

FIRE RESISTANCE OF HIGH-PERFORMANCE CONCRETE REINFORCED WITH SELECTED FIBERS

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ABSTRACT. One of the biggest issues of high-performance concrete is its behavior during fire. Because of the much lower amount of pores in high-performance concrete, extremely high water vapor pressure is created. This leads to explosive spalling of the concrete. One way to prevent this effect is by adding fibers to the concrete mixture. In this article, the impact of commonly used polypropylene fibers is compared to that of flax fibers and viscose fibers. Subsequently, mechanical compressive and flexural strength were tested on those samples that remained intact after the fire experiment. Their mechanical properties were compared with the reference samples without exposure to fire at the same age.

KEYWORDS: High-performance concrete, fiber-reinforced concrete, fire, elevated temperature, compressive strength, flexural strength.

1. INTRODUCTION

Civil engineering, particularly cement production, is one of the largest sources of CO₂ emissions in the industrial sector. To reduce its effects on the environment, it is essential to focus on improving material efficiency and using alternative materials. One of the ways is using high-performance concrete (HPC). In HPC, the number of pores is reduced, which leads to higher strength. However, fewer pores result in explosive spalling of concrete – there is only limited space for water vapor evaporation increasing water vapor pressure that eventually leads to explosive spalling. Fiber-reinforced concrete (FRC) is created by adding certain fibers and can prevent concrete spalling [1]. There are several materials that can be used. Polypropylene (PP) fibers are commonly used as a spalling prevention. These synthetic fibers have a relatively low melting point (160 °C [2]), which creates more space for water vapor evaporation. Another possibility is using natural materials, for example flax. Research has shown that flax fibers can partially prevent spalling; they do not decompose at temperatures below 300 °C, they only shrink, which leads to limited space for water vapor evaporation. Therefore, their effectiveness in enhancing fire resistance is limited, and a higher number of fibers or a combination of fibers would be required [3]. The last material considered in this article is viscose, which is produced from natural materials. It is widely used in the textile industry, providing opportunities for recycling. The use of viscose fibers in spalling prevention is not well known and therefore requires thorough exploration.

In this article, a fire experiment using the temper-

ature curve according to ISO 834 with a duration of 15 minutes was performed. Beam FRC samples with dimensions of 40 × 40 × 160 mm were prepared and provided with the wire thermocouples to measure the temperature inside the samples.

2. MATERIALS AND METHODS

2.1. MATERIALS AND SAMPLES

For the experiment, nine variants of FPC samples were prepared. Three sets contained polypropylene fibers (PP), three sets contained flax fibers (Flax), and the remaining three sets contained viscose fibers (see Figure 1). Each variant consisted of six beams with dimensions of 40 × 40 × 160 mm – three samples for the fire experiment and three samples for comparison of subsequent compression and bending tests. Samples for the fire experiment were provided with the wire thermocouples (Figure 2). All samples were stored in water for 28 days and then moved to a room with a constant relative humidity of 60 % and a temperature of 22 °C.

The HPC mixture without fibers used for the preparation of samples was developed at CTU in Prague (Table 1) [5]. The amount of water and superplasticizer was then slightly modified to achieve better workability of the concrete. Compressive strength of this mixture was around 145 MPa and tensile strength reached a value of approximately 11 MPa. As stated before, three different fiber materials were used – polypropylene, flax, and viscose.

PP fibers are commonly used as a prevention of concrete explosive spalling; therefore, PP fibers MasterFiber 012 were chosen for comparison with other



FIGURE 1. Fibers user – polypropylene, flax, and visose.

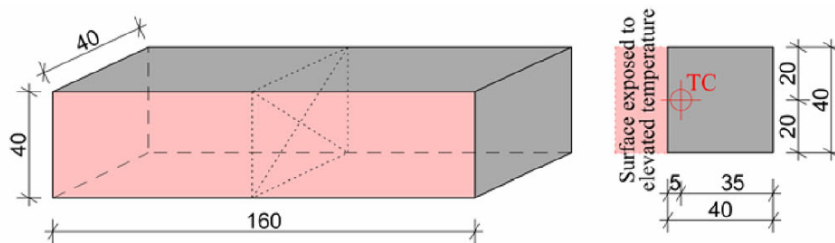


FIGURE 2. Location of a wire thermocouple [4].

Mix content	PP1	PP2	PP2 PL25	Vis 1	Vis 2	Vis 2 PL25	Flax 1	Flax 2	Flax 2 PL25
	kg m^{-3}								
Cement I 42.5R	650	650	650	650	650	650	650	650	650
Silica sand	1 200	1 200	1 200	1 200	1 200	1 200	1 200	1 200	1 200
Silica flour	235	235	235	235	235	235	235	235	235
Silica fume (microsilica)	75	75	75	75	75	75	75	75	75
Superplasticizer	18	18	25	18	18	25	18	18	25
Water	190	190	190	190	190	190	190	190	190
PP fibers	1	2	2						
Flax fibers				1	2	2			
Viscose fibers							1	2	2

TABLE 1. Mixture of FRC.

fibers. These fibers have a length of 12 mm and are very fine, which allows them to disperse equally. The manufacturer’s recommended fiber amount varies between 600 g m^{-3} to 3 kg m^{-3} .

Since flax shows one of the best mechanical parameters of natural fibers, it was chosen as a representative of natural fibers. Long flax roving was cut into fibers of a length of approximately 12 mm for better comparison with PP fibers.

The last selected material, viscose, is produced from natural materials and is industrially compostable at the same time, which makes viscose a compromise between artificial and natural fibers that can be unpredictable. Just like flax, viscose roving was also cut into fibers of a length of approximately 12 mm.

2.2. EXPERIMENT

For the fire experiment, a mobile fire furnace, mini-FUR, developed by FireLAB at the University Centre for Energy Efficient Buildings, was used. This furnace is designed to achieve the temperature curve according to ISO 834 for up to 45 minutes. After 15 minutes, a problem with the furnace occurred after spalling of some samples, and the experiment had to be aborted. Consequently, the duration of this indicative experiment was set to 15 minutes. Samples were placed between 100 mm thick aerated concrete blocks, which form the front walls (Figure 3).

After the fire experiment, intact samples were left to cool. Afterwards, mechanical flexural strength test (three-point bending test) on beams was performed

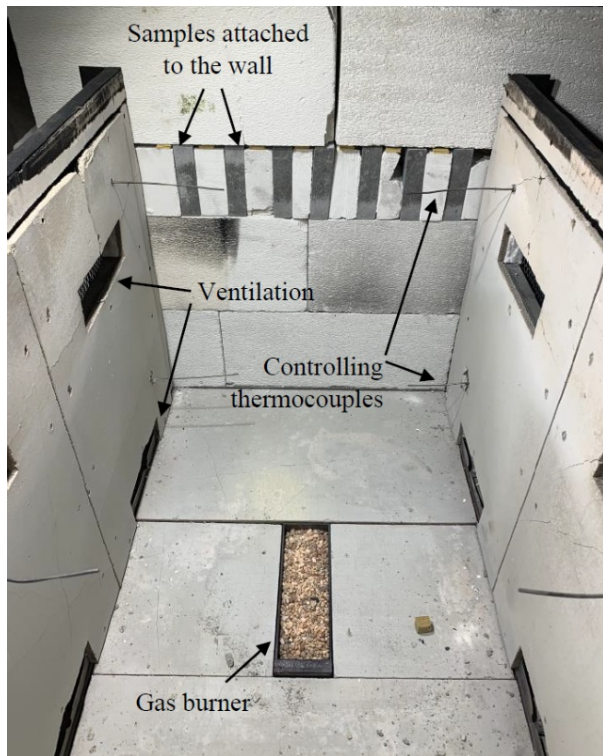


FIGURE 3. Arrangement of the fire furnace.

according to CSN EN 12390-5 [6], along with compressive strength test on fragments of beams according to CSN EN 12390-3 [7]. Mechanical properties were also tested on the reference samples that had not been exposed to fire.

3. RESULTS AND DISCUSSION

The duration of the fire experiment was 15 minutes because of a problem with the furnace. There were some samples from another experiment so that the furnace would be used effectively, but the spalling of those samples caused a temperature drop in the furnace, and the experiment had to be stopped after 15 minutes. Therefore, the duration of all the following fire tests with the rest of the samples were set to 15 minutes.

The courses of some samples' curves and the ISO 834 curve from uninterrupted test are shown in Figure 4. The measured temperature curve during the experiment was within the range of the ISO 834 curve, average temperature in the samples was around 250 °C at the end of the experiment. This value is important when changes in mechanical properties are evaluated.

As can be seen in Figure 5, all samples remained intact except for those with 1 kg m⁻³ flax fibers, Flax 1, whose exposed side completely spalled. This may be caused by the fact that flax fibers tend to clump together. It is also known that flax fibers do not melt at temperatures below 300 °C; they only release absorbed water and shrink that leads only to limited space for water vapor evaporation [3]. PP fibers, on the other hand, expand with increasing temperature

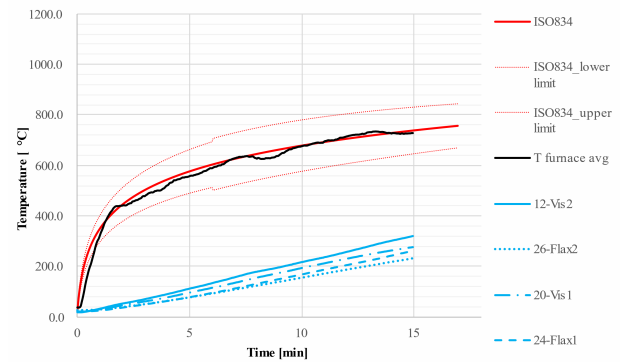


FIGURE 4. Temperature curves during the fire experiment of selected samples.



FIGURE 5. Samples after the fire experiment.

creating microcracks, and at 170 °C they start to melt, which leads to even wider space [8].

Afterwards, mechanical flexural strength and compressive strength were measured. According to [4, 9], those values depend on the temperature reached. In the case of HPC, there is a certain increase in compressive strength up to approximately 450 °C followed by a decrease in this strength. Tensile and flexural strength, on the other hand, decrease with heat increase, especially in the case of FRC.

The results in Figure 6 show that in all samples flexural strength decreased compared to the reference samples (not exposed to fire). This behavior of FRC corresponds with EN 1992-1-2 [10] as well as with other articles [4, 9], where tensile and flexural strength mostly decreased. Only in the case of plain HPC, there was a small range of temperatures around 220 °C with a slight increase in splitting tensile strength in those articles.

Figure 7 also shows that all samples reached lower values of compressive strength compared to the reference samples (not exposed to fire). This corresponds with EN 1992-1-2 [10], but not with other articles [4, 9]. They found that compressive strength increases after being exposed to higher temperature up to approximately 450 °C. This may be caused by additional cement hydration enabled by evaporating water. But the fire exposure of our samples may not be long enough; the temperature reached in the samples was

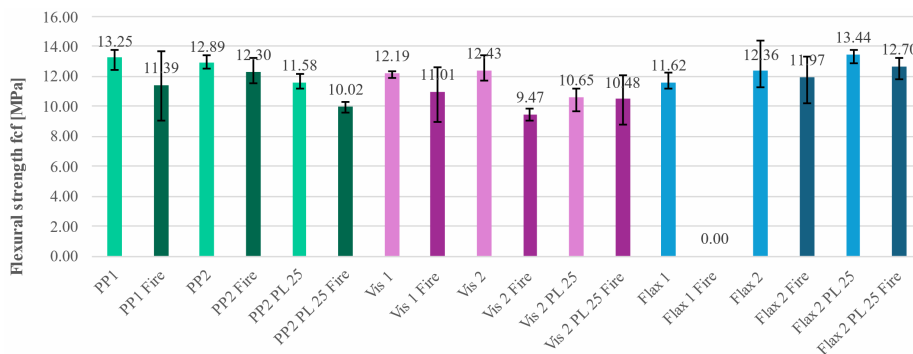


FIGURE 6. Flexural strength of the samples exposed to fire in comparison with the reference samples.

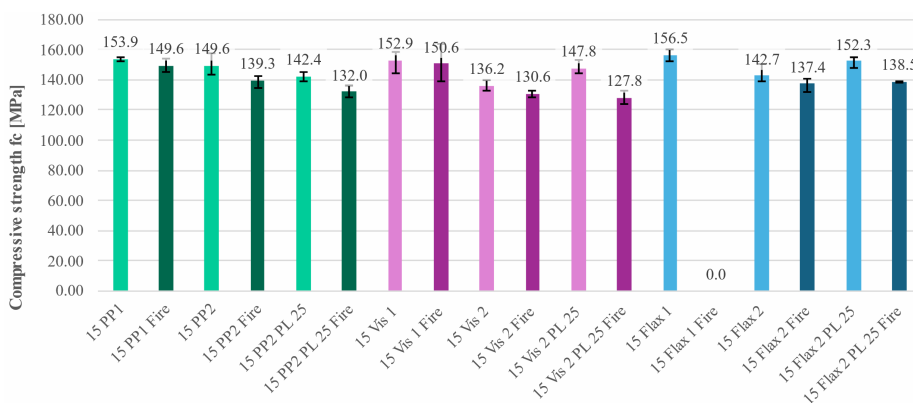


FIGURE 7. Compressive strength of the samples exposed to fire in comparison with the reference samples.

only around 250 °C and it was reached at the very end of the experiment. A slight decrease in compressive strength is believed to be caused by the development of microcracks.

4. CONCLUSION

By adding PP fibers and viscose fibers, we were able to prevent spalling of the concrete when exposed to fire for the short period of time. Adding flax fibers was less effective – samples containing only 1 kg m⁻³ of flax fibers were damaged. The reason is in fibers' behavior during elevated temperatures; flax fibers only shrink and do not melt at temperatures below 300 °C, meanwhile PP fibers first expand, creating microcracks, and then begin to melt at temperatures around 170 °C. Consequently, the behavior of viscose fibers must be investigated through microstructure observation. Furthermore, longer exposure to fire should be performed.

As for mechanical properties, all samples reached lower compressive, as well as tensile strength, which partly corresponds with other articles [4, 9]. They found that exposure to temperature around 450 °C leads to higher compressive strength. The main difference was in the duration of the fire experiment which implies that change of mechanical properties depends both on temperature and time of exposure to that temperature.

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