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COMPRESSIVE STRENGTH OF CONCRETE WITH FIBRES AT ELEVATED TEMPERATURE

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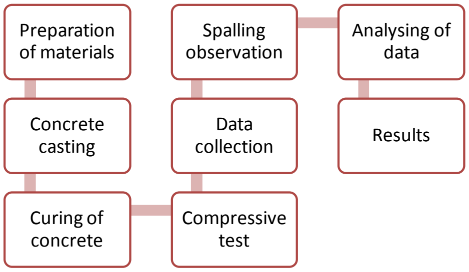
Graphical abstract



Abstract

Concrete, when exposed to high temperature, can cause spalling, cracking, and severe damage, which could lead to a sudden collapse of a building. One of the solutions for overcoming this weakness of concrete is by incorporating fibres in the concrete mix. Concrete incorporated with more than one type of fibres is often known as hybrid concrete. In this paper, the compressive strength of the hybrid concrete when exposed to elevated temperature is studied. The result is compared to concrete mixed with a single type of fibre of polypropylene or steel fibres. An observation of spalling is also carried out to verify the compressive strength test. The test results showed that both the single fibre specimens with steel fibre and hybrid specimen improved by 23.34% and 24.60% in residual strength compared with other residual strengths of concrete specimens.

Keywords: Compressive strength, single fibre, hybrid fibres, elevated temperature

1.0 INTRODUCTION

Concrete is a commonly used material used in construction. Normal concrete consists of cement, water, fine and coarse aggregates. Concrete can be heated, steam-cured, autoclaved, vacuum-treated, hydraulically pressured, shock-vibrated, extruded and sprayed [1]. Concrete in this study is considered a mixture of Ordinary Portland Cement (OPC), water, coarse and fine aggregates, superplasticiser and fibres. Concrete proportions must be carefully designed to provide desired workability, consistency, strength, density, water-cement ratio, durability, and generation of heat for the particular application.

Concrete often spalls when exposed to extreme temperature. Hence, fire may be one of the major factors affecting concrete's properties. Explosive spalling is the most dangerous type of concrete failure. Explosive spalling happens due to excessive pore pressure inside the concrete [2]. When this happens, the explosive energy causes the concrete fragments to fly at high speed, causing damage to the surrounding environment, for instance smashing windows [3]. In addition, explosive spalling can threaten the strength of the whole structure and could lead to sudden structural collapse. During concrete exposure to fire, water inside the concrete starts to evaporate. Concrete with a high air void will cause pore pressure to increase its stress on the concrete. Vapour stress becomes high with temperature increase. If vapour stresses overcome the tensile strength of the concrete, existing concrete failure will cause a high explosion of the concrete [4], [5].

To enhance the performance of concrete, fibre is utilised as the replacement for the steel reinforcement in the concrete. It is also known as

Fibre Reinforced Concrete (FRC) where concrete containing fibre material can increase structural performance [6]. Previous studies have utilised many types of fibres to reinforce concrete, for example steel fibre (SF) [7], [8], glass fibre [9], [10], carbon fibre [9], [11], polypropylene fibre (PPF) [2], [12], and polyvinyl alcohol fibre [13], [14]. Fibres are usually used in concrete to control cracking and spalling. Fibres are also capable of reducing the permeability of concrete and thus reducing the bleeding of water [15].

In this study, the use of SF and PPF in high strength concrete is seen as one of the alternatives to enhance the performance of high strength concrete without increasing the cost. The hybridisation concept was applied with 0.5% of PPF and SF by concrete volume respectively, to assess the suitability of the fibres towards concrete performance. This study employed elevated temperatures to all test specimens.

2.0 EXPERIMENTAL

2.1 Materials & Sample Preparations

In this study, cement type OPC is used for concrete characteristic strengths of 50 MPa [16]. The aggregates used were sand and crushed granite of particle sizes range from 5 mm to 20 mm. The types of fibres used in this study were hooked SF and PPF. The illustration for SF and PPF as in Figure 1. PPF is one of the cheapest and readily available fibres. PPF exhibits fairly good mechanical properties, a relatively high melting point (165°C) [17]–[19], low density (0.91 kg/cm^3), good chemical stability, and high elongation, but it is low in modulus and tensile strength [20]. 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.

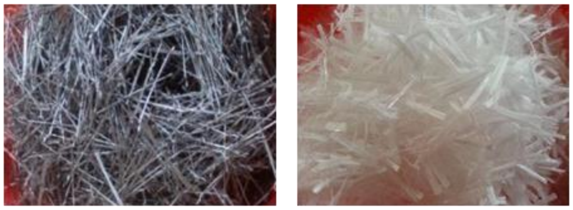


Figure 1 Type of SF and PPF used in this study [25].

The type of SF used was hooked SF. 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. Table 1 shows the properties of SF and PPF used in this study. The SF was made from the high tensile strength wire with greater than 1000 MPa accordance with ASTM A820M04 Type 1, and EN 14889 [21], [22]. The properties of the SF have relatively high strength and modulus of elasticity and are protected from corrosion by the highly alkaline matrix. The bonding of the fibre matrix can be enhanced by mechanical anchorage through surface roughness or deformation [14], [23]. The fibre ratio by volume used for SF and PPF is 0.5% based on optimum volume. A similar amount of fibre was also employed by Suhaendi & Horiguchi [24], Song, Wu, Hwang & Sheu [23] and Banthia, Majdzadeh, Wu & Bindiganavile [6].

The hooked SF was in glued form initially. A specified amount of bulk SF was kept in water for an hour to make sure the bulk SF loosens into single SF. The mixing process started with mixing dry cement with coarse and fine aggregates for 1 min; then water was 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 could disperse evenly 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 for curing process up to 28 days.

Table 1 Properties of SF and PPF used in this study

Type of fibre	Specific gravity	Diameter	Shape	Melting point	Length (mm)
PPF	0.9 g/cm2	22 μm	Circular	160°C-170°C	20
SF	7.8 g/cm2	0.7 mm	Hooked end	0°C	60

2.2 Test Methods

Prior to experimental testing, the specimens were left to air dry at room temperature for 4 hours. Then, the specimens were placed in a muffle furnace at elevated temperatures of 200°C, 400°C, 600°C and 800°C for an hour at each respective temperature. All specimens were left to cool for approximately 24 hours in the muffle furnace before conducting the compressive test. The compressive strength was conducted on the concrete cubes with a continuous load increment of 6.8 kN/sec until the specimens failed.

3.0 RESULTS AND DISCUSSION

3.1 Compressive Strength

An increase in temperature leads to changes in the concrete matrix. Concrete with fibres can provide more ductile structure compared to plain concrete matrix. Concrete with fibre was expected to enhance the compressive strength.

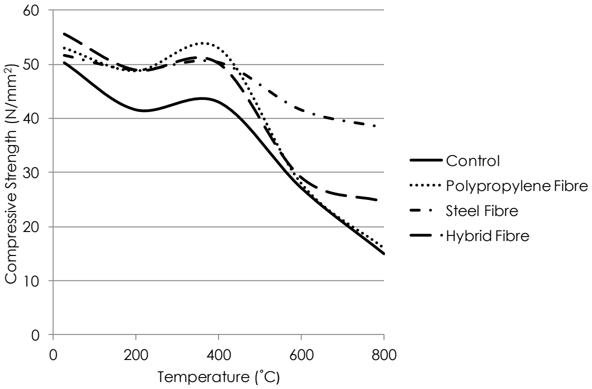


Figure 2 Compressive strength for all specimens respected to elevated temperature

Figure 2 shows the compressive strength of all concrete specimens for plain concrete (control), concrete with single fibre of PPF and SF, and concrete with hybrid fibre after being exposed to elevated temperatures. As observed in Figure 2, as the temperature rises from 200°C and 400°C, the compressive strengths of all specimens fluctuated in ranges of 40 N/mm^2 and 55 N/mm^2. The compressive strengths fall drastically after 400°C. All of the specimens showed similar behaviour after being exposed to elevated temperatures, except SF and hybrid fibre specimens tested at 600°C to 800°C. The residual compressive strengths for both specimens showed better behaviour; which both showed higher value than other specimens at 800°C. In addition, the residual compressive strengths for both control and PPF specimens showed a close value of 27.16 N/mm^2 and 27.97 N/mm^2 at 600°C and 14.98 N/mm^2 and 16.00 N/mm^2 at 800°C respectively as in Table 2.

Table 2 Result of compressive strength for all concrete specimens

Temperature, °C	27	200	400	600	800
Control (N/mm²)	50.31	41.61	43.04	27.16	14.98
SF (N/mm²)	51.65	48.98	50.35	41.58	38.32
Percentage improved (%)	1.33	7.37	7.31	14.42	23.34
PPF (N/mm²)	52.98	48.76	52.97	27.97	16.004
Percentage improved (%)	2.67	7.15	9.93	0.81	1.02
Hybrid Fibre (N/mm²)	55.64	48.98	50.2	29.1	24.6
Percentage improved (%)	5.33	7.37	7.16	1.94	9.62

Figure 4 Condition of control concrete specimens after exposed to elevated temperature

Figure 3 Condition of concrete specimens with PPF after exposed to elevated temperature

From this result, the highest residual compressive strength is the single fibre specimen of SF with 38.32 N/mm^2 at 800°C. This specimen showed the best performance in regards to the compressive strength for all specimens. The hybrid fibre specimen with 24.60 N/mm^2 has the second highest compressive strength.

3.2 Spalling Behaviour

Figure 4 shows the condition of the concrete control specimens after being exposed to elevated temperatures for an hour. As the temperature increased, concrete control specimens at 600°C started to spall. Specimens that are exposed to temperatures below 600°C showed no spalling at all.

Meanwhile, as the temperature increased, the hybrid specimen with PPF, as in Figure 3, also showed no spalling at all. Other concrete specimens also indicated similar spalling conditions as the PPF specimens for single and hybrid fibres.

Therefore, the addition of fibres in concrete specimens showed improvement in spalling as the temperature increases. The PPF functioned as a binder between cement and the aggregate and also proved to be efficient in acting as a cement-aggregate bond.

Besides, the addition of hooked SF in concrete specimens produced a bridging effect between cracks that occurred.

4.0 CONCLUDING REMARKS

In this study, the effects of elevated temperature on the compressive strength of single and hybrid fibres specimen were investigated. The conclusions from this study were:

1. The compressive strengths of all tested specimens reduced with an increase in temperature. However, the concrete specimens incorporated with fibres had relatively higher compressive strength compared to concrete specimens without incorporation of fibres.
2. Although the initial compressive strength of the control and PPF specimens were recorded at 50.31 N/mm^2 and 52.98 N/mm^2 respectively, the residual compressive strengths obtained at 600˚C and 800˚C were almost identical. Similar behaviour was also observed for control specimens and PPF specimens with a different value of 0.81 N/mm^2 at 600˚C and 1.02 N/mm^2 at 800˚C.
3. The SF specimens showed a higher residual compressive strength compared to PPF specimens in single fibre condition.
4. The hybrid fibre specimen with 24.60 N/mm^2 demonstrated the second highest compressive strength.
5. Based on the observations, PPF helped to improve the cement-aggregate bond while the hooked SF in concrete specimens functioned as bridging effect between cracks.

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