Effect of fire flame exposure on basalt and carbon fiber reinforced concrete

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Abstract. Concrete in general is a poor conductor of heat, but it can suffer significant damage when exposed to fire. Investigation of concrete behaviour when exposed to fire has generated interest where most of the fire cases take place in buildings and tunnels. Incorporation of fiber in concrete can improve the mechanical performance as it acts as crack arresters, resisting the development of cracks, hence making the concrete composite matrix stronger. In this study, mechanical behaviour of basalt and carbon fiber reinforced concrete for different characteristic strengths at 28 days were investigated for its performance when exposed to fire flame. Fire flame test using methane gas was developed to simulate real fire phenomena. Concrete specimens were subjected to fire flame at the temperature of 1000 °C for a period of 90 minutes. Visual observation (colour change, cracking and spalling), loss of density and residual compressive strength of the concrete specimens were performed. The results obtained were compared with reference specimens. Test results showed that tested samples experienced cracking and spalling, reduction of mass and compressive strength. All samples experienced compressive strength loss except for G20 OPC which recovers 7.8 % compressive strength. Addition of carbon fiber showed an increased in strength before exposure compared to basalt fiber. Minor damages were observed for carbon fiber in concrete after fire exposure compared to basalt fiber.

1. Introduction
One of the biggest threats to concrete integrity is fire destruction. Compared to other hazards, damage by fire exposure extends further than during the occurrence of the incident. Concrete undergoes gradual strength loss in temperatures exceeding 200 °C, which is inevitable in a fire incident. With reduced strength, the building may collapse and cause damage even hours after an incident. Depending on the type of concrete, porosity, aggregates and other factors, concrete may experience substantial damage that may not be reparable or in worst scenarios, cause fatalities.
In recent years, utilization of fibers in concrete to improve fire resistance has shown promising results. Fibers that are commonly used to improve compressive and tensile strength as well as fire resistance in terms of spalling and cracking prevention include polypropylene, steel and nylon fibres. Fundamentally, fibres possess high tensile strength, which serves to provide tension between voids and weak areas within the concrete matrix.

The use of basalt fiber as reinforcement to concrete has progressively been a subject of interest due to the obvious mechanical improvements resulting from high stiffness and strength as well as corrosion and oxidation resistance from its application [1,2]. As for the behaviour of basalt fiber reinforced concrete against heat, several studies have shown relatively promising results because basalt offered high temperature properties such as elastic modulus at elevated temperature (high softening temperature of up to 1050 °C) [3]. As reported by Novakova [4], the residual compressive strength of basalt fiber reinforced concrete was displayed at 41.3 % of the initial compressive strength. However, Shaikh and Taweel [5] reported a lower residual compressive strength against the control Ordinary Portland Cement (OPC) concrete, which is at 13.77 % of its initial compressive strength.

Carbon fiber has been choose as another type of reinforcement in concrete due to its high stiffness, tensile strength as well as high chemical resistance. In addition, carbon fiber also possesses high thermal resistance with low thermal expansion [6,7]. In the context of carbon fiber reinforced concrete behaviour against heat, the limited existing literature shows for high residual compressive strength. Tanyildiz [8] reported findings of 37 % of original compressive strength with 1% carbon fiber inclusion after exposure to heat at 800 °C for 1 hour. Likewise, Chen and Liu [9] reported a 32 % reduction in carbon reinforced high strength concrete after exposure to 800 °C for 3 hours. In both cases, the occurrence of spalling had occurred though to a small degree. This may be attributed to the high elastic modulus of fibres, which can resist cracking and increase the time taken to spall as mentioned by Chen and Liu [9].

This paper aims to study the effect of basalt and carbon fibers as reinforcement in concrete to improve its mechanical properties when exposed to fire against conventional OPC concrete with regard to its residual compressive strength as well as the occurrences of cracking and spalling. The implementation of direct fire flame was intended to simulate the real fire event that caused most of fire accident for concrete structure.

2. Experimental program

2.1. Experiment material

For the development of experimental work with the aim to study the effect of fiber-reinforced concrete when exposed to fire flame, the following materials listed below were used.

- Cement of CEM type 1 is used for the concrete mixture. The concrete mixture proportion were designed according to BS 8500-2: 2002 [10] standard for grades 20 and 40. 6 batches of concrete samples were produced, which consist of 3 batches for each grade of concrete. The mixture proportions used to manufacture the concrete samples are shown in Table 1. OPC represents the reference sample without any addition of fiber.
- Coarse aggregates of size range 5-20 mm granulometric fraction obtained from locally-available pulverized rock. The aggregates were washed to remove dirt and dust, and then dried to prepare them in a saturated surface-dry condition.
- Washed river sand < 5 mm granulometric fraction with a fineness modulus of 2.6 from a local sand supplier. The sand delivered was cleaned to remove the dirt and clay upon packaging.
- Monofilament-type carbon and basalt-fiber were used for this work. The physical appearance of the fibers are shown in Figure 1 and Figure 2. The characteristic indicators of each fiber are shown in Table 2. The proportion of fibers used in the mixture are derived from the cement content. The final mixture is selected according to the required strength achieved by the trial mix performed previously.
2.2. Mixing and casting
The concrete samples were prepared in cube block size 100 mm. The mixing was done according to the mix proportions in Table 1. The materials were mixed using a VMI mixer in the civil engineering laboratory. For mixing, firstly, the sand and coarse aggregates were mixed for 30 seconds. Half of the water was then added and mixed for one minute. Then, cement was added into the mixture and mixed for another one minute. Finally, the remaining half of the water with fiber are added into the mixture and mixing continues for another one to two minutes until it becomes homogeneous. Then, the mixture was poured into the mould. The mixture was placed with two layer and tamping using a tamping rod was done for each layer to remove the entrapped air or voids present in the mixture. The cast concrete samples were cured at ambient curing for 24 hours to let them harden. Next, the samples were removed from the mould and kept in the curing tank with water until 28 days prior to test activities.

Table 1. Mixture proportions (kg.m⁻³)

| Mix ID   | OPC  | Coarse Agg. | Sand  | Water | Basalt Fiber | Carbon Fiber | Compressive @28 days (MPa) |
|----------|------|-------------|-------|-------|--------------|--------------|----------------------------|
| OPC20    | 342  | 1211        | 652   | 205   | -            | -            | 28                         |
| OPC20 BF | 342  | 1211        | 652   | 205   | 5.13         | -            | 29                         |
| OPC20 CF | 342  | 1211        | 652   | 205   | -            | 3.42         | 33                         |
| OPC40    | 405  | 1193        | 642   | 190   | -            | -            | 47                         |
| OPC40 BF | 405  | 1193        | 642   | 190   | 8.1          | -            | 43                         |
| OPC40 CF | 405  | 1193        | 642   | 190   | -            | 8.1          | 49                         |

Figure 1. Basalt fiber  
Figure 2. Carbon fiber

Table 2. Characteristic indicators of fibers

| Type of fiber | Specific gravity | Tensile strength (MPa) | Elastic modulus (GPa) | Monofilament diameter (µm) | Elongation at break (%) |
|---------------|------------------|------------------------|-----------------------|---------------------------|------------------------|
| Basalt        | 2.7              | 4800                   | 89                    | 7                         | 3.15                   |
| Carbon        | 1.77             | 3950                   | 127.7                 | 12                        | 15                     |

2.3. Testing program
The concrete samples were subjected to fire flame test to simulate the real fire events using a natural gas fire test setup. The 100 mm cube samples were exposed to fire flame at temperature 1000 °C for
90 minutes duration without any imposed load. The fire temperature was captured using a thermocouple attached to the surface of exposure. Prior to fire testing, the concrete samples were weighed to check the loss of mass after the fire exposure. During the fire test, visual observation on colour changes, cracking and possible spalling was recorded. After burning, the concrete specimens were left to cool for 24 hours at room temperature.

All the concrete samples casted were subjected to compressive strength test before and after the fire exposure at 28 days. The compressive strength test was done to check the residual strength of the concrete sample after fire exposure. The compressive strength test was performed according to BS EN 206 [11]. Reported results are the averages of three samples.

3. Results and discussion

3.1. Visual observation of concrete after exposure to fire
In general, assessment of the concrete damage begins from the visual observation of colour changes, appearance of cracking and goes up to the spalling of the surface exposed. Figure 3 shows an image of the concrete samples before and after fire exposure with regard to changes in colour as well as the visible cracks on the surface. The colour of the burnt sample changed from grey to whitish grey after exposure at 1000 °C for 90 minutes. When the temperature was maintained at 1000 °C, the exterior surface became light red until the end of 90-minutes exposure. As the concrete cooled to room temperature, the surface became whitish grey as in Figure 3. During fire exposure, small cracks started to appear after 20 minutes of exposure. The cracks increase in number and width up to the edge of the sample with the increase of time exposure.

As for spalling effects, no spalling was observed for G20 concrete samples for both OPC and fiber-reinforced OPC. On the other hand, there is explosive spalling observed for G40 concrete samples. G40 OPC and G40 OPC BF experienced a layer of explosive spalling while G40 CF only suffered minor damages on the side wall and at the edge of the exposed surface as shown in Figure 4. The spalling occurred after 10 minutes exposure, which is when the temperature is rapidly increased from ambient to 1000 °C. It is due to internal pore pressure and thermal stresses in denser matrix structure of G40 sample as compared to G20 sample. The photo revealed that spalling has caused a reduction of the concrete cross-section on the exposed surface. The depth of spalling goes up to 10 mm for G40 OPC sample.
3.2. Loss of mass/density
Loss of density of the samples were measured before and after exposure. Measurement of mass reduction describes the loss of mass due to extensive damage produced from spalling as well as loss of water within the body of the concrete. The percentage of mass reduction of the concrete samples can be found in Figure 5.

From Figure 5, G40 samples experienced a higher loss of mass compared to the G20 samples. G40 samples with OPC concrete without fiber reinforcement lost an average of 7.87% of its mass out of the 3 categories of samples. The higher loss in mass can be attributed to an increased occurrence of spalling from a higher pore pressure trapped within the body of concrete. G40 samples are regarded as medium strength concrete with less porosity. The lack of pores increases the risk of spalling. Likewise, G20 samples, which possess low strength, possess higher permeability due to its higher porosity. Therefore, a reduced risk of spalling occurs for low strength concrete. The loss in mass in G20 samples may be attributed to loss of moisture through evaporation process during the burning process.

With fiber reinforcement, G40 CF experienced a lower mass reduction at 7.33% of its mass. As the likely cause of mass loss in G40 samples is due to spalling, G40 CF was no exception. However, G40 CF samples did not experience extensive damage on the exposed surface compared to G40 OPC and G40 BF samples. The reduced damage can be related to the increased tensile strength provided by carbon fibre reinforcement. Carbon fibres have a better cement-fiber interfacial adhesion when compared to basalt fibers [12].

![Figure 5. Mass reduction (%) of G20 and G40 concrete samples](image)

![Figure 6. Compressive strength (MPa) of G20 and G40 concrete samples at 1000 °C](image)

3.3. Residual compressive strength
In general, when concrete is exposed to high temperature, its strength gradually reduced over the duration of exposure. Through this work, the effect of fire flame on the compressive strengths of G20 and G40 concrete samples were determined. The average compressive strengths of G20 and G40 concrete samples before and after fire exposure are illustrated in Figure 6. It shows the reduction of compressive strength for concrete samples with the exception of G20 OPC. For G20 samples, the OPC without fiber have gained 7.8% compressive strength after fire exposure. The increment may be attributed to the high porosity matrix structure. Compressive strength reduction of G20 BF is higher than G20 CF by a difference of 34% due to the degradation of basalt fiber at temperatures higher than 700 °C. Carbon fiber is more capable at sustaining high temperature compared to basalt fiber. All G40 samples showed reductions in compressive strength after exposure at 1000 °C for 90 minutes. G40 OPC without fiber experienced major compressive strength loss due to spalling, which reduced the concrete cross-section. G40 CF showed experienced a compressive strength reduction of 42% while G40 BF which is lost 51% of its compressive strength after fire exposure. This indicates that concrete
with carbon fiber have a better performance compared to concrete with basalt fiber and without the addition of fiber.

4. Conclusions
This paper presents the results of an experimental work on G20 and G40 fiber-reinforced concrete that is exposed to a temperature of 1000 °C. Exposure to fire flame compromises the integrity of concrete matrix. Test results showed that physical and chemical changes took place, which is water evaporation that caused cracking, spalling and reductions of mass and compressive strength. All samples experienced compressive strength losses of higher than 53% except for G20 OPC, which recovers 7.8% of its compressive strength. Addition of carbon fiber showed a higher increase in strength before exposure at 28 days compared to basalt fiber. After fire exposure, damage to carbon fiber concrete samples was lower in terms of mass and strength loss compared to reference and basalt fiber samples.

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