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The Mechanical Properties of HFRC Under Elevated Temperature Exposure

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Abstract. This paper discusses the effect of exposure to elevated temperature on the mechanical properties of hybrid fibre reinforced concrete (HFRC). Literature review indicates that high strength concrete is prone to sudden explosion particularly, when exposed to elevated temperature. Polypropylene fibres (PPF), play an active role in improving spalling resistance of concrete induced to elevated temperature. However, it has less significant effect on the strength of concrete. The proposed HFRC by incorporating Steel Fibre (SF) and Polypropylene Fibre (PPF) with certain ratios is expected to improve the mechanical properties of concrete. The experimental program examined the mechanical properties of HFRC at a temperature of 800˚C with four different heating time. The compression and flexural test were conducted on thirty (30) cubes, twenty (20) cylinders and ten (10) beams. From the experimental results, it was found that the HFRC with 0.5% PPF and 0.5% SF has effectively improved the interfacial bonding, lowering the tendency of spalling and increased both the compressive and tensile strength at high temperature.

1. Introduction

Exposure of concrete to fire or to extreme heat can cause severe effects on concrete's strength and caused massive cracking and spalling failure due to loss of cement paste-aggregate bond [1]. High strength concrete tends to experience pressure build up because of its low permeability compared to normal strength concrete [2]. The strength of concrete depends most on the hydration products (calcium silicate hydrate gel, calcium hydroxide) formed during hydration reaction between water and cement components. During concrete exposure to fire, evaporation occurs at lower elevated temperatures that cause free water to escape from the concrete. With increasing temperature, dehydration process and loss of chemically bonded water might occur. Previous researchers indicate that aggregates dissociated when heated to temperature over 800˚C. At this point, pore size and porosity of hydrated matrix will increase which reduce the volume and consequently the strength of concrete will be weakened [3].

Recently, many researchers studied the mechanical properties of the HFRC incorporating with different kind of fibres; such as carbon fibres and PPF [4], glass fibre and PPF [5], carbon fibre and glass fibre [6], or SF and PPF [7-8]to concrete. In general, they reported that, by incorporating concrete with fibres, proven to overcome concrete weakness and also increase in tensile strength, strain capacity, toughness and durability. However, information on the behaviour of HFRC when exposed to extreme temperature is still limited. Therefore, in this study, the mechanical and microstructure of high strength concrete with the addition of SF and PPF at extreme temperature is investigated. These two complementary fibres can enhance mechanical properties and improve the residual strength of the concrete [3], [10–15]. Polypropylene can resist the initial crack and shrinkage while steel fibre can increase the strength [9]. The mechanical properties investigated in this study are compression and flexural strengths of HFRC exposed to high temperature with different heating time.

2. Experimental Detail

High strength concrete with 50 MPa and 60 MPa characteristic strengths made of Ordinary Portland Cement (OPC) with proportion of 0.3:1:0.11:0.35 and 0.3:1:1:1.9 respectively were used in this study. The aggregates used were sand and crushed granite of particle sizes range from 5 mm to 20 mm. The ratio of both hooked SF and PPF used were 0.5% of concrete volume respectively. The diameter of PPF is 22 μm, the length is 15 mm, the elastic modulus is 8 GPa and the tensile strength is 800 MPa. The length of SF is 50 mm with a diameter of 0.7 mm, the elastic modulus is 200 GPa and the tensile strength is 1500 MPa.

2.1. Sample preparations

Specified amount of bulk SF was kept in water for an hour to make sure the bulk SF losses into single SF. The mixing process started with mixing the dry cement, coarse and fine aggregates for 1 min; then water is added and mixed for another 3 min. After the mixing process, the specified amount of single SF and PPF was added to the wet concrete. The mixture was mixed for about 3 min to ensure that the fibres can evenly disperse throughout the concrete mixture. For this study, 30 cubes (100 mm *x* 100 mm *x* 100 mm), 20 cylinders (150 mm *x* 300 mm) and 10 beams (500 mm *x* 100 mm *x* 100 mm) were prepared. All specimens then removed from their mould after 24 hours and then cured for 28 days.

2.2. Test methods

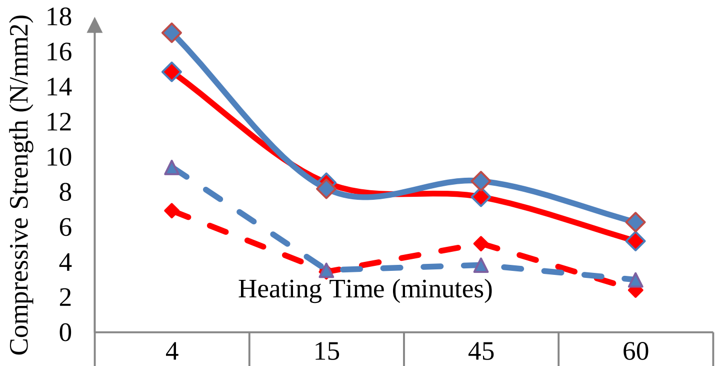
Prior to the experimental testing, the specimens left at room temperature for 4 hours. The specimens were then placed in the muffle furnace and heated to 800˚C with increment of 5˚C/min. The heating time divided into two phases; namely phase 1 for 0-30 minutes and phase 2 for 30-60 minutes for data analysing. After the temperature reaches 800˚C, the temperature was allowed to cool at the rate of 2˚C/min. The specimens were left in the muffle furnace until the muffle furnace had completely cooled, before conducting the compressive and flexural tests. The compressive strength was tested on cube and cylinder specimens with a continuous load increment of 6.8 kN/sec and 5.3 kN/sec respectively until the specimens failed. The flexural test was conducted using ASTM C78/C78M – 10e1 [13] for the flexural toughness and the first crack strength of HFRC [17-18]. A constant rate of 0.2 kN/sec loaded on the beam specimens.

3. Results and Discussions

3.1. Compressive strengths

Exposure to high temperature resulted in significant strength loss for HFRC. FIGURE. 1 and FIGURE. 1 show the compressive strength of the HFRC for cube and cylinder specimens after exposed to the temperature of 800˚C at four different heating times. The results show significant reduction of compressive strength especially at phase 1. However, when the heating time increases to phase 2, the residual strength rose to 8.63% for concrete grade C60 at 45 minutes before gradually drops to 6.28%. The compressive strength decreased with increasing heating time. This occurs due to the high elastic modulus of fibers as SF bridging effects that mitigate the initiation and expansion of micro-

defects on HFRC. In additional, phase 1 may also be regarded as a significant heating time for the strength loss of HFRC because, denser specimens with first exposure may experience hydration in this phase. Due to first exposure to extreme temperature on concrete with high moisture content, transportation of water vapour inside the concrete matrix is difficult to release [3].
Table 2 shows the compressive strength reduction for all specimens. The highest strength reduction occurred at heating time in phase 2 which is recorded about 10.94%. However, the total strength reduction percentage of all specimens showed a small increment at 45 minutes heating time. This small increment occurred due to the fiber's tensile resistance behaviour to an extreme temperature that maintains the residual strength of HFRC. This lowest reduction happened when HFRC exposed to an extreme temperature, HSC-C-S creates high vapour pressure due to the inner moisture of concrete. Since there are no micro-channels to release the pressure that will caused more damage and cracking in the concretes. This phenomenon also explains why there is a sudden-collapse of a structure during a fire. The sudden-collapse of a structure is due to the exposure to extreme heat that causing the inner moisture trapped within concrete matrix. Therefore, adding PPF and SF to HFRC mitigate the deterioration process of HFRC after exposed to extreme temperature.



	4	15	45	60
C50 cube sample	14.85	8.53	7.72	5.21
C60 cube sample	17.07	8.19	8.63	6.28
C50 cylinder sample	6.93	3.45	5.06	2.41
C60 cylinder sample	9.41	3.54	3.84	3.00

FIGURE. 1. Compressive strength for cube and cylinder specimens.

TABLE 1 Reduction of strengths in HFRC

Time (min)	Reduction of Strength (%)						Total Strength Reduction (%)
	Cube		Beam		Cylinder		
	C50	C60	C50	C60	C50	C60	
Phase 1 0-30	6.32	8.88	1.86	2.24	3.67	4.49	8.16
Phase 2 30-60	9.64	10.79	1.87	2.27	4.52	6.42	10.94

3.2. Flexural strength

Figure 2 shows the decrement of flexural strength of HFRC beam specimens after exposed to the temperature of 800˚C up to a duration of 60 minutes. As expected, the strengths of HFRC beam specimens of C60 at phase 1 improved than the specimens at C50 as compared to the residual strength at phase 2. However, the percentage difference of the flexural strength between both concrete grades are 1.86% and 2.24%. It was observed to be insignificant for beam specimens with C50 as stated in TABLE 1 with a minimum average of 0.38% and the behaviour of both grades were almost identical. The reason is likely due to failure of well-bonded PPF that supposed to provide post-crack ductility that refine the pores inside the concrete [19].

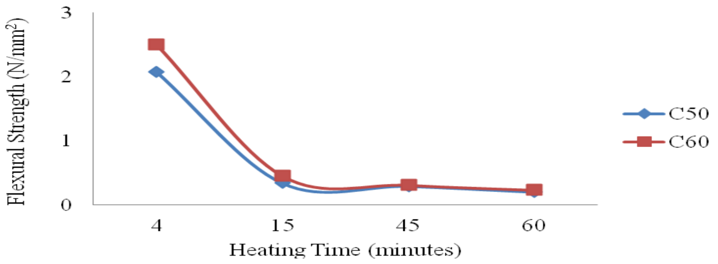


FIGURE. 2 Flexural strength for beam specimens.

4. Conclusions

Based on the scope of this study, it is concluded that incorporating 0.5% SF and PPF respectively of the volume to HFRC enhanced the mechanical and microstructure properties. Although the concrete specimens of HFRC were exposed to an extreme temperature of 800°C, the concrete specimens were able to provide advantageous results on the compressive and flexural strengths.

- The residual compressive strength for C60 remains higher than the residual compressive strength for C50 where it decreases until reached 60 minutes steadily. This behaviour shows that higher concrete grade improves the residual compressive strength for cylinder samples.
- The percentage difference of the flexural strength between both concrete grades are 1.86% and 2.24%. It was observed to be insignificant for beam specimens of C50 with a minimum average of 0.38%. This is due to the failure of well bonded PPF that supposed to provide post-crack ductility which refine the pores inside the concrete and the SF that will improves in plastic restraint by bridging effect.
- Generally, it is found that the HFRC with 0.5% PPF and 0.5% SF has effectively improved in the residual strength at 45-60 minutes (in phase 2) wheby the total strength reduction has minimised by 8.53%.

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