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ORIGINAL ARTICLE

Effect of fibre content and specimen shape on residual strength of polypropylene fibre self-compacting concrete exposed to elevated temperatures

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Air cooling

Abstract This experimental study investigates the effect of specimen shape on residual mechanical properties of polypropylene (PP) fibre self-compacting concrete (SCC) exposed to elevated temperatures from 200 to 600 °C. Various shaping regimes were used including cylindrical and cubical shapes for a series of durations of 2 and 4 h, and air cooling to the room temperature before testing. The temperature determination results prove that the shaping regimes caused an action of "thermal shock" to SCC under elevated temperatures, characterized by a high temperature at fixed time of exposure. The experimental results indicate that, compared cylindrical specimen with cubical one, thermal shock induced by cylindrical shape air cooling caused more severe damage to concrete in terms of greater losses in compressive strength than those with cubical shapes. The fact that the impact of shapes on mechanical properties indicates that shaping could cause thermal shock to specimens, which is in good agreement with the results of the temperature determination. PP fibre can enhance residual strength and fracture energy of concrete subjected to thermal shock induced by air cooling from high temperatures up to 600 °C to room temperature.

1. Introduction

Concrete has inherent fire resistance and it is a material ideally suited for providing fire safe construction. However, recent well-publicized fires in tunnels and the collapse of the World Trade Center in New York on September 11, 2001 have focused attention on the performance of all construction materials in fire. In addition, concrete design Euro code (EN 1992: 1–2) includes a design methodology that can lead to a more efficient concrete design. Guth (1998) has pointed out that the occurrence of spalling in reinforced concrete (RC) structures using high-strength concrete must be prevented. It is well known that spalling is prone to occur under certain conditions such as; low water to cement ratios, high moisture content and exposure to abrupt increase in temperatures. Liu et al. (2008), in their paper, define spalling as a phenomenon in which the surface of the concrete scales falls off from the structure along with an explosion at elevated temperatures.

Hertz and Sørensen (2005) devised a test method for determining the suffering of the actual concrete due to explosive

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spalling at a specified moisture level, taking into account the effect of stresses from progressive thermal expansion at the surface exposed to the fire. The study used cylinder shapes for testing, with different variations of concrete. The study concluded that the sufficient quantities of polypropylene fibres with suitable characteristics may prevent spalling of a concrete sample even when thermal expansion is showing restraint. Thus the material can be used in Self-Compacted Concrete (SCC) to prevent spalling when it is exposed to elevated temperatures, taking into consideration the characteristics of the SCC, and the different percentages of PP fibres under different conditions and elevated temperatures.

Fares et al. (2009, 2010) studied the performance of SCC subjected to high temperatures. Two mixtures of SCC and one vibrated concrete were used. Specimens were heated at different temperatures (150, 300, 450, and 600 °C) with 1 h time of exposure. They measured the mixtures' mechanical (compressive strength, flexural strength, and modulus of elasticity) and physical (water loss, density, porosity, and permeability) properties. They conclude that spalling happens at 315 °C. Moreover, compressive strength, flexural strength, and modulus of elasticity decrease with an increase in temperature. Between 20 and 150 °C, a small strength with no sensible degradation of the microstructure was observed just departure of bound water contained in C–S–H, and of free water contained in the concrete. From 150 to 300 °C, an increase in compressive strength, due to hydration of anhydrous cement and water movement, and cracks in the concrete within the paste for SCC were observed. In temperature beyond 300 °C, the mechanical and physical properties decreased quickly. At 600 °C the mixture became very weak in mechanical properties, and microstructure of concrete deteriorated quickly, with some chemical transformation such as, the crystal change of the Brucite and the decomposition of the portlandite which produce more cracks resulting in an increase in porosity of about 7%.

Overall, if concrete has been well prepared for inhibiting explosive spalling, then the main damage to concrete caused by fire accident should be the loss in mechanical properties. Experimental results (Chan et al., 1999; Khoury, 1992) confirmed that compressive strength can be broadly maintained within a range of temperatures from 20 to 400 °C. Considerable loss in compressive strength occurs between 400 and 600 °C, and most of the original compressive strength before heating may be lost from 600 to 800 °C. Compared with compressive strength, tensile splitting strength suffers a more severe loss under an identical temperature, as the latter is more sensitive to thermally induced cracking (Chan et al., 1999). Therefore, the effect of cooling regimes on mechanical properties of concrete is of great concern, especially after a fire case was reported (Anonymous, 2003; Chen, 2004), which happened in the city of Hengyang, Hunan Province, China, November 3rd, 2003. In this case, an 8-storey reinforced concrete building collapsed catastrophically during fire extinguishing and twenty fire fighters died from the building collapse. Furthermore, apart from these reports on the effect of cooling on plain concrete with no fibre (Khoury, 1992; Luo et al., 2000; Anonymous, 2003; Chen, 2004) there is little literature on properties of fibre concrete moulded in various shape regimes.

Nowadays in construction, self-compacting concrete is widely used and there is a need to understand its behaviour when subjected to elevated temperatures. As it has been found in a preceding investigation by Peng et al. (2006) that using hybrid fibre (steel fibre and polypropylene fibre) is an optimum approach for enhancing fire resistance of HPC this study presents an investigation on the effect of specimen shape for a duration from 2 to 4 h, and air cooling to room temperature, on residual mechanical properties of SCC incorporating PP fibre after exposure to elevated temperatures at 200, 400, and 600 °C.

Banthia and Sheng illustrated that the interfacial bond between PP fibres and cement paste is weak due to their smooth fibre surface. They explained that there is no strength enhancement with PP fibres even at a volume fraction of 5%. Nevertheless, PP is chemically inert and hydrophobic, thus removing the potential for chemical bonding. Therefore, the fibrillation (the quality of being made up of fibrils) has a considerable effect on the bonding. Bentur et al., (1989) and Bentur, (1991) suggested that the interfacial adhesion and mechanical anchoring are the two main factors that affect the fibre–matrix interaction.

Moreover, the compressive strengths of M0.15 (0.15% of PP fibres by volume of SCC mixture) concretes were slightly decreased. This may be ascribed to the formation of a multifilament structure due to the insufficient diffusion of this amount of PP fibres in the mixture (Lankard et al., 1971). The enhancement in residual compressive strength for all four concretes at 200 °C is attributed to the increase in surface forces between gel particles (Van der Waals) due to the removal of water content (Sarshar and Ga, 1993).

Kalifa et al. (2001) showed that the compressive strength gain may be attributed to the rehydration of the gel, the hydration of un-hydrated cement grains, and the carbonation of calcium oxide. The strength loss generally is attributed to rehydration of lime accompanied by a 44% increase in volume. Furthermore, PP fibres turn into vapour at 341 °C. The decomposition products of PP fibres have been reported to be a variety of hydrocarbons, with the major components being propylene, pentene, and heptene. The strength recovery of concretes containing PP fibres was different from those of SCC without fibres. The improvement at 200 °C is attributed to the amount of water vapour that escapes freely through the pathways formed by the melting of the PP fibres between 170 and 175 °C and getting out the of surface of the concrete through the pores. The permeability of a concrete mixture containing 10% silica fume and 0.91 g/cm^3 of PP fibres were close to that of Ordinary Portland Cement concrete at 200 °C. Kalifa et al. suggested that the cement matrix is able to absorb the melted PP, despite the large size of the molecules compared to diameter of paste pores.

Pore pressure thus, depends on the porosity of concrete. Since the PP fibres melt before reaching 200 °C, the porosity of the concrete is increased and more escape routes are added to reduce the water vapour pressure. Furthermore, the decomposition of the PP fibres may reduce the results of thermal incompatibility between aggregates and cement paste due to the provision of more free space which acts as a thermal shock absorber. After exposure to 600 °C, the relative residual compressive strengths dropped a little for all concretes. In terms of water vapour pressure, as indicated previously, the behaviour of fibre concretes was better than that of the M0.0 concretes. In terms of lime, some post-cooling behavioural changes were reported in the form of strength gain and loss in the concrete mixtures (Petzold and Rohrs, 1970; Ozawa, 1989).

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Table 1 Mix design proportions with addition of PP fibres.

Materials	Concrete mixture number			
	M0.0	M0.05	M0.10	M0.15
Cement, kg/m^3	437.5	437.5	437.5	437.5
Fly ash, kg/m^3	120	120	120	120
Coarse aggregate, kg/m^3	730	730	730	730
Fine aggregate, kg/m^3	907	907	907	907
Water, kg/m^3	178	178	178	178
w/p (ratio)	0.32	0.32	0.32	0.32
Superplasticizer, kg/m^3	8.1	8.1	8.1	8.1
Polypropylene fibres, % by volume of mix	0.0	0.05	0.10	0.15

Table 2 Fresh properties of SCC mixtures with addition of PP fibres.

Fresh property tests	SCC mixture with and without PP fibres			
	M0.00	M0.05	M0.10	M0.15
Slump flow (mm)	730	725	705	665
T50 (s)	4.2	4.0	3.0	8.8
J-ring (mm)	663.5	715.0	685.0	625.0
V-funnel (s)	7.8	6.0	9.7	50
Orimet (s)	1.2	1.5	2.0	3.4

2. Materials and mixing

2.1. Mixture proportioning

Water to powder ratio used was 0.32, while varying PP fibres with a mixing ratio of 0%, 0.05%, 0.10% and 0.15% (by volume) were used. Fly ash 120 kg/m^3, superplasticizer 8.1 kg/m^3, and cement 437.5 kg/m^3 were also used. The mixture proportions of concrete were determined to satisfy an air content requirement of 2%. The parameters and the mixture proportions of the SCC with addition of PP fibres are shown in Table 1.

2.2. Materials

Ordinary Portland Cement (OPC) available in the local market, was used in the investigation. The cement used has been tested for various proportions according to (ASTM C150-85A) the specific gravity was 3.15 and specific surface area was 2910 cm^2 g^{-1}. Type-II fly ash from the Kapar Thermal Power Station, Selangor, Malaysia, was used as a cement replacement material. Fly Ash is used as Pozzolana and Admixture. Class F fly ash was obtained which had a specific gravity of 2.323 and specific surface area of 2423 cm^2 g^{-1} which conforms to (ASTM C 618). Crushed angular granite material of 20 mm maximum size from a local source was used as course aggregate. The specific gravity was 2.45; the absorption value was 1.5%, fineness modulus 6.05 and with a bulk density of 1480 kg/m^3 which conforms to ASTM C 33-86 was used. The fine aggregates consisted of river sand with a maximum size of 4.75 mm, with a fineness modulus of 2–3 normal grading. The specific gravity was 2.33 and the absorption value was 4%. Short Polypropylene (PP) fibres (19 mm) were used in the experimental study which consisted of one type of polypropylene fibre with a density of 0.91 g/cm^3, a melting temperature of 160 °C, a vaporization temperature of 341 °C and a burning temperature of 460 °C (Kalifa et al., 2000). While the addition of PP fibres varying with a mixing ratio of 0%, 0.05%, 0.10% and 0.15% (by volume) were used. Polycarboxylicether (PCE) based superplasticizer (SP) was used which is a brown colour and a free flowing liquid and having specific gravity 1.15; superplasticizer conforms to ASTM C494-92. Type A and Type F superplasticizer were used in aqueous form to enhance workability and water retention. A sulphonated, naphthaleneformaldehyde superplasticizer was used in all the concrete mixtures. Potable water conforming to British Standard (BS 3148, 1980) for mixing the concrete and curing of the reaction was used.

3. Experimental methods

All concrete mixes were prepared in 40 L batches in a rotating planetary mixer. The batching sequence consisted of homogenizing the sand and coarse aggregate for 30 s, then adding about half of the mixing water into the mixer and continuing to mix for one more minute. The mixer was covered with a plastic cover to minimize the evaporation of the mixing water and to let the dry aggregates in the mixer absorb water. After 5 min, the cement and fly ash were added and mixed for another minute. Finally, the SP and the remaining water were introduced and the concrete was mixed for 3 min. PP fibres were added to the mix gradually and separately for each mix within 2 min. Twelve cylinders (75 × 150 mm) and twelve cubicals (100 × 100 × 100 mm) were cast and kept in sink moist under wet conditions for each mix to determine compressive strength after 90 days.

Compressive strength was determined by using a total of 42 cylinder specimens (75 × 150 mm) and 42 cubical specimens (100 × 100 × 100 mm) which were cast in 1 day then removed from the moulds, and cured in water at 20 °C for 89 days. The surfaces were then smoothed by grinding to achieve a leveled appearance then tested at elevated temperatures (200, 400,

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and 600 °C) and heating periods (2 and 4 h). The samples were then cooled at room temperature by using fans and tested for compressive strength using a 88,964.4 kN capacity compression machine. SCC mixtures were used after the addition of PP fibres using three sets of specimens for every mixture taken and tested according to ASTM C39-83.

3.1. Mixture proportions

The SCC mix was designed using the central composite method. The method has been chosen to be employed to limit the number of experimental runs compared to factorial design. This would enable modelling of the mixture proportions involving interaction and quadratic terms. These models were used for optimization of self-compacting concrete mixes. The final mix proportions are given in Table 1. The optimum mixture of 31 mixtures from the central composite design mix that satisfies the European Federation of National Associations Representing producers and applicators of specialist building products for Concrete EFNARC criteria (2002) was chosen to be the mix that will be used to test under elevated temperatures with different percentages of PP fibres. The fresh (Table 2) property tests were done on concrete with and without the PP fibres to investigate the passing ability, filling ability, and resistance to segregations of the mixtures.

3.2. Tests of concrete at elevated temperatures

The electrical box furnace is of chamber size (600 $w \times 300\ h \times 300\ d$ mm) with a maximum temperature of 1200 °C, and heating rate of 5–10 °C per minute just to raise the temperature of the furnace to fixed temperatures for a fixed time. Concrete specimens were taken out from the curing environment at 89 days, and kept for 1 day. Then specimens were weighed before exposed to the fire test. The temperature was kept at fixed temperatures of 200, 400, and 600 °C each maintained for 2 and 4 h exposure time. The specimens were then taken out from the oven. Cooled down to room temperature by keeping it in room temperature and exposed them to air circulation from a fan then the specimens were weighted and coded, and were tested for compressive strength. Each three specimens were tested and the average value reported.

4. Experimental results and discussion

4.1. Hardened properties

4.1.1. Compressive strength

It is observed that the overall effect of subjecting SCC specimens to high temperatures generally results in reduction in strength. The strength reduction on heating is due to a series of complex physical and chemical changes. This takes place within the concrete, which is not yet fully explained. The failure loads under the compression test were calculated by averaging of the result of three heated concrete specimens in the same batch to calculate the compressive strength. The behaviour of the heated SCC specimens under varying conditions is presented in the graphical plots (Figs. 1 and 3). This figure also explains the compressive strength ratio (CSR) as the specimens fail after heating to the compressive strength of the unheated control cylinders.

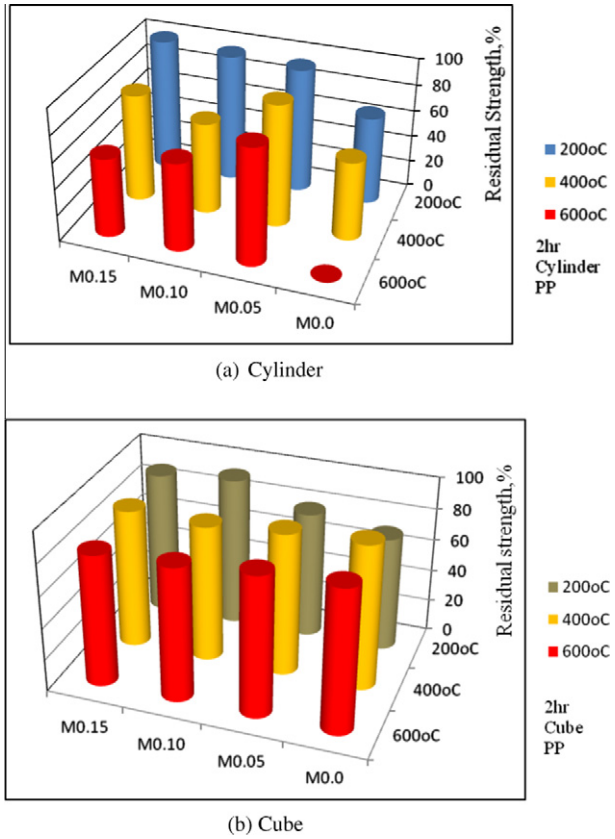


Figure 1 Relative residual compressive strength of SCC.

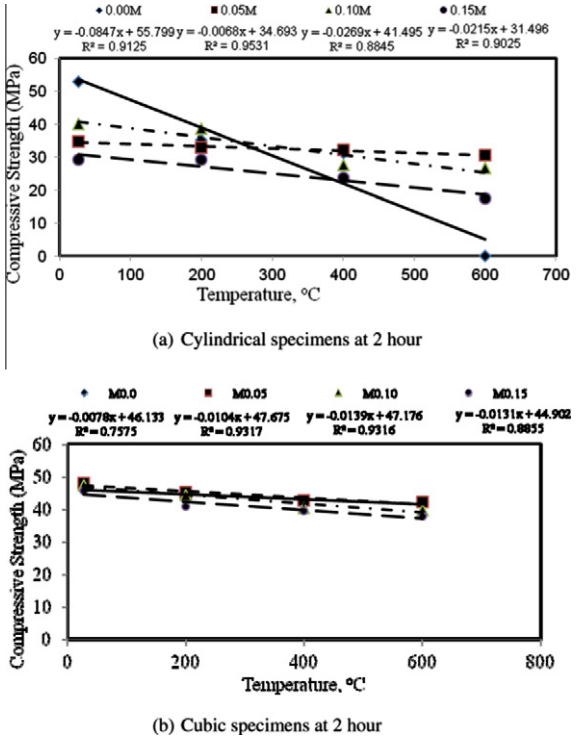
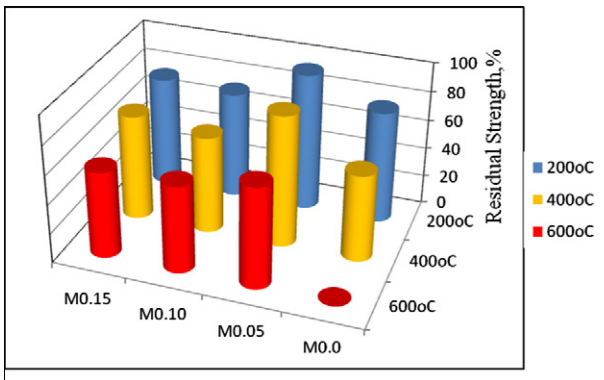
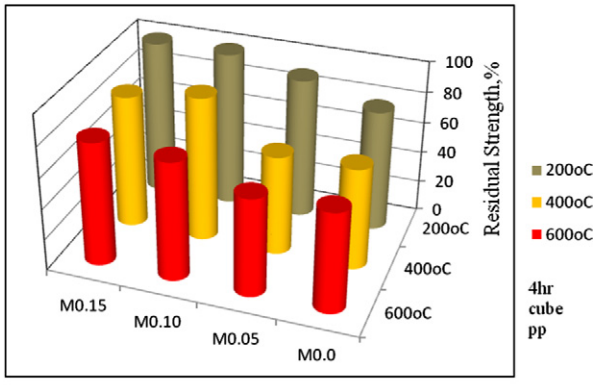


Figure 2 Relationship between temperature and compressive strength.



(a) Cylinder



(b) Cube

Figure 3 Relative residual compressive strength of SCC.

4.1.1.1. Residual compressive strength for the addition of PP fibres in cylindrical and cubical specimens at 2 h time of exposure. The results of the residual compressive strength of the SCC are shown in Table 3.The relative residual compressive strengths of all SCC mixtures are shown between parentheses. The value in each pair of parentheses is the ratio of the strength at a desired temperature to the origin value which is at 27 °C room temperature. No significant increase in compressive strength is observed in Fig. 1 in the concrete mixtures by adding PP fibres at the room temperature.

After being subjected to a temperature of 400 °C, the relative compressive strengths of the M0.0 (SCC mixture with 0% PP fibres) M0.05 (SCC mixture with 0.05% PP fibres), M0.10 (SCC mixture with 0.10% PP fibres), and M 0.15(SCC mixture with 0.15% PP fibres) following mixture specimens were reduced. The significant reductions at 400 °C are attributed to the dense microstructures of these concrete mixture specimens that cause a high pore vapour pressure, and because explosive spalling happens at this temperature. The formation of high vapour pressure can extend the interconnected network of micro-cracks and change them into macro-cracks and consequently, the strength drops sharply. As seen in Table 3 the residual compressive strengths of the M0.05, M0.10, and M0.15 concrete specimens were higher than those of the M0.0 concrete specimen at 200 °C.

Furthermore, the mathematical relationship between temperature and compressive strength of SCC with different percentages of PP fibres by volume of the mixture is given in Fig. 2(a) and (b), respectively. The figure shows that the compressive strength with temperatures 200, 400, and 600 °C for 2 h exposure time and different percentages of PP fibres obey a linear law mathematical model with correlation coefficients (R^2) of 0.9125, 0.9531, 0.8845, and 0.9025 for the 2 h duration and 0.7575, 0.9317, 0.9316, and 0.8855 for the 2 h duration of SCC mixes M0.0, M0.05, M0.10, and M0.15. Curves of mixture M0.0 with 0% PP fibres show an increase in compressive strength until 400 °C then a drop with an increasing temperature till 600 °C, probably because of explosive spalling occurring between 400 and 600 °C for the cylindrical specimens (75 × 150 mm).

Generally, it can be concluded that the presence of PP fibres at different dosages does not affect the relative residual compressive strength at 200, and 400 °C, while they considerably increase the residual compressive strength of concretes after exposure to 600 °C. Furthermore, 0.05% PP fibres by volume can be identified as an optimum amount of PP fibres in concretes due to its superior performance during heating related to other percentages of PP fibres and the control without fibre. The mathematical models for a cylindrical and cubical shapes specimen are found to be obeying a linear law at 2 h duration and the best correlation coefficients are as follows $f_c = -0.0068T + 34.693$ and $f_c = -0.0104T + 47.675$, with R^2 equals to 0.9531 and 0.9317 with decreasing points of

Table 3 Residual compressive strength at 90 days.

Mix no.	Normal strength	2 h Exposure strength in MPa (residual strength%)			4 h exposure strength in MPa (residual strength%)		
	27 °C	200 °C	400 °C	600 °C	200 °C	400 °C	600 °C
Strength of cubes							
M0.00	47.00 (100)	43.20 (71.6)	42.70 (90.9)	42.10 (89.6)	36.67 (78.0)	30.66 (65.2)	30.20 (64.3)
M0.05	47.90 (100)	45.30 (79.3)	42.70 (89.1)	42.10 (87.9)	44.30 (90.6)	30.66 (64.0)	30.20 (63.1)
M0.10	47.37 (100)	44.20 (93.3)	40.40 (85.3)	39.71 (83.8)	48 (101.3)	44.10 (93.1)	36.17 (76.4)
M0.15	45.70 (100)	40.83 (89.3)	39.30 (87.2)	37.75 (82.6)	46.10 n(100.3)	39.19 (85.8)	36.47 (79.8)
Strength of cylinder							
M0.0	52.80 (100)	35.20 (66.3)	31.30 (59.3)	0.0 (0.0)	40.50 (76.7)	31.30 (59.3)	0.0 (0.0)
M0.05	34.80 (100)	32.80 (94.3)	32.20 (92.5)	30.60 (87.9)	32.80 (94.3)	31.30 (89.9)	24.00 (69.0)
M0.10	40.10 (100)	38.60 (96.3)	27.70 (69.1)	26.60 (66.3)	29.20 (72.8)	26.60 (66.3)	23.90 (59.6)
M0.15	29.20 (100)	29.20 (100)	23.80 (81.5)	17.40 (59.6)	22.00 (75.3)	21.10 (72.2)	17.30 (59.3)

The value in each parenthesis is the ratio of the strength at a desired temperature compared to the origin value which at 27 °C room temperature.

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0.0068 and 0.0104 and intersection points of 34.693 and 47.675 MPa.

4.1.1.2. Residual compressive strength for the addition of polypropylene fibres in cylindrical and cubical specimens at 4 h exposure time. It is observed from (Table 3 and Figs. 3 and 4) that the overall effect of subjecting SCC specimens to different temperatures generally results in reduction in strength. The strength reduction on heating is due to a series of complex physical and chemical changes within concrete which is not yet fully understood. An increase in temperature causes loss of moisture from the concrete. The free moisture is lost first followed by physically absorbed water and finally the chemically combined water of the hydrated cement products, the latter causing the progressive strength loss. In contrast, the aggregate tends to expand while the paste is shrinking.

The results of the residual compressive strength of the SCC are given in Table 3. The relative residual compressive strengths of all SCC mixtures are shown between parentheses. The value in each pair of parentheses is the ratio of the strength at a desired temperature to the origin value which is at 27 °C room temperature. From Fig. 3 one can observe no significant increase in compressing strength in the concretes by adding PP fibres at room temperature.

After being subjected to a temperature of 400 °C, the relative compressive strengths of the M0.0 (SCC mixture with 0% PP fibres), M0.05 (SCC mixture with 0.05% PP fibres), M0.10 (SCC mixture with 0.10% PP fibres), and M0.15 (SCC mixture with 0.15% PP fibres) mixture were correlated with coefficient

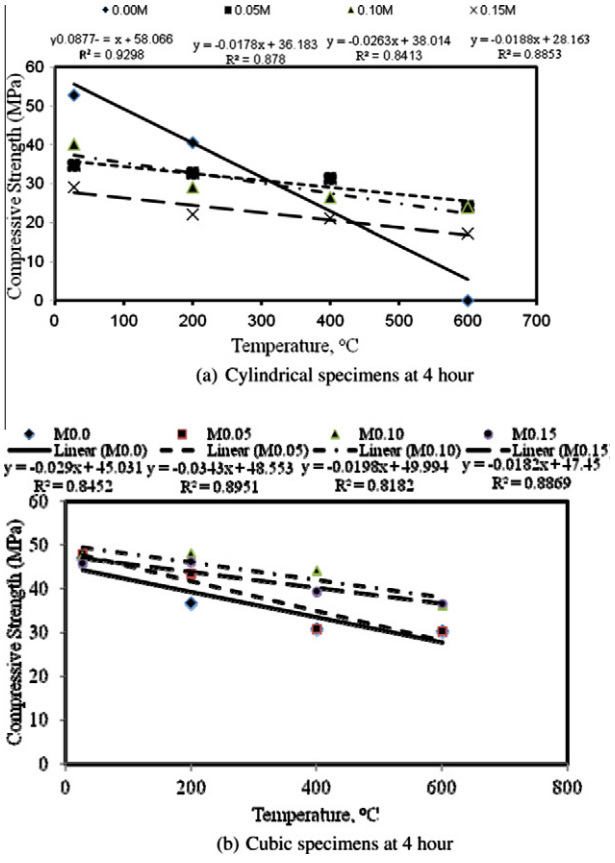

Figure 4 Temperature and compressive strength curves.

0.9298, 0.878, 0.8413, and 0.8853 for cylindrical specimens and 0.8452, 0.8951, 0.8182, and 0.8869 for cubical specimens respectively. The significant reductions at 400 °C are attributed to the dense microstructures of these concretes that cause a high pore vapour pressure. The formation of high vapour pressure can extend the interconnected network of micro-cracks and change them into macro-cracks and consequently, the strength drops sharply.

As seen in Table 3 and Fig. 4 the residual compressive strengths of the M0.05, M0.10, and M0.15 concrete specimens were higher than those of the M0.0 concrete specimen at 200 °C. The pore pressure depends on the porosity of concrete.

After heating, the colour turned grey up to 600 °C and beyond 600 °C the concrete is reddish i.e. burning red with the specimen literally burning. SCC specimens tested did not show any occurrence of surface cracks of heating temperature of 200 °C, both with fibres and without fibres for different duration of exposures; on the other hand, the specimen showed signs of occurrences of surface cracks when heated to 600 °C for both with and without fibres for different duration of exposures. It was observed that miniature surface cracks started at edges and propagated towards the face and was seen that the width of crack less than 1 mm increased with increasing heating periods. Explosive spalling was noticed in the present investigation, but it is noticed frequently in SSC investigations which recommended the usage of PP fibres for reducing explosive spalling in concrete especially in columns.

The failure loads under compression test were calculated by averaging of the three heated concrete specimens in the same batch for calculation of compressive strength. The behaviour of the heated SCC specimens under varying conditions is presented in the graphical form using compressive strength ratio as the compressive strength at failure after heating to the compressive strength of the unheated control cubes. It can be concluded that the presence of PP fibres at different dosages does not affect the relative residual compressive strength at 200, and 400 °C, while they considerably increase the residual compressive strength of concretes after exposure to 600 °C. It has been found that, 0.10% PP fibres identify the optimum for cylindrical and cubical shapes and models found to be obeying a linear law at 4 h time of exposure, with best model and correlation coefficient as follows: $f_c = -0.0263T + 38.014$ and $R^2 = 0.8413$ for cylindrical shape with a decreasing slope equal to 0.0263 and intersect point of 38.014 MPa and $f_c = -0.0198T + 49.994$ and $R^2 = 0.8182$ for cubical shape and a decreasing slope equal to 0.0198 and intersection point equal to 49.994 MPa.

In general, for cylindrical and cubical shape test specimens, the findings agree with the literature reviews related to the following researchers: Banthia and Sheng, Bentur et al. (1989), Bentur (1991), Lankard et al. (1971), Sarshar and Ga (1993), Kalifa et al. (2001), Petzold and Rohrs (1970) and Ozawa (1989).

5. Conclusions

The following conclusions can be drawn:

- The presence of PP fibres at different dosages in cylindrical specimen does not affect the residual compressive strength at 200, and 400 °C, while they considerably increase the residual compressive strength of concretes after exposure to 600 °C. Furthermore, 0.05% PP fibres by volume can be identified as the optimum amount of PP fibres to use

in concretes due to its superior performance during heating. A mathematical model for the cylindrical shape was found to be obeying a linear law for 2 and 4 h heat exposure.

- The presence of PP fibres in cubical specimens and at different dosages cannot affect the relative residual compressive strength at 200, and 400 °C, while they considerably increase the residual compressive strength of concretes after exposure to 600 °C. Whereas, 0.10% PP fibres identify the optimum for cubical shape and models are obeying a linear law at 2 and 4 h time of exposure.
- The cubical specimens show a better residual compressive strength than cylindrical specimens that means it is easy for the temperature to transfer from the surface of cylindrical specimen to the centre and there is a symmetrical distribution of heat more than it is observed in the cubical specimen as the distance from the edge is greater than the other side of the cube thus the distribution of heat is irregular. Physically there is a difference of 25% in the compressive strength between cubical and cylindrical specimens. This could advice to avoid symmetrical shapes in the building and using columns with cubical shape is better than cylindrical one.

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