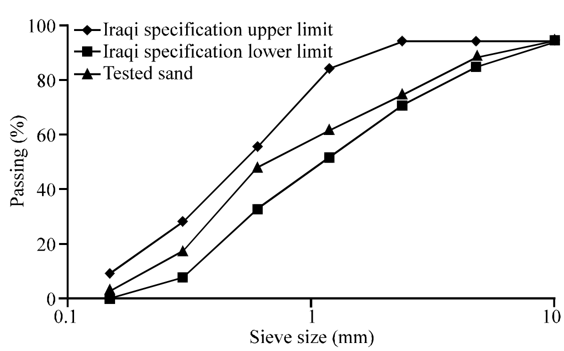

Fig. 1: Grading of fine aggregate

Waste plastic fibers: Because of the rapid growth of the population in the recent years which leads to increase the waste plastic products. The type of waste plastic considered in this study is the soft drink bottles waste plastic. The waste plastic bottle is sliced to small uniform pieces with an average length equal to 34 mm width equal to about 4 mm and thickness equal to 0.3 mm. The density of the WPF was 1100 kg/m^3. The major components of these waste plastic bottles are Poly Eethylene Terephthalate (PET). Generally, it has good resistance to mineral oils, acids and solvents but not to bases. The semi-crystalline PET has good strength, ductility, hardness and stiffness while the amorphous type has better ductility but less stiffness and hardness (Mark, 1999). The common examples of PET are fibers, barrier films, soft drink bottles (amorphous PET), etc. (Moreley and Royels, 1983). Below, shows properties of WPFs in Table 3 and Fig. 2 show pictures of the sliced pieces of the waste plastic used in this study.

Mortar mixes and mortar mixing procedure

Cement mortar mixes: Five types of cement mortar mixes were investigated in this study. All cement mortar mixes consist of one part of cement and two parts of sand by weight. Waste plastic fibers are added to the mortar as volumetric ratios of 0.5, 1, 1.5 and 2% as the reference mix was used for comparison purposes. The proportion specifications for all types of cement mortar mixes which

Table 3: Some of the physical properties of (PET) plastics

Types	Poly Ethylene Terephthalate (PET)
Density (kg/m^3)	1100
Tensile (Young's Modulus) (GPa)	0.19
Water absorption (%)	0.5
Ultimate strain (ε, %)	180
Flexural modulus (rigidity) (E MPa) (3-point flexure)	2.000
Yield strain ε % (Tensile)	4
Breaking strength (σB MPa, tensile)	50

Fig. 2: Waste plastic fibers

Table 4: Mortars mixed proportions

Symbol	Mix. proportion (Cement:Sand)	Proportions by weight			Waste Plastic Fiber (WPF) (%) (V_f)
		Cement	Sand	Water	
Ref.	1:2	1	2	0.5	0.0
M0.5	1:2	1	2	0.5	0.5
M1.0	1:2	1	2	0.5	1.0
M1.5	1:2	1	2	0.5	1.5
M2.0	1:2	1	2	0.5	2.0

are shown in Table 4. Water/cement which was used equal to 0.50%. All dry composition (except Waste Plastic Fibers WPF) is mixed for about three minutes in mortar electric mixer then WPF were randomly distributed into the mix slowly in five minutes during the mixing process. Three 50 mm cubes and (40×40×160) mm prism specimens were molded from each type of cement mortar for each elevated temperature for age of 28 days.

Preparations, casting and curing of the test specimens: The moulds were well cleaned, after that the internal faces were oiled with machine oil to avoid adhesion with the cement mortar after hardening. Casting the cement mortars was carried out in one layer and then, the compaction was performed by means of vibrating table for a sufficient time until reach full compaction. The last step, the mortar surfaces were leveled and specimens were warped with nylon sheets for 24 h prior demolding to prevent the evaporation of moisture from the surfaces and to avoid plastic shrinkage cracking. After demolding, the specimens were completely immersed in tap water until the time of the test.

Mechanical properties testing: The heating process is performed by using electric furnace. The maximum furnace temperature was equal to 1000°C. Controlling of temperature achieved by an electronic controller. Cement mortar specimens are heated slowly at a constant rate equal to 2.5°C/min to avoid steep thermal gradient. When the required temperature level is reached, the cement mortar specimens are saturated thermally at that level for 1 h. The cement mortar specimens are then air cooled until testing.

Compressive strength: The determination of compressive strength was determined by using 50 mm cube according to ASTM C109-02 (Anonymous, 2010a, b). The cement mortar specimens were demolded after one day then they were cured according to ASTM C 511-03 (Anonymous, 2003). The compressive strength test was performed at the age 28 days. The 9 cement mortar cubes were prepared from each mix. The final compressive strength value recorded is the average of the results of three cement mortar cubes.

Flexural strength: (40×40×160 mm) prisms were prepared according to ASTM 348-02 (Ravindrarajah *et al*., 2002). The specimens were demolded after 1 day. The mentioned prisms were cured according to ASTM C 511-03 (Anonymous, 2010a, b). The flexural strength test was performed at the age of 28 days. The final flexural strength recorded was the average of the result obtained from three cement mortar prisms.

RESULTS AND DISCUSSION

Effect of elevated temperature on compressive strength: Table 5 and Fig. 3 show the relationship between temperature and the compressive strength value for all cement mortar mixes. In general, it can be clearly seen that all cement mortar mixes whether plain or waste plastic fibers mortar WPFM mixes exhibited a loss in compressive strength as temperature increases. As the temperature increases above 400°C there is a major decrease in compressive strength this can be attributed to the loss of cement paste plasticity at high temperatures (Ravindrarajah *et al*., 2002; Awal and Shehu, 2015).

WPFM mixes at room temperature about 20°C with V_f value equal to 1 and 1.5% exhibited slightly higher compressive strength compared to reference cement mortar mix; the other WPFM mixes had lower compressive strength than reference mix. at the same temperature. That decrease in compressive strength might be due to the forming of segregation on WPFM mixes and this action led to form a stiff bond about these bulks. Therefore, the existing of waste plastic fibers allows the absorption of water inside the porous. Also, existing of waste plastic fiber reducing the density of cubes and that led to decrease the compressive strength of composite (Al-Hadithi *et al*., 2013). Using of waste plastic fiber increased the porous inside the mortar structure and that caused reduced the compressive strength.

Figure 4 plots for all cement mortar compositions the ratio between the residual compressive strength value before and after exposure to elevated temperature. This figure shows the relationship between temperature and the residual compressive strength value in relation to the original strength prior to heating of reference cement mortar and waste plastic fibers mortar WPFM mixes.

The residual strength for all cement mortar mixes was 58.3-103.7% of the corresponding initial strength when the concrete was heated to elevated temperature of 200°C. According to Noumowe (2005), Weigler and Fischer (1972) results the following transformations can be identified: water evaporation at 110°C, fiber melting at about 170°C and first stage of CSH dehydration at 170°C. When the temperature was elevate to 400°C the residual

Table 5: Effect of high temperature on compressive strength of Waste Plastic Fibers Mortar (WPFM)

Mix.	Comp. St. at Room temp.	100°C	200°C	400°C	700°C
Ref.	29.60	30.70	29.8	22.95	17.10
M0.5	20.73	21.00	21.1	19.00	11.55
M1.0	36.35	30.00	27.0	25.05	11.60
M1.5	37.75	28.00	22.0	25.05	8.17
M2.0	25.00	21.37	19.1	8.17	5.60

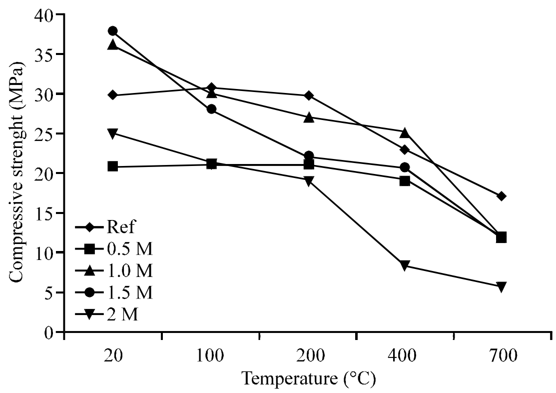

Fig. 3: Relationships between compressive strength at 28 days and temperature of plain mortar and WPFM mixes

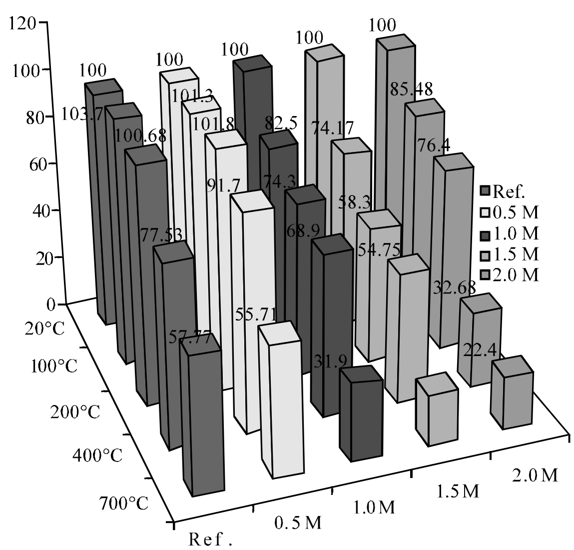

Fig. 4: The relationship between residual compressive strength and temperature of plain mortar and WPFM mixes

strength of reference cement mortar was about 77.53%. Otherwise the residual strength for WPFM mixes with volume fraction (0.5, 1, 1.5 and 2%) were 91.7, 68.9, 54.75 and 32.68%, respectively. Beyond 400°C the strength continued to drop and at 700°C the residual strength of reference concrete was equal to 57.77% while for WPFM mixes with the volume fraction of 0.5, 1, 1.5 and 2% the residual strength equal to 55.71, 31.9, 21.64 and 22.4%, respectively. These losses in strength can be attributed to several physical phenomena occurred in the temperature range varies between 100 and 250°C published by Phan and Carino (1998): vaporization of water in the cementitious matrix (110°C), CSH dehydration, fibre shrinkage and melting (170°C). At 573°C Quartz transformation from a rhomboedric shape to hexagonal shape.

Comparing with the reference mortar mix, adding of WPF which resulted in decreasing in the compressive strength after exposure to elevated temperatures that means, the use of this kind of fibers had a negative effect on the compressive strength for WPFM mixes. Similar results had been reported by other researchers by using Polypropylene (PP) fibers like (Poon *et al*., 2004; Qian and Stroeven, 2000).

Effect of high temperature on modulus of rupture: Modulus of rupture results at the age of test equal to 28 days of cement mortar mixtures under elevating temperature is shown in Table 6 and Fig. 4. A decrease in modulus of rupture value with an increasing in heating temperature for all groups of cement mortar mixtures whereas, Fig. 5 shows the residual flexural strength for reference cement mortar and WPFM mixes as a function of the maximum temperature. Comparable to compressive of refernce cement mortar mix and WPFM, flexural strength decreases with increasing the temperature. It can be seen that WPFM has approximately the same modulus of rupture up to 400°C, except the mortar mix with volumetric fiber content V_f equal to 2% which appears a big decrement in modulus of rupture value comparing with all of other mortar mixes for all elevated temperatures.

When the temperature was increased to 200°C the residual modulus of rupture of reference mortar was about 69.7%, moreover, the residual strength for WPFM mixes with $V_f$value equal to 0.5, 1, 1.5 and 2% were 71.4, 59.8, 67.9 and 79%, respectively. For the elevated temperature equal to 400°C the residual modulus of rupture of reference mortar was about 65.8% whereas the residual strength for WPFM mixes with volume fraction 0.5, 1, 1.5 and 2% were 49.4, 35.3, 55.2 and 27.7%, respectively. Beyond 400°C the flexural strength value keep to drop down and at 700°C the residual strength of reference cement mortar was equal to 31.7% while for WPFM mixes with the volume fraction of 0.5, 1, 1.5 and 2% the residual strength equal to 6.8, 6.7, 16.2 and 11.2%, respectively. These losses in strength can be attributed to several physical phenomena occurred in the temperature range between 100 and 700°C as mentioned in Fig. 6.

Table 6: Effect of high temperature on modulus of rupture of Waste Plastic Fibers Mortar (WPFM)

	M.O.R. at				
Mix.	Room temp.	100°C	200°C	400°C	700°C
Ref.	12	11.47	8.36	6.7	3.8
M0.5	12.43	9.4	8.87	6.14	0.845
M1.0	12.7	9.06	7.6	4.48	0.845
M1.5	13	10.19	8.83	7.17	2.1
M2.0	7.725	6.78	6.1	2.14	0.8625

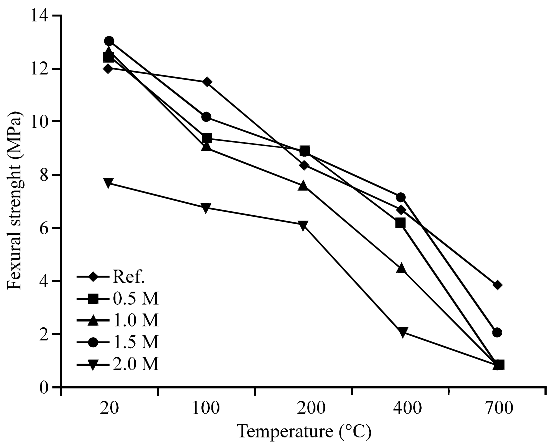

Fig. 5: Relationships between modulus of rupture (flexural strength) at 28 days and temperature of plain mortar and WPFM mixe

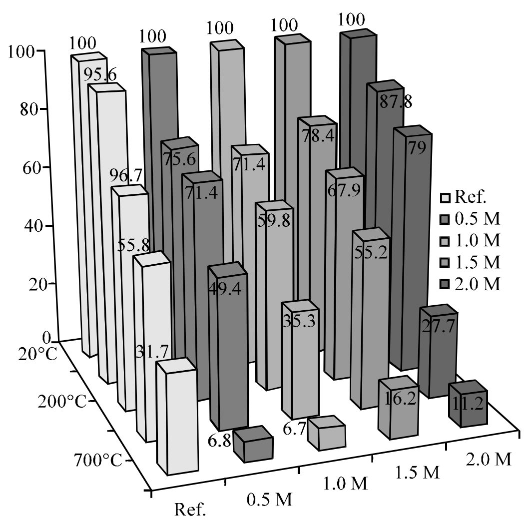

Fig. 6: The relationship between residual modulus of rupture (flexural strength) and temperature of plain mortar and WPFM mixes

Color change and thermal crack development: The change in color with elevating temperature was an indication of physical and chemical changes of mortar mixes components. The samples which were heated to temperature equal to 200°C maintained their original color and no apparent visual discoloration occurred in the mortar as shown in Fig. 7a-d while specimens heated

Fig. 7: Continue

(d)

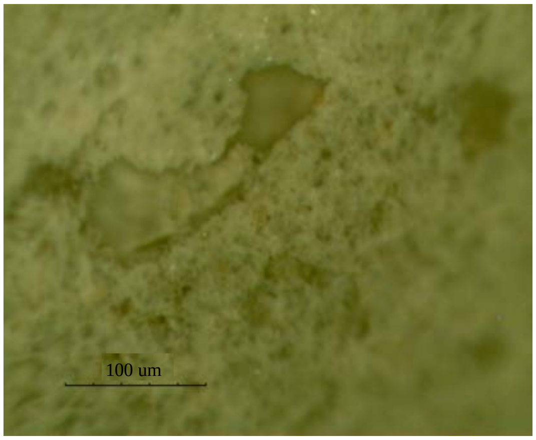

Fig. 7: a) Mortars samples with 0.5% WPF after exposure to 200°C temperature; b) With 1.5%; c) Optical microscope photo of mortar sample surface with 1.5% WPF after exposure to 200°C temperature and d) With 1.5%

to 400°C black spots appear on the top surfaces of both mortar cubes and prisms as shown in Fig. 8a-c and this is might due to burning of PET, the sole material of WPF. Inside the microstructure of the cement mortar the PET fibers are surrounded by cement paste and sand particles and the elevated temperature leads to melting WPFs whereas the materials at the surface of mortar samples were subjected to a higher temperature than that inside the structure of the mortar samples and this temperature leads not only to melt these type of fibers but also to burn WPF is converting PET to carbon and that leads to the appearance of black spots. When cement mortar specimens are exposed to high temperatures they suffering from moisture loss due to increased pore pressure from evaporating water inside the concrete and due to the difference in modulus of thermal expanding of cement paste with normal aggregate and WPFs and this process leads to increase the internal stresses and therefore, the apearance of significant cracks (Al-Baghdadi, 2017). During the experiments, visible micro cracks on specimens appeared when temperatures of exposure were 400°C. As the increase in moisture loss results in the appearance of more excessive cracking, cubes heated to 700°C had a significant increase in the number and size of cracks, compared to cubes exposed to 400°C. At 700°C the black spots disappear because of evaporation of the burned PET resduales and specimen suffered noticeable color changes with a spalling occurred on the samples surfaces as seen in Fig. 9a-f.

When specimens are exposed to elevated temperatures and due to the difference in modulus of

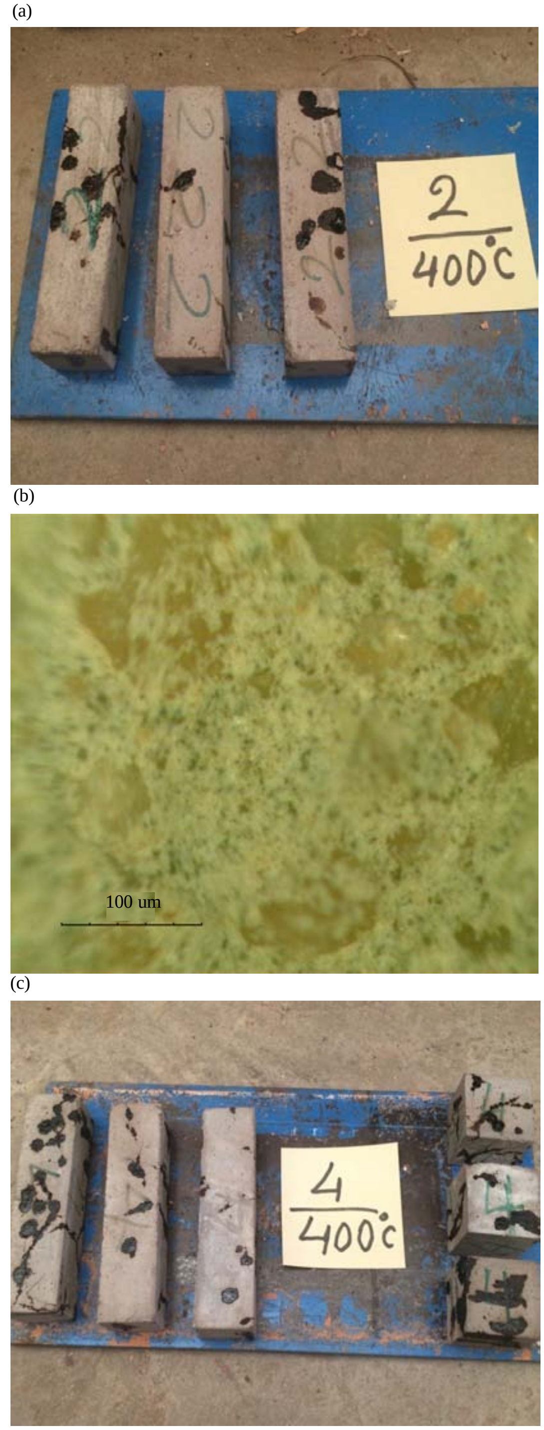

Fig. 8: a) Mortars samples with 0.5% WPF after exposure to 400°C temperature; b) 1% and c) 1.5%

thermal expanding of cement paste with normal aggregate and WPFs that cause an increment in internal stresses and therefore, the appearance of significant cracks as shown in Fig. 9.

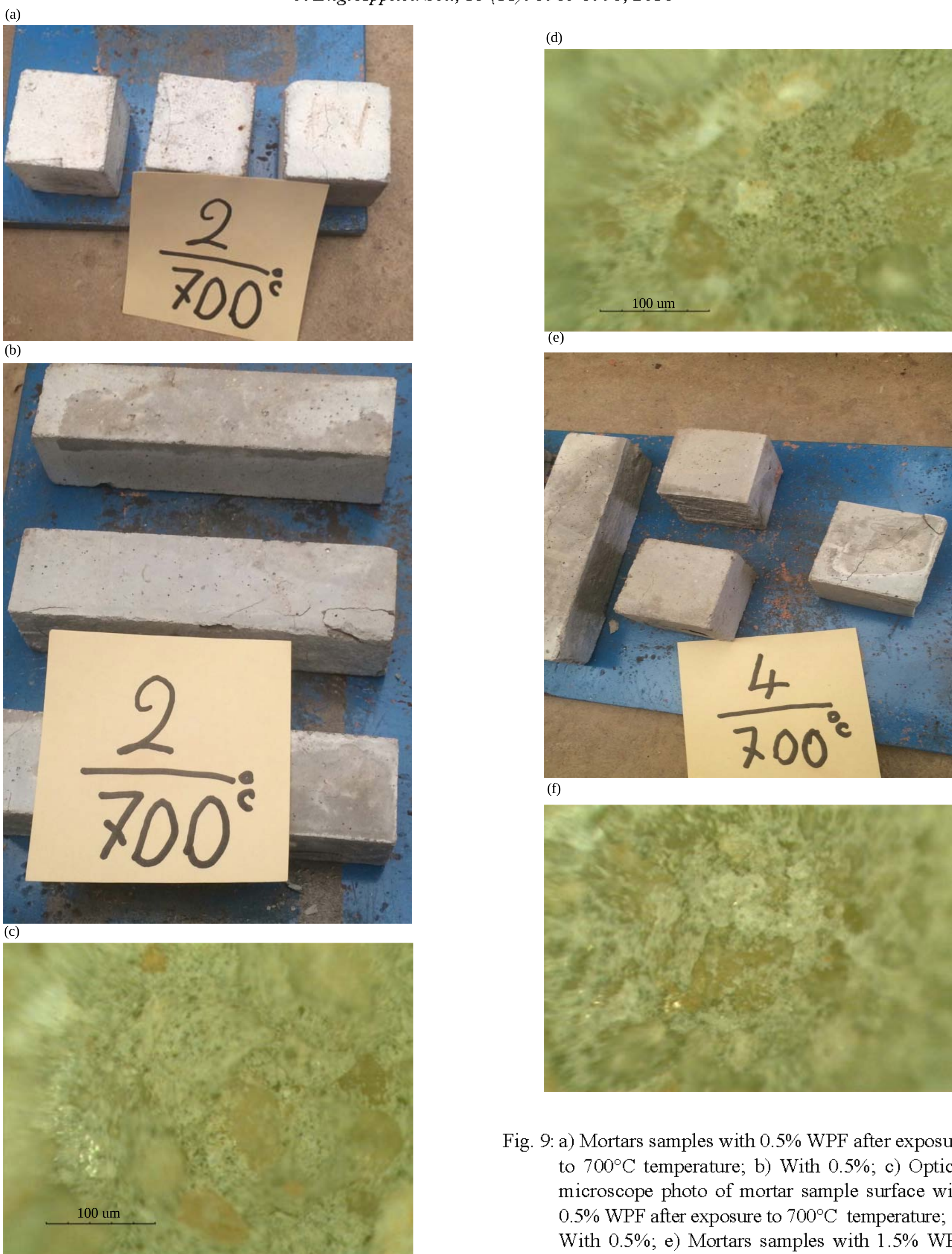

Fig. 9: Continue

Fig. 9: a) Mortars samples with 0.5% WPF after exposure to 700°C temperature; b) With 0.5%; c) Optical microscope photo of mortar sample surface with 0.5% WPF after exposure to 700°C temperature; d) With 0.5%; e) Mortars samples with 1.5% WPF after exposure to 700°C temperature and f) Optical microscope photo of mortar sample surface with 2% WPF after exposure to 700°C temperature

CONCLUSION

The compressive strength and flexural strength values of reference cement mortar and WPFM are reduced by an amount depending on the value of the exposed temperature. For specimens tested at temperatures between room temperature 20 and 200°C, the reduction of the compressive strength value was relatively small. However, when samples were exposed to temperatures higher than 400°C, a severe decrease in residual strength was measured. The samples which were heated to elevated temperature equal to 200°C maintained their original colour and no apparent visual discoloration occurred in the mortar. Specimens heated to 400°C black spots appear on the top surfaces of both mortar cubes and prisms due to burning of PET fibers.

REFERENCES

Abrams, M.S., 1971. Compressive strength of concrete at temperatures to 1600F. Spec. Publ., 25: 33-58.

Akoz, F., N. Yuzer and S. Koral, 1995. The influence of high temperature on the physical and mechanical properties of ordinary Portland cement and silica fume mortar. Tech J. Turk Chamber Civ. Eng., 6: 287-292.

Al-Baghdadi, H.M., 2017. Effect of high temperature on some properties of light weight concrete. AlQadisiyah J. Eng. Sci., 7: 176-188.

Al-Hadithi, A., A.T. Al-Ejbari and S.J. Ghassan, 2013. Behaviour of waste fiber concrete slabs under low velocity impact. Iraqi J. Civ. Eng., 9: 135-148.

Al-Hadithi, A.I. and N.N. Hilal, 2016. The possibility of enhancing some properties of self-compacting concrete by adding waste plastic fibers. J. Build. Eng., 8: 20-28.

Al-Hadithi, A.I., 2008. Some properties of concrete using waste plastic fiber with a very small percentages. Proceedings of the 1st International Conference on Engineering Sciences (IESC'08), November 2-4, 2008, University of Aleppo, Aleppo, Syria, pp: 1-8.

Al-Hadithi, A.I., 2013. Improving impact and mechanical properties of gap-graded concrete by adding waste plastic fibers. Intl. J. Civ. Eng. Technol. India, 4: 118-131.

Al-Owaisy, S.R., 2006. Post heat exposure properties of steel fiber reinforced concrete. J. Eng. Dev., 10: 194-207.

Anonymous, 1982. State-of-the-art report on fiber reinforced concrete. ACE Committee 544, ACI Concrete International-American Concrete Institute, Michigan, USA.

Anonymous, 1984a. Iraqi standard specification for Portland cements. Iraqi Standards No.5, Iraqi Central Organization for Standardization and quality control (ICOSQC), Baghdad, Iraq.

Anonymous, 1984b. The aggregates of the natural resources used in concrete construction. Iraqi Standard Specification No. 45, Iraqi Central Organization for Standardization and quality control (ICOSQC), Baghdad, Iraq.

Anonymous, 1989. Guide for determining the fire endurance of concrete elements. ACI 216R-89, American Concrete Institute, Michigan, USA.

Anonymous, 2003. Standard specification for moist cabinets, moist room and water storage tanks used in the testing of hydraulic cements and concrete. ASTM C 511-03, ASTM, West Conshohocken, Pennsylvania.

Anonymous, 2005. Bangkok State of the environment, environmental quality management and control division. Bangkok Metropolitan Administration, Bangkok, Thailand.

Anonymous, 2010. Standard test method for compressive strength of hydraulic cement mortars. ASTM C 109, American Society for Testing and Materials (ASTM), West Conshohocken, Pennsylvania.

Anonymous, 2010. Standard test method for flexural strength of hydraulic. ASTM C 348, ASTM, West Conshohocken, Pennsylvania.

Awal, A.A. and I.A. Shehu, 2015. Performance evaluation of concrete containing high volume palm oil fuel ash exposed to elevated temperature. Construct. Build. Mater., 76: 214-220.

Batayneh, M., I. Marie and I.M. Asi, 2007. Use of selected waste materials in concrete mixes. J. Waste Manage., 27: 1870-1876.

Chan, Y.N., X. Luo and W. Sun, 2000. Compressive strength and pore structure of high-performance concrete after exposure to high temperature up to 800°C. Cem. Concr. Res., 30: 247-251.

Chen, B. and J. Liu, 2004. Residual strength of hybrid-fiber-reinforced high-strengthconcrete after exposure to high temperatures. Cem. Concr. Res., 34: 1065-1069.

Choi, Y.W., D.J. Moon, J.S. Chung and S.K. Cho, 2005. Effects of waste PET bottles aggregate on the properties of concrete. Cement Concrete Res., 35: 776-781.

Correia, J.R., J.S. Lima and J. de Brito, 2014. Post-fire mechanical performance of concrete made with selected plastic waste aggregates. Cem. Concr. Compos., 53: 187-199.

Diederichs, U. and U. Schneider, 1981. Bond strength at high temperatures. Mag. Concr. Res., 33: 75-84.

Fadhil, S. and M. Yaseen, 2015. The production of economical precast concrete panels reinforced by waste plastic fibers. Am. J. Civ. Eng. Archit., 3: 80-85.

Faiyadh, F.I. and M.A. Al-Ausi, 1986. Effect of elevated temperature and method of recooling on the compressive strength of plain and fiber reinforced concrete. Proceedings of the 3rd RILEM International Symposium on Developments in Fiber Reinforced Cement and Concrete, July 7-16, 1986, University of Sheffield, Sheffield, England, UK., pp: 225-230.

Faiyadh, F.I. and M.A. Al-Ausi, 1989. Effect of elevated temperature on splitting tensile strength of fibre concrete. Intl. J. Cem. Compos. Lightweight Concr., 11: 175-178.

Foti, D., 2011. Preliminary analysis of concrete reinforced with waste bottles PET fibers. Constr. Build. Mater., 25: 1906-1915.

Guerrero, L.A., G. Maas and W. Hogland, 2013. Solid waste management challenges for cities in developing countries. Waste Manage., 33: 220-232.

Hannawi, K., W. Prince and S. Kamali-Bernard, 2010. Effect of thermoplastic aggregates incorporation on physical, mechanical and transfer behavior of cementitious materials. Waste Biomass Valorization, 1: 251-259.

Hannawi, K., W. Prince and S.K. Bernard, 2012. Strain capacity and cracking resistance improvement in mortars by adding plastic particles. J. Mater. Civ. Eng., 25: 1602-1610.

Harada, T., J. Takeda, S. Yamane and F. Furumura, 1972. Strength, elasticity and thermal properties of concrete subjected to elevated temperatures. Spec. Publ., 34: 377-406.

Iadav, I., 2008. Laboratory investigations of the properties of concrete containing recycled plastic aggregates. Master Thesis, Civil Engineering Department, Thapar University, Patiala, India.

Ismail, Z.Z. and E.A. Al-Hashmi, 2008. Use of waste plastic in concrete mixture as aggregate replacement. Waste Manage., 28: 2041-2047.

Iucolano, F., B. Liguori, D. Caputo, F. Colangelo and R. Cioffi, 2013. Recycled plastic aggregate in mortars composition: Effect on physical and mechanical properties. Mater. Des., 52: 916-922.

Kalifa, P., G. Chene and C. Galle, 2001. High-temperature behaviour of HPC with polypropylene fibres: From spalling to microstructure. Cem. Concr. Res., 31: 1487-1499.

Kim, Y.J., T. Siriwardanage, A. Hmidan and J. Seo, 2014. Material characteristics and residual bond properties of organic and inorganic resins for CFRP composites in thermal exposure. Construct. Build. Mater., 50: 631-641.

Liguori, B., F. Iucolano, I. Capasso, M. Lavorgna and L. Verdolotti, 2014. The effect of recycled plastic aggregate on chemico-physical and functional properties of composite mortars. Mater. Des., 57: 578-584.

Malhotra, H.L., 1956. The effect of temperature on the compressive strength of concrete. Mag. Concr. Res., 8: 85-94.

Mark, J.E., 1999. Polymer Data Handbook. Oxford University Press, Inc., Oxford, England, UK.,.

Marzouk, O.Y., R.M. Dheilly and M. Queneudec, 2007. Valorization of post-consumer waste plastic in cementitious concrete composites. Waste Manage., 27: 310-318.

Mesbah, H.A. and F. Buyle-Bodin, 1999. Efficiency of polypropylene and metallic fibres on control of shrinkage and cracking of recycled aggregate mortars. Constr. Build. Mater., 13: 439-447.

Mohamedbhai, G.T.G., 1986. Effect of exposure time and rates of heating and cooling on residual strength of heated concrete. Mag. Concr. Res., 38: 151-158.

Moreley, P.D. and R. Royels, 1983. Response of the bond in reinforced concrete to high temperature. Mag. Concr. Res., 38: 67-75.

Muthadhi, A. and S. Kothandaraman, 2014. Experimental investigations on polymer-modified concrete subjected to elevated temperatures. Mater. Struct., 47: 977-986.

Nikolai, G.Z., 1971. Thermal properties of concrete under sustained elevated temperatures. ACI-SP25, American Concrete Institute, Farmington Hills, Michigan, USA.

Nishida, A. and N. Yamazaki, 1995. Study on the properties of high strength concrete with short polypropylene fibre for spalling resistance. Proceedings of the International Conference on Concrete Under Severe Conditions (CONSEC'95), August 2-4, 1995, E&FN Spon, Sapporo, Japan, pp: 1141-1150.

Noumowe, A., 2005. Mechanical properties and microstructure of high strength concrete containing polypropylene fibres exposed to temperatures up to 200°C. Cem. Concr. Res., 35: 2192-2198.

Pandya, J.M. and B.M. Purohit, 2014. Experimental study on the mechanical properties of concrete incorporating PET fibers. Intl. J. Sci. Res. Dev., 2: 43-45.

Panyakapo, P. and M. Panyakapo, 2008. Reuse of thermosetting plastic waste for lightweight concrete. Waste Manage., 28: 1581-1588.

Phan, L.T. and N.J. Carino, 1998. Review of mechanical properties of HSC at elevated temperature. J. Mater. Civ. Eng., 10: 58-64.

Poon, C.S., Z.H. Shui and L. Lam, 2004. Compressive behavior of fiber reinforced high-performance concrete subjected to elevated temperatures. Cem. Concr. Res., 34: 2215-2222.

Purkiss, J.A., 1984. Steel fibre reinforced concrete at elevated temperatures. Intl. J. Cem. Compos. Lightweight Concr., 6: 179-184.

Qian, C.X. and P. Stroeven, 2000. Development of hybrid polypropylene-steel fiber reinforced concrete. Cem. Concr. Res., 30: 63-69.

Ravindrarajah, R.S., R. Lopez and H. Reslan, 2002. Effect of elevated temperature on the properties of high-strength concrete containing cement supplementary materials. Proceedings of the 9th International Conference on Durability of Building Materials and Components, March 17-20, 2002, Australasian Corro sion Association, Brisbane, Australia, pp: 1-8.

Remadnia, A., R.M. Dheilly, B. Laidoudi and M. Queneudec, 2009. Use of animal proteins as foaming agent in cementitious concrete composites manufactured with recycled PET aggregates. Constr. Build. Mater., 23: 3118-3123.

Romualdi, J.P. and G.B. Batson, 1963. Mechanics of crack arrest in concrete. J. Eng. Mech. Divis. ASCE., 89: 147-168.

Safi, B., M. Saidi, D. Aboutaleb and M. Maallem, 2013. The use of plastic waste as fine aggregate in the self-compacting mortars: Effect on physical and mechanical properties. Constr. Build. Mater., 43:436-442.

Saikia, N. and J. de Brito, 2012. Use of plastic waste as aggregate in cement mortar and concrete preparation: A review. Constr. Build. Mater., 34: 385-401.

Salem, S.M.A., P. Lettieri and J. Baeyens, 2009. Recycling and recovery routes of Plastic Solid Waste (PSW): A review. Waste Manage., 29: 2625-2643.

Salman, B.T., 2015. Study the effect of preparation and diagnosis of Polyethylene Terephthalate (PET) as additive modification on concrete properties. Basrah J. Eng. Sci., 15: 25-31.

Shakir, A.S. and A.T. Jasim, 2009. Performance of fiber light-weight aggregate concrete exposed to elevated temperatures. Eng. Technol. J., 27: 2393-2410.

Tam, V.W.Y. and C.M. Tam, 2006. A review on the viable technology for construction waste recycling. Resourc. Conserv. Recycl., 47: 209-221.

Verdolotti, L., F. Iucolano, I. Capasso, M. Lavorgna and S. Iannace *et al*., 2014. Recycling and recovery of PE-PP-PET-based fiber polymeric wastes as aggregate replacement in lightweight mortar: Evaluation of environmental friendly application. Environ. Progress Sustainable Energy, 33: 1445-1451.

Weigler, H. and R. Fischer, 1972. Influence of high temperatures on strength and deformation of concrete. Intl. Concr. Abstracts Portal, 34: 481-494.

Wu, G., J. Li and Z. Xu, 2013. Triboelectrostatic separation for granular plastic waste recycling: A review. Waste Manage., 33: 585-597.