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Experimental Analysis of Various Temperature Loadings Influence on Cement Composite

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Abstract. This contribution deals with the experimental investigation of mechanical, fracture and basic properties of refractory cement composite after the action of various temperatures loadings. Investigated refractory cement composite on aluminous cement based with high dosage of metakaolin was reinforced by basalt fibres. The temperature loading was especially focused on temperature between 700°C and 1000°C (grading after 100°C) and between 100°C and 700°C (grading after 200°C). The bulk density, dynamic modulus of elasticity, compressive strength, flexural strength and fracture energy were investigated after the action of mentioned temperatures. The action of temperature between 300°C and 500°C means the highest decrease of mechanical properties. The percentage decrease of flexural strength and fracture energy was higher than compressive strength. The decrease of investigated properties after the action of temperature higher than 700°C was gradual and not so rapid. The residual mechanical properties after the action of 1000°C achieved sufficient values for cement composite with natural aggregate.

Introduction

The issue of general cement composites´ reaction on the effect of elevated temperature has been investigated in various research works. The gradual chemical decomposition of CSH gels characterizes composites based on ordinary Portland cement. The portlandite $Ca(OH)_2$ is decomposited to quick-lime and CO_2 at 400°C [1]. The calcium aluminate cements characterize different phase composition and also the reaction and stability for elevated temperatures environments. The decomposition of crystalline gibbsite AH_3 starts at 300°C, while the formation of $C_{12}A_7$ starts at 500°C [2]. The growing temperature means conversion to calcium aluminate (CA) and calcium di-aluminate (CA_2) [3].

Description of performed experiments

Used refractory composite. Investigated refractory composite was on hydraulic base. Aluminous cement Secar®71 produced by Lafarge company in dosage of 675 kg/m^3 was supplemented by matakaolin Mefisto L05 in dosage of 225 kg/m^3. Natural crushed basalt aggregate 0/4 mm and 2/5 mm was used in total amount of 1100 kg/m^3. Totally 280 kg/m^3 of basalt fibers (combination of two lengths - 12.7 mm and 6.35 mm) were used as reinforcement. The water to binder ration achieved 0.25 level because of using of super-plasticizer SIKA.

Tab.5 Composition of investigated refractory composite

Aluminous cement	Metakaolin	Basalt aggregate		Basalt fibres	Water	Plasticizer
Secar®71	MefistoL05	0/4 mm	2/5 mm		potable	SVC 1035
kg/m^3						
675	225	880	220	29	225 kg/m^3	22.75

Temperature treatment and loading. Steel forms with fresh mixture were covered by foil for 3 days. Unformed specimens (40 × 40 × 160 mm) were stored in humidity conditions (approx. 90% of relative humidity and 20°C) till the age of 28 days. The drying process (100°C for three days) took place at the age of 28 days. Dried specimens (reference level) were exposed to thermal loading of different levels (300°C, 500°C, 700°C, 800°C, 900°C and 1000°C) for 3 hours (the temperature rise up in gradient 10°C/minute) in automatic electric furnace. After 3 hours the source of heat was automatically turn off and the furnace cooled down till laboratory conditions.

Investigated parameters. Measurement of weight took place at the end of thermal loading cycle, approximately at 60°C (to avoid the absorption of air humidity). The height of specimens was measured at laboratory conditions before drying and temperature loading. The remaining two dimensions were given by the size of used mould. From these values the average bulk density (ρ_m) was calculated. At this time the measurement of ultrasonic speed by PunditLab+ device took place. The test arrangement of specimen, producer and receiver of ultrasonic signal was one-dimensional and direct. The dynamic modulus of elasticity (E_{cum}) was calculated according to Czech standard [4]. The three-points bending test with clear distance of supports of 100 mm was performed by universal loading machine MTS100. Bending test was controlled by increase of deformation with speed 0.2 mm/min. The average flexural strength (f_{tm}) was calculated from maximal achieved force using theory of elasticity, as recommended in Czech Standard [5]. Fracture energy (G_{fm}) was calculated according to RILEM recommendation described by eq. (1) based on data record from bending test, where a and b (mm) are dimensions of cross-section, while the integral expression means the consumed work (area under the load-deflection diagram).

$$G_f = \frac{\int_0^{\delta max} F(\delta) d\delta}{a \cdot b} \quad (1)$$

Finally the compressive test (f_{cm}) was performed on two fragments left from bending test. The loading machine EU 40 was used and the increase of deformation 0.2 mm/min controlled the test. The maximal testing area was defined by steel plate with dimensions 40 × 40 mm according to [5].

Results and discussion

All results of bellowed described parameters are summarized in Table 1. From each parameter the average calculated values are shown and the percentage influence of temperature loading influence is expressed. The comparable level (100%) corresponds to the action of 100°C (drying).

The highest decrease of bulk density takes occur between 300°C and 500°C (5.1%) and between 100°C and 300°C (3.1%). The decrease of bulk density between laboratory conditions and drying at 100°C was not the aim of interest (this decrease is connected with loss of free and part of physically bounded water). The recorded bulk density drop between 100°C and 1000°C corresponds to 89.8%.

The first thermal loading after drying (300°C) means decrease of dynamic modulus of elasticity by 32.6% of reference value. A decrease of approximately 77% characterizes the action of 700°C. It should be noted the values of dynamic modulus of elasticity depend on bulk density. This parameter is suitable for description of temperature influence trend.

The action of 300°C means only 19% decrease of compressive strength, while the highest decrease expressed by 58.1% of the original value takes occur between 300°C and 500°C. The decrease between 700°C and 900°C is expressed by approx. 10%, while the action of 1000°C characterizes decrease of 12.3% of the value of 900°C. The relatively small decrease of compressive strength after the action of 300°C is describe for ordinary concrete in [6].

The dependence of flexural strength and fracture energy on the effect of various high temperatures is similar. Unlike compressive strength, the highest decrease of flexural strength and especially fracture energy takes place after the action of 300°C. The fracture energy is expressed by 45.2%, while flexural strength means 57.7% of the original value. The increasing of temperature characterizes the gradual decrease of mentioned parameters (see Fig. 2 and Fig. 4).

Tab.6 Summarization of investigated parameters (values and percentage expression)

Parameters		100°C	300°C	500°C	700°C	800°C	900°C	1000°C
Bulk density - *(ρ_m)*	[kg/m^3]	2265	2195	2080	2065	2055	2040	2035
	[%]	*100*	*96.9*	*91.8*	*91.2*	*90.7*	*90.1*	*89.8*
Dynamic modulus of elasticity - *(E_{cum})*	[GPa]	42.7	28.8	17.6	10.0	9.6	8.4	8.5
	[%]	*100*	*67.4*	*41.2*	*23.4*	*22.5*	*19.7*	*19.9*
Flexural strength - *(f_{tm})*	[MPa]	17.5	10.1	7.4	6.9	6.0	5.5	5.0
	[%]	*100*	*57.7*	*42.3*	*39.4*	*39.3*	*31.4*	*28.6*
Compressive strength - *(f_{cm})*	[MPa]	104.5	85.1	60.7	56.6	52.5	42.6	29.8
	[%]	*100*	*81.4*	*58.1*	*51.2*	*50.2*	*40.8*	*28.5*
Fracture energy - *(G_{fm})*	[J/m^2]	644.5	291.3	257.5	203.6	182.7	197.8	153.4
	[%]	*100*	*45.2*	*40.0*	*31.6*	*28.3*	*30.7*	*23.8*

Graphs on Fig. 1, Fig. 2, Fig. 3 and Fig. 4 provide the graphical evaluation of investigated parameters and bring the information about gradual decrease of mentioned properties.

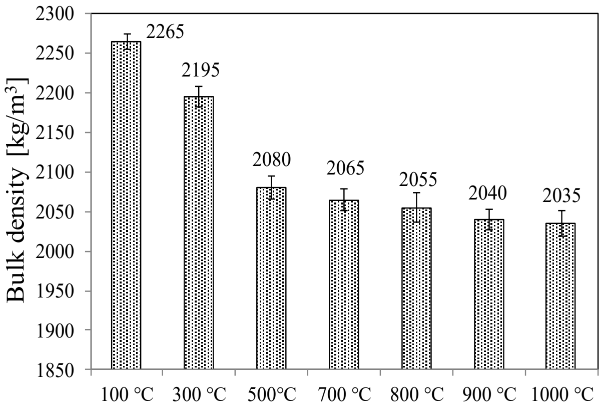


Fig.1 Evaluation of bulk density

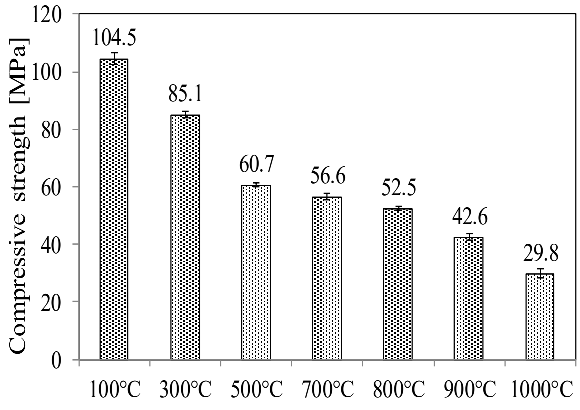
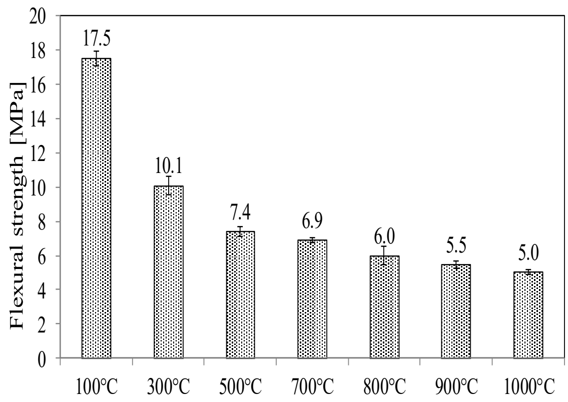


Fig.2 Evaluation of compressive strength



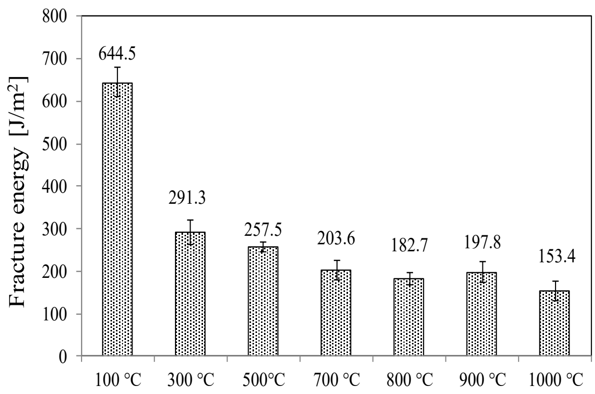


Fig.3 Evaluation of flexural strength

Fig.4 Evaluation of fracture energy

Conclusions

Described parameters were tested after the action of elevated temperature of various levels. The highest decrease of basic and mechanical parameters takes occur between 100°C and 500°C. This research was specifically focused on the temperature range between 700°C and 1000°C. The decrease of bulk density is connected with evaporation of free, physically and chemically bounded water. All investigated parameters gradually decrease. The highest decrease was observed in the case of dynamic modulus of elasticity, which caused by decrease of bulk density. For practical purposes the flexural and compressive strength mean the main parameter. Based on performed experimental program we can conclude that mentioned parameters are on sufficient level even after the action of 1000°C.

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