Use of Short Carbon Fibres as a Reinforcing Material for the Refractory Cement-based Composite

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Abstract: A type of fibre-reinforcing material was developed by carbonization of high quality polyacrylonitrile precursor, which is specifically engineered. Together with resin, carbon fibres are usually manufactured into a composite. These carbon fibre components are light-weight and strong compared to parts made of metals (e.g. aluminum) or other fibre reinforced composites. For the purpose of this experiment, the attention was focused on the application of chopped, dispersed carbon fibres. These extremely strong and stiff fibres are typically 6 mm in length and due to their properties they can also be used as reinforcement for high-temperature resistant composites. This experimental program addresses the effect of the addition of short carbon fibres on mechanical properties of fibre reinforced cement-based composites exposed to high temperatures of 600 °C and 1000 °C. The proposed composites differed in doses of fibres, which are 0.0 %, 0.5 % and 2.0 % by volume.

Keywords: aluminous cement; carbon fibre; short dispersed fibre, cement-based composite, mechanical properties; high temperature.

1 Introduction

The bond and failure mechanisms in fibre-reinforced concrete are presently being investigated widely by many researchers [1, 2, 3, 4]. Fibre-reinforced composites rank to the most frequently used composites because of their suitable mechanical properties. Application of fibre reinforcement in the form of short fibres ensures increased load capacity of such developed materials [1, 5]. Carbon fibre is exceptionally versatile in the civil engineering field thanks to its high strength and flexibility. It can be used to restore existing structures just as efficiently as it can be used to reinforce brand new ones. In case of high-temperature resistant cement-based composites fibres significantly contribute to the reduction of crack initiating which accompanies volume changes caused by the structural transformation due to high temperature impact.

In this research the main goal of realized experimental was to determine the influence of carbon fibres [6] in refractory cementitious composites after exposure to high temperatures.

2 Creation of the Composites

The main component of interest in this experiment was short carbon fibres. The carbon fibre production process is relatively energy intensive, but carbon fibres popularity is growing because they have excellent strength due to its weight, see Tab. 1. In comparison with steel, the carbon material delivers twice the strength at one-fifth the weight.

Tab. 1: Properties of carbon fibres.

Properties	Specific Weight $[g.cm^{-3}]$	Tensile Strength [MPa]	Elastic Modulus [GPa]	Thermal Conductivity $[W.m^{-1}.K^{-1}]$	Coefficient of Thermal Expansion at 100 °C $[K^{-1}]$
	1.80	3000	500	25	0

Each experimental mixture for the manufacture of composites, shown in Tab. 2, contains as refractory binder the aluminous cement Secar®71, which due to its high content of aluminium oxide (Al_2O_3) ensure sufficient temperature resistance over 1000 °C [7, 8]. Expanded glass Liaver was applied as lightweight aggregate to reduce final bulk density of composites. Liaver is produced by recycling of waste glass by patented technology. The plasticizer Sica Viscocrete 1035 provides fluidizing effect of the fresh mixture and required workability while the low water/cement (w/c) ratio is kept.

To investigate the structural effect of carbon fibre reinforcement in cement-based composites nine prismatic specimens were tested for each proposed mixture. Composite mixtures were cast in steel forms (prisms 40×40×160 mm) and then cured at temperature 20 ± 3 °C and wet condition, the curing time lasted for 28 days.

Tab. 2: Composition of experimental specimens.

Components		Ref $[kg.m^{-3}]$	C0.5 $[kg.m^{-3}]$	C2.0 $[kg.m^{-3}]$
Aluminous cement	Secar®71	900	900	900
Carbon fibres	6.0 mm	0	8.75	35
Water	potable	224	224	224
Plasticizer	Sika 1035	22.75	22.75	22.75
Fireclay aggregate	0.0-1.0 mm	490	490	490
Liaver	0.25-0.5 mm	70	70	70
	0.5-1.0 mm	15	15	15
Amount of fibres	[volume %]	0.0 %	0.5 %	2.0 %

3 Measurement Methods and Results

Dried samples were divided into three groups. The first group was represented by dried specimens at temperature 105 °C. The second and the third groups were submitted to high-temperature loading up to 600 °C and 1000 °C. The required high temperature was maintained for 180 minutes for each composite. It is necessary to carry out a drying procedure and firing after cement composites maturity [9].

A series of uniaxial, deformation-controlled tests was performed to study the strength of specimens. After high-temperature loading was investigated flexural strength of the composites and on the remaining fragments was tested compressive strength. All measurements of mechanical properties were carried out according to the standard EN 196-1:2005 [10]. On the basis of these data, the mechanisms of the interaction between short dispersed fibres and the matrix of cement-based composite are discussed.

The summary results of the measured properties of the produced refractory composites are shown in Tab. 3. Table shows also an overview of the dependence of bulk density on temperature.

Tab. 3: Summarized characteristic of experimental specimens.

	Bulk Density ρ [kg.m^{-3}]			Flexural Strength f_{tm} [MPa]			Compressive Strength f_{cm} [MPa]		
	105 °C	600 °C	1000 °C	105 °C	600 °C	1000 °C	105 °C	600 °C	1000 °C
Ref	1911	1725	1721	8.9	8.2	7.6	44.5	36.1	34.4
C0.5	1868	1647	1635	14.9	12.3	10.8	52.0	41.5	37.6
C2.0	1737	1526	1504	19.4	13.8	10.4	72.3	52.5	25.2

We can observe the gradual decline of bulk density due to effect of high temperature loading, when moisture and physically bounded water is evaporated first. Increase of temperature led to further decrease of bulk density which is caused by partial chemical decomposition of hydration products.

4 Conclusion

Realized program confirmed satisfactory application of short carbon fibres as reinforcement for high-temperature resistant composites. Flexural strength f_{tm} measurement was organized as a three point test with supports distance of 100 mm and was calculated by help of the maximum reached force. Graph on Fig. 1 and Fig. 2 compares values of flexural and compressive strength according the different amount of fibres in total volume of cement composite after exposure to elevated temperature.

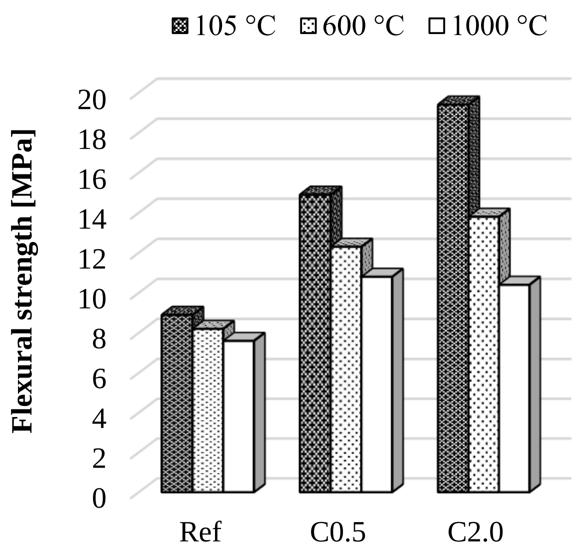

Fig. 1: Values of flexural strength.

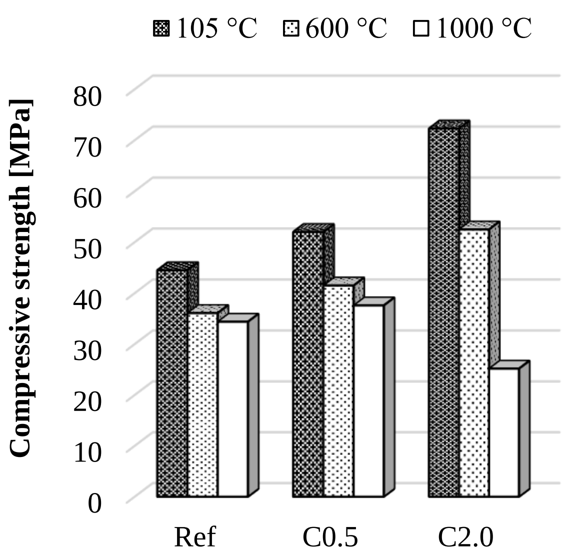

Fig. 2: Values of compressive strength.

The resulting values of Ref composites, after drying and high-temperature loading, exhibited the lowest flexural resistance of all specimens as it was expected. On the other hand, the specimens with 2.0 % of carbon fibres reached the highest values of flexural (f_{tm}) and compressive (f_{cm}) strength in experimental program after drying and exposure to 600 °C. But at the load temperature of 1000 °C occurs the most significant changes in strength. The reduction is probably caused by disruption of the interaction between the mixtures components. According to performed tests we can also determine the positive influence of fibre dosage of 0.25 % (due to mechanical properties and good workability of fresh mixture).

The optimal temperature level for using this type of composite is below 1000 °C, where the values are still sufficient. Good mechanical parameters can be observed on specimens after exposure to 600 °C. None of the thermal loading scheme did not resulted into visible cracks in aggregates or cement matrix, volume expansion, observable disintegration or any negative phenomenon know from interaction ordinary concrete and environment characterized by high temperature (typically up to 600 °C).

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