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Mechanical properties of steel-polypropylene fibre reinforced concrete under elevated temperature

Aminuddin Jameran[a,*], Izni S. Ibrahim[a], Siti Hamizah S. Yazan[a], Siti Nor A. A. Rahim[a]

[a]*Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310, Skudai, Johor, Malaysia*

Abstract

Fibre reinforced concrete (FRC) has been found to improve strength, ductility, toughness, and durability of the structures. The application of FRC includes tunnel lining, ground slab, façade and many more. However, when exposing them to high temperature such as fire, there is still little information on the impact on its mechanical properties. The main objective of the study is to understand the fundamental behaviour of FRC when it is exposed to elevated temperature. However, rather than relying on one type of fibre, this study proposed of mixing two different types of fibre in concrete which will then be exposed to elevated temperature at normal temperature i.e. 27°C (room temperature), 200°C, and 400°C. The two types of fibres i.e. steel and propylene has different characteristics. The study is mainly focused on the experimental work. The fibre dosage will also be varied with percentage of steel-to-propylene of (100-0), (75-25), (50-50), (25-75) and (0-100) at 1.5% of fibres proportion from the volume of the concrete. Therefore this research is expected to answer the fundamental question whether if one type is vulnerable to fire, the other one will take place to avoid catastrophic failure of the whole structure. Experimental work will be carried out to study the impact of elevated temperature on the compressive strength, tensile strength, and flexural strength.

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Keywords: Fibre reinforced concrete; mechanical properties; elevated temperature; steel; polypropylene.

1. Introduction

Fibre reinforced concrete (FRC) displays improved flexural strength, toughness, ductility, and crack resistance. The mechanical properties of FRC can be affected when exposed to heat. Heat can come from many sources such as

* Corresponding author. Tel.: +6013-327 3573.
E-mail address: aminuddinjameran@gmail.com

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fire and prolonged high temperature on the exposed surface. It remains one of the most serious risks for tunnels, buildings and other concrete structures. Explosive spalling has been observed by many researchers often resulting in serious deterioration of the concrete [1-4]. High temperature causes dramatic physical and chemical changes, resulting in the deterioration of the concrete [5,6]. The absence of voids, which could relieve the continuous pressure build-up as a consequence of vaporization of evaporable water, may cause serious damage or even spalling to the concrete.

To reduce the risk of deterioration and spalling, previous literatures claimed that the use of fibre such as polypropylene and steel can have sufficient fire protection on the concrete structures [7,8]. But minimal or even negative effects of polypropylene fibres on the residual performance of the heated concrete may also occur [9]. The initial moisture state of the concrete and the rate of heating may be the main parameters determining the effect of polypropylene fibres [10]. Therefore, there is necessity to quantify this claim in terms of the fibre dosage, the strength of the concrete and most important is to know the residual mechanical properties of FRC under exceptional actions such as high temperature from fire.

2. Literature Review

In this study, steel (ST) fibre and propylene (PP) fibre is used to achieve the objectives of the study. PP fibres significantly decrease the plastic shrinkage cracking as well as drying shrinkage cracking [11,12], while ST fibres approximately doubled the energy absorption capacity of the unheated concrete. They are effective in minimizing the degradation of compressive strength for the concrete after exposure to elevated temperature. In comparison, the use of PP fibres reduced the energy absorption capacity of the concrete, although it had minor beneficial effect on the energy absorption capacity of the concrete before heating.

In 2012, Bangi and Horiguchi [13] carried out test on high strength fibre reinforced concrete (HSC) using propylene, polyvinyl alcohol and steel fibres of varying lengths and diameters. Experimental and statistical study was carried out to investigate the effect of fibre type and geometry on the amount of maximum pore pressures measured at different depths exposed to elevated temperature. Pore pressure measurements showed that addition of organic fibres regardless of the type significantly contributes to pore pressure reduction in the heated HSC. Polypropylene fibres were more effective in mitigating maximum pore pressure development compared to polyvinyl alcohol fibres while steel fibres had a slightly low effect. Longer organic fibres of length 12 mm with smaller diameter of 18 μm showed better performance than the shorter ones of length 6 mm with larger diameter of 28 μm and 40 μm.

Most of the literature reviews showed that the use of fibres in concrete can significantly improve the concrete resistance. However, when exposed to elevated temperature, previous studies only tested for one or two parameters instead of the whole mechanical properties of FRC. Mixing only a single fibre can improve only a certain aspect of the mechanical properties and at the same time reduced some of its properties. This can be improved by mixing two or more types of fibres to overcome the weakness of such properties. The current fundamental research is proposed since there is still little information on the effect on the mechanical properties of concrete when mixed with two or more types of fibres and further exposed to elevated temperature.

3. Experimental Program

Experimental work is carried out to achieve the objectives of the study. In the experimental work, the total fibre volume fraction, V_f for both ST and PP fibres is applied at 1.5% from the volume of concrete. The application of V_f= 1.5% in this study is chosen based on the findings from previous study with the best percentage proportion for the combined fibres is 75% ST and 25% PP (75-25) [14]. In this study, the percentage proportions of the fibres are divided into five concrete batches: (i) 100% ST and 0% PP (100-0), (ii) 75% ST and 25% PP (75-25), (iii) 50% ST and 50% PP (50-50), (iv) 25% ST and 75% PP (25-75), and (v) 0% ST and 100% PP (0-100). Each concrete batch is exposed at 200°C and 400°C for one hour or 60 minutes, including one batch which is left exposed to room temperature (27°C). This means that in every concrete batch, there are 5 sub-batches. The number of specimens for each concrete batch is 3 cubes (150 mm × 150 mm × 150 mm), 3 prisms (150 mm × 150 mm × 550 mm) and 3 cylinders (150 mm diameter × 300mm height). Concrete grade of C40 is used in the experimental work.

In calculating the volume of ST fibre to be mixed in concrete, Eq. (1) below is used given as:

$$Volume = \frac{x_{st}}{100} \cdot \frac{1.5}{100} \cdot (steel\ density) \cdot (volume\ of\ mix\ design) \quad (1)$$

where x_{st} is the percentage of ST fibre and the steel density is taken as 7850 kg/m^3. Meanwhile, for calculating the volume of PP fibre, Eq. (2) below is used given as:

$$\text{Volume} = \frac{x_{pp}}{100} \cdot \frac{1.5}{100} \cdot (PP\ density) \cdot (volume\ of\ mix\ design) \quad (2)$$

where x_{pp} is the percentage of PP fibre and the PP density is taken as 869.14 kg/m^3.

3.1. Compression Test

In the compression test, apart from its compressive strength, the strain hardening behaviour is also studied in detailed. The compression test is carried out in accordance to BS EN12390-3: 2009 [15]. The test setup is shown in Fig. 1. The cube size is 150×150×150 mm and 9 samples are casted for each concrete batch. The cubes undergo water curing at room temperature until the test day which is at 28 days. The compressive strength and weight of each cube are also recorded.

3.2. Splitting Tensile Test

Splitting tensile test carried out on cylinders is to determine the tensile strength of the concrete. The test follows BS EN12390-5: 2009 [16]. The test setup is shown in Fig. 2. For each concrete batch, 3 cylinders are tested having size of 300 mm height and 150 mm diameter. They are water cured at room temperature for 28 days until the test day.

Fig. 1. Compression test

3.3. Flexural Test

Flexural test is carried out on prisms to determine the flexural strength and also to study the cracking behaviour. The test follows BS EN14651:2005+A1:2007 [17] as shown in Fig. 3. For each concrete batch, 3 prisms with size of 150 × 150 × 550 mm are prepared and they are water cured at room temperature for 28 days until the test day.

Fig. 2. Splitting tensile test

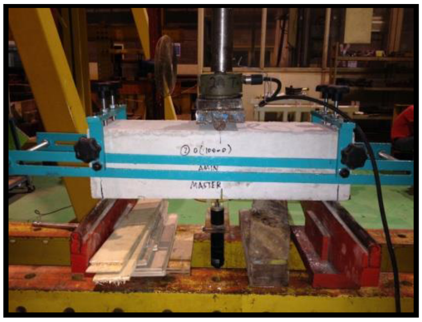

Fig. 3. Flexural and toughness test

4. Results and Discussions

4.1. Compression Test Results

Table 1 show the results from the compressive test for cubes which have been exposed to elevated temperature at 200°C and 400°C including the ones which are left at room temperature (27°C). The graphical relationship from the results in Table 1 is shown in Fig. 4.

Table 1. Compressive strength test results

	Compressive Strength (MPa)		
Concrete Batch	27°C	200°C	400°C
Control (0-0)	45.662	-	-
(100-0)	50.733	48.211	47.713
(75-25)	48.337	46.753	46.57
(50-50)	47.985	42.877	46.137
(25-75)	39.765	41.201	40.852
(0-100)	36.493	40.033	39.192

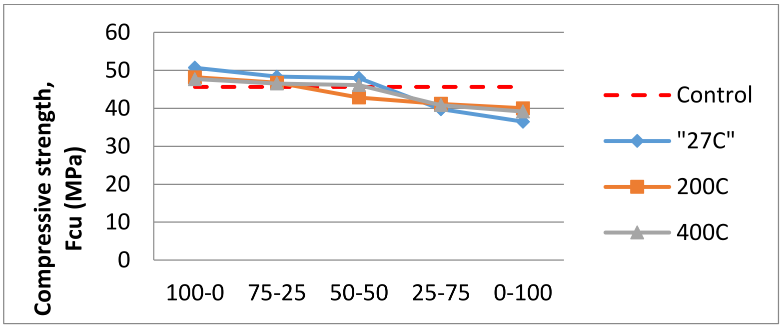

Fig. 4. Compressive strength relationship

From Fig. 4, the findings show that there is very small difference of the compressive strength between the concrete batches. The relationship also shows that when the cubes are exposed to temperature up to 400°C, there is a decrement on the compressive strength. However, the percentage differences on the compressive strength are in the range of 1% to 20%. All samples from concrete batch of ST-PP (100-0), ST-PP (75-25), and ST-PP (50-50) are above the design concrete grade of C40.

4.2. Flexural Test Results

Table 2 show the results from the flexural test of prisms which have been exposed to elevated temperature at 200°C and 400°C, including the ones which have been left at room temperature (27°C) for comparison purposes.

Table 2. Flexural strength test results

	Flexural Strength (MPa)		
Concrete Batch	27°C	200°C	400°C
Control (0-0)	4.974	-	-
(100-0)	13.904	12.426	12.414
(75-25)	10.032	10.676	10.560
(50-50)	8.026	8.131	6.170
(25-75)	7.690	5.690	4.410
(0-100)	7.530	5.420	4.353

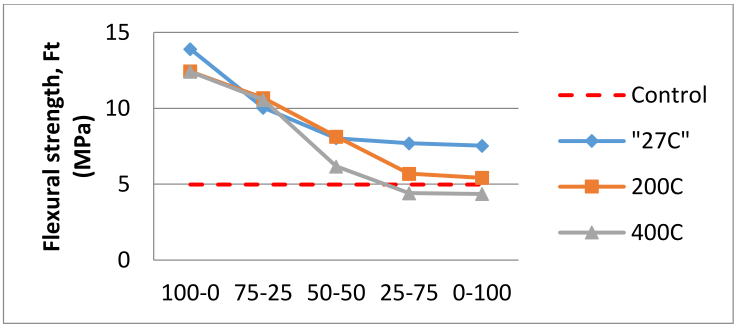

Fig. 5. Flexural strength relationship

Fig. 5 showing the graphical relationship of the flexural strength proved that there are large decrement of flexural strength between the concrete batches of ST-PP (100-0), ST-PP (75-25) and ST-PP (50-50). Meanwhile, between concrete batches of ST-PP (25-75) and ST-PP (0-100), there is only a small decrease in the flexural strength. This also shows that when the temperature exposed to the prism increases, the flexural strength reduces. Most of the concrete batches are above the control value of f_t = 4.974 MPa from the (0-0) batch except for the ST-PP (25-75) and ST-PP (0-100) batches that are exposed at 400°C.

4.3. Splitting Tensile Test Results

Table 3 show the results from the tensile test for cylinders which have been exposed to temperature at 200°C and 400°C, including the ones left at room temperature (27°C). The graphical relationship of the tensile strength for all concrete batches is shown in Fig. 6.

From Fig. 6, the finding shows that most of all the concrete batches are above the control tensile strength of f_{ct} = 4.731 MPa for batch (0-0), except for batch ST-PP (25-75) at 400°C and also batch ST-PP (0-100) for all exposure conditions. This shows that the addition of fibres in the concrete mixture enhanced the tensile strength of the concrete. However, as more PP fibres are added to the mixture, there is a significant dropped in the flexural strength and even lower that the control value. The relationship also shows that when the cylinders are exposed to temperature up to 400°C, the tensile strength reduces.

Table 3. Tensile strength test results

	Tensile Strength (MPa)		
Concrete Batch	27°C	200°C	400°C
Control (0-0)	4.731	-	-
(100-0)	7.567	7.187	6.811
(75-25)	8.48	6	5.854
(50-50)	6.976	5.96	5.547
(25-75)	4.862	5.275	4.281
(0-100)	3.989	4.042	3.827

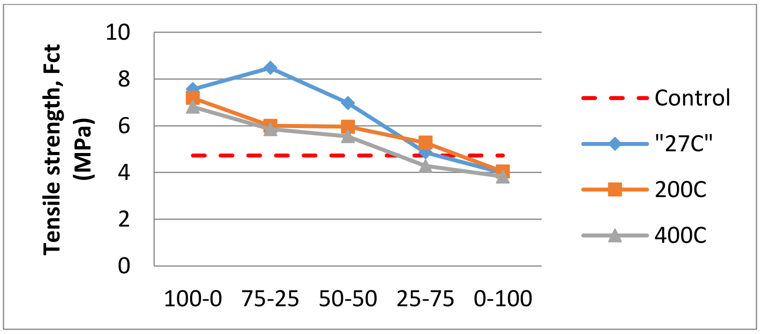

Fig. 6. Tensile strength relationship

5. Conclusion

The study concluded that when the samples exposed to elevating temperature increases, the strength of the concrete is reduced. This is because the concrete experienced spalling effect and at the same time it began to deteriorate. This makes the concrete become more brittle. However, the addition of fibres into the concrete mixture minimised the effects that occur in the concrete. The addition of fibres also enhanced the mechanical properties of the concrete, as the ST and PP fibres inhibit the cracking growth that occurred in the concrete. Observation from the experimental work also found that for the single fibre mixture, batch of ST-PP (100-0) is better than batch of ST-PP (0-100). Meanwhile for the combined fibres, batch of ST-PP (75-25) is better than the batch of ST-PP (50-50) and ST-PP (25-75).

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References

[1] T. Horiguchi, T. Sugawara & N. Saeki (2004). "Fire Resistance of Hybrid Fibre Reinforced High Strength Concrete". RILEM Publications PRO. 39, pp: 303-310.
[2] L.T. Phan & N.J. Carino (2002). "Effects of Testing Conditions and Mixture Proportions on Behaviour of High-Strength Concrete Exposed to High Temperature". ACI Material Journal. pp: 54-66.
[3] S.l. Suhaendi T. Horiguchi (2008). "Explosive Spalling Mitigation Mechanism of Fibre Reinforced High Strength Concrete under High Temperature Condition". Proceeding of The International FIB Workshop on Fire Design of Concrete Structure. pp: 189-197.
[4] K.D. Hertz (1992). "Danish Investigation on Silica Fumes Concrete at Elevated Temperatures".ACI Material Journal. 328 (89), pp: 345-347.
[5] M. Heikal (2000). "Effect of Temperature on ThePhysico-Mechanical and Mineralogical Properties of HomraPozzolanic Cement Pastes". Cement & Concrete Research. 30, pp: 1835-1839.
[6] Y. Xu, Y.L. Wong, C.S. Poon & M. Anson (2001)."Impact of High Temperature on PFA Concrete".Cement and Concrete Research. 31, pp: 1065-1073.
[7] A. Nishida & 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). Sapporo, Japan. August. E&FN Spon, London, pp: 1141-1150.
[8] P. Kalifa, G, Chene& Ch. Galle (2001)."High-Temperature Behaviourof HPC with Polypropylene Fibres from Spalling to Microstructure".Cement & Concrete Research. 31, pp: 1487-1499.
[9] Y.N. Chan, X. Luo W. Sun (2000)."Compressive Strength and Pore Strucutre of High Performance Concrete after Exposure to High Temperature up to 800 C".Cement & Concrete Research. 30, pp: 247-251.
[10] X. Luo, W. Sun & S.Y.N Chan (2000)."Effect of Heating and Cooling Regimes on Residual Strength and Microstructure of Normal Strength and High Performance Concrete".Cement & Concrete Research. 30, pp: 379-383.
[11] Y.W. Mai, R. Andonian& B. Cotterell (1980)."Thermal Degradation of Polypropylene Fibres in Cement Composites".International Journal Composite. 3(3), pp: 149-155.
[12] P. Soroushian, F. Mirza & A. Alhozaimy (1993)." Plastic Shrinkage Cracking of Polypropylene Fibre-Reinforced Concrete Slabs. National Research Council, Washington, pp: 64-68.
[13] M.R. Bangi& T. Horiguchi (2012)."Effect of Fibre Type and Geometry on Maximum Pore Pressures in Fibre-Reinforced High Strength Concrete at Elevated Temperatures".Cement & Concrete Research. 42, pp: 459-466.
[14] I.S. Ibrahim, F.A. Othman, M.I. Ghazali& A. Jameran (2013)." The Mechanical Properties of Hybrid Fibre Reinforced Composite Concrete". Proceedings of the 13th East Asia-Pacific Conference on Structural Engineering and Construction.11-13 September. Sapporo, Japan: University of Hokkaido.
[15] BS EN 12390-3 (2009). Compressive Strength of Test Specimens. Testing Hardened Concrete.1-22.
[16] BS EN 12390-6 (2009). Tensile Splitting Strength of Test Specimens. Testing Hardened Concrete.1-14.
[17] BS EN14651:2005+A1: (2007). Test Method for Metallic Fibre Concrete - Measuring The Flexural Tensile Strength (Limit of Proportionality(LOP), residual). 1-20.