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Experimental Investigation of Hydrothermal Curing Influence on Mechanical Properties of Fiber-Cement Composite

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Abstract. Special industrial application of fiber-cement composites is currently one important issue of concrete industry and research activity. Hydrothermal curing together with using aluminous cement with refractory basalt aggregates and fibers shows high potential for its applications in high temperature. These composite is characterized by compressive strength over 140 MPa and tensile strength in bending 12 MPa (investigated on specimens 40 x 40 x 160 mm). After exposure to temperature 1000 °C these parameters are 60 MPa respective 6 MPa. Achieved values are significantly higher than in the case of laboratory curing condition and there are suitable especially for prefabricated fire resistance cladding or other special application in the industry.

Introduction

The influence of curing condition on mechanical parameters, durability and final compressive strength were investigated on several materials including UHPC. Especially in the field of prefabricated concrete elements water condition, hot steam or other kinds of curing applies at the early ages. Graybeal investigated the influence of hot steam and high humidity over 95 % on the final compressive and tensile strength and modulus of elasticity compared to laboratory condition samples [1]. These special curing conditions take place in the prefabricated concrete production of special elements, usually made from high-performance concrete. Hydrothermal curing has a strong effect on mechanical properties of concrete. The most widely used of hydrothermal curing condition is the production of autoclave aerated porous lightweight concrete [2]. Major effect is the development of a denser microstructure with the formation of calcium silicate hydrate (C-S-H) phase, with results in higher mechanical properties [3]. The texture of autoclaved UHPC showed a homogeneous, dense cement paste which consisted of close networked crystal fibers with a length up to one micrometer in the specimen cured at 200 °C and 15 bars [4]. According to literature research many authors deal with the study of hydrothermal cured high-performance concrete and its influence on mechanical parameters, microstructure and final the chemical compositional of final products. The hydrothermal curing condition positively influences especially mixtures containing puzzolanic and other special admixtures which also improve the durability characteristics, which was described in [5].

Experimental Investigation

Experimental Program. The primary goal of the proposed experimental program is to determine the effect of hydrothermal curing conditions on the mechanical properties of the special fiber-cement composite for high temperature applications. The reference set of samples was cured for 28 days in the laboratory conditions and the second set was hydrothermal cured. Investigated parameters were tensile strength in bending, compressive strength, dynamic modulus of elasticity and bulk density. All these properties were investigated after exposition of high temperature 600 °C and 1000 °C compared with dried samples at 105 °C.

Used Mixtures of Composite. For the experimental program one essential mixture was designed and subsequently supplemented by combination of two lengths of fibers. Mixture A is reference without fibers the other two Mixture B and Mixture C contain fibers (100 % of 12.7 mm length respectively 90 % of 12.7 mm and 10 % of 6.35 mm). Aluminous cement Secar®71 and basalt aggregates two fractions (0 - 4 mm and 2 - 5 mm) were used in the same amount in all mixtures. Sufficient workability was achieved by using super-plasticizer Sika1035. Water-cement ratio has a value of 0.25. The composition is shown in Table 1.

Table 1. Composition of used mixtures.

Mixture		A	B	C
		$[kg \cdot m^3]$	$[kg \cdot m^3]$	$[kg \cdot m^3]$
Secar®71		900	900	900
Basalt aggregates	0-4 mm	1080	1080	1080
Basalt aggregates	2-5 mm	220	220	220
Water		224	224	224
Plasticizer		22.75	22.75	22.75
Basalt fibers	6.35 mm	0	0	1.45
	12.7 mm	0	14.50	13.05

Hydrothermal Curing. All samples were removed from the steel form at the age of one day from the first contact of water with cement. After the measurement of basic dimensions and weight all samples were put in the autoclave, where the hydrothermal curing takes place.

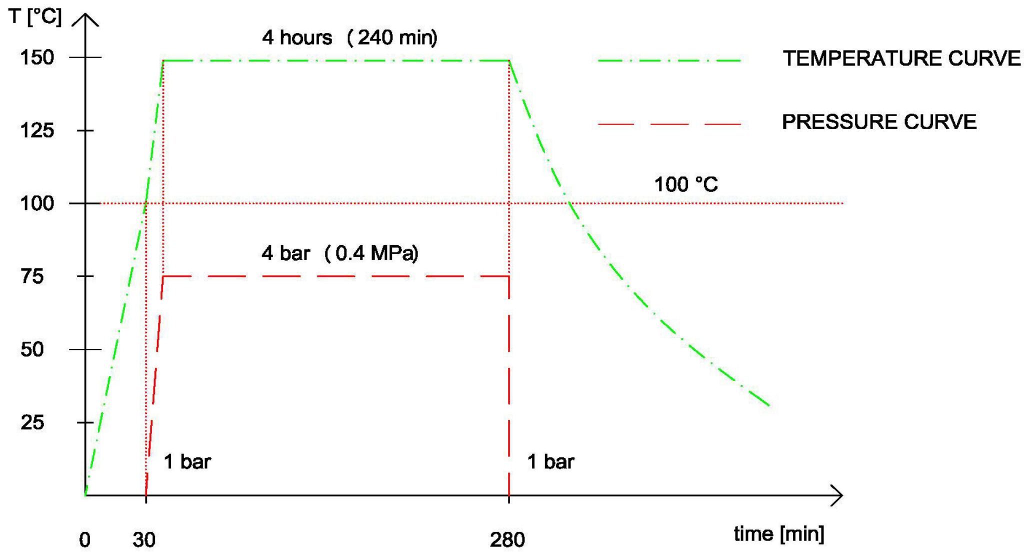

Fig. 1. Temperature and pressure curve during hydrothermal curing.

The basic prerequisites of the hydrothermal curing consist of high pressure in combination with the saturated steam. The water at the bottom of the high pressure vessel is a source of steam for the samples above its surface. After turning on the heat source water temperature begins to rise. After exceeding the value of the boiling water is necessary to close the pressure valve and the temperature with pressure begin to rise. Due to the precision pressure-release valve the chosen value of pressure in the autoclave chamber can be maintained.

The hydrothermal curing took a total four hours from the moment of desired pressure achievement, in our case 4 bar (0.4 MPa). The hydrothermal curing was stopped after four hours, by turning the heating units off and opening the pressure-release valve (Fig. 1. shows the immediate drop in pressure from 0.4 MPa to 0.1 MPa).

Investigated Parameters and Temperature Load. All parameters were investigated on specimens 40 x 40 x 160 mm. Dynamic modulus of elasticity measured by ultrasonic waves three point bending test of tensile strength were provided. Two compressive strength tests were provided on fragments after bending test. Dried specimens were divided into three groups three without temperature loading and the other two were loaded by temperature 600 °C and 1000 °C. The gradient of temperature was 10 °C per minute till the set temperature that was kept for three hours when the electric furnace was turned off and all samples naturally cooled.

Results

The following tables summarize the results of mechanical parameters (compressive strength f_c and tensile strength in bending f_t, dynamic modulus of elasticity E_{cu}) and density ρ. All parameters were investigated on reference samples and autoclave cured samples after drying (105 °C) and after exposure to 600 °C and 1000 °C.

Table 2. Results of mechanical properties.

	105 °C		600 °C		1000 °C	
	f_c [MPa]	f_t [MPa]	f_c [MPa]	f_t [MPa]	f_c [MPa]	f_t [MPa]
A_r	78.9	9.2	49.4	4.7	23.9	2.8
A_a	152.1	9.6	102.4	56	61.1	3.0
B_r	93.8	8.2	53.8	3.1	21.8	1.4
B_a	149.3	12.0	84.2	7.9	30.1	4.1
C_r	64.5	10.0	39.3	4.4	19.6	2.4
C_a	148.9	12.3	73.0	6.9	59.3	6.1

Table 3. Values of bulk density and dynamic modulus of elasticity.

	105 °C		600 °C		1000 °C	
	ρ [kg·m^3]	E_{cu} [GPa]	ρ [kg·m^3]	E_{cu} [GPa]	ρ [kg·m^3]	E_{cu} [GPa]
A_r	2400	47.7	2320	11.0	2250	6.3
A_a	2540	53.3	2345	9.2	2300	6.6
B_r	2295	28.2	2245	17.4	2200	16.2
B_a	2460	47.3	2280	8.5	2150	8.2
C_r	2280	33.1	2180	8.6	2150	5.3
C_a	2450	48.5	2190	7.3	2180	8.2

Conclusions

Using hydrothermal curing condition leads to significant increase of tensile and compressive characteristics of the refractory fiber-cement composite. The tensile strength in bending of reference samples (A_r, B_r, C_r) corresponds to only 39 % of autoclaved samples (A_a, B_a, C_a). Higher values of bulk density correspond with higher mechanical properties.

Results from non-destructive testing by ultrasonic waves (values of dynamic modulus of elasticity E_{cu}) show the successive decreasing trend of mechanical properties after the high temperature exposure. The influence of high temperature load is also noticeable in the softening part of stress-strain diagram. During the bending of dried specimens the failure has brittle characteristic, while the specimens loaded by high temperatures has clear necking part of stress-strain diagram. The provided experiments show rapid increase of compressive strength of fiber-cement composite, when the values of reference samples correspond in average to 55 % of hydrothermal cured samples. The positive effect of autoclaving is the most effective for samples loaded by temperature 600 °C and 1000 °C. Special the tensile strength in bending is positively affected; the hydrothermal curing caused better cohesion of hydration products and the surface of used basalt fibers. Experimental results clearly showed that the decrease of mechanical properties autoclave cured composite is lower than the laboratory condition cured specimens. Even the density shows higher values in the case of hydrothermal curing condition.

The energy intensity of hydrothermal treatment is compensated by the characteristics of the final product and the initial costs are offset by the results characteristics and their achievement after one day after the first contact of water with cement. Autoclave curing seems to be an appropriate way how to achieve high utility properties of fiber-cement composite for high temperature applications.

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