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Research Article

Development of Composite for Thermal Barriers Reinforced by Ceramic Fibers

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The paper introduces the development process of fiber-reinforced composite with increased resistance to elevated temperatures, which could be additionally increased by the hydrothermal curing. However, production of these composites is extremely energy intensive, and that is why the process of the design reflects environmental aspects by incorporation of waste material—fine ceramic powder applied as cement replacement. Studied composite materials consisted of the basalt aggregate, ceramic fibers applied up to 8% by volume, calcium-aluminous cement (CAC), ceramic powder up to 25% by mass (by 5%) as cement replacement, plasticizer, and water. All studied mixtures were subjected to thermal loading on three thermal levels: 105°C, 600°C, and 1000°C. Experimental assessment was performed in terms of both initial and residual material properties; flow test of fresh mixtures, bulk density, compressive strength, flexural strength, fracture energy, and dynamic modulus of elasticity were investigated to find out an optimal dosage of ceramic fibers. Resulting set of composites containing 4% of ceramic fibers with various modifications by ceramic powder was cured under specific hydrothermal condition and again subjected to elevated temperatures. One of the most valuable benefits of additional hydrothermal curing of the composites lies in the higher residual mechanical properties, what allows successful utilization of cured composite as a thermal barrier in civil engineering. Mixtures containing ceramic powder as cement substitute exhibited after hydrothermal curing increase of residual flexural strength about 35%; on the other hand, pure mixture exhibited increase up to 10% even higher absolute values.

1. Introduction

Rapid progress on the field of concrete technology and material engineering enabled the formulation of modern types of high utility cement-based composites far exceeding the properties of ordinary structural concrete. The purposes of the newly developed composites can be found in special applications characterized by certain conditions and environment. Crucial structural parts are exposed to risk of extreme temperature attack, what requires additional protection. That is why the refractory cement composite takes important role in the current civil engineering.

Historically, the most successful and widespread solution for fire protection of structures was the application of composite reinforced by asbestos fibers. Due to several research works focused on health risks of asbestos [1], use of this material has been strictly prohibited for several decades. The negative influence of asbestos describes, for example [2–4], and contains parenchymal fibrosis (asbestosis), mesothelioma, lung cancer, and so on. The inhalation of asbestos fibers causes enumerated diseases. The asbestos has been replaced by modern materials, usually used for high strength and high utility application, namely, basalt, carbon, glass, and ceramic [5].

The reason of fibers application in the cement-based refractory composites is multiple. They significantly contribute to the flexural properties, ductility, and to the increasing of volume stability during thermal exposure by the elimination of microcrack propagation. The suitable resistance to elevated temperatures of cement-based composite with fibers addition is involved by three intermediate aspects: stability of the matrix and used filler, resistance of fibers to elevated temperatures, and quality of interfacial bond between matrix and the fibers, especially in terms of

elevated temperatures to achieve transfer of stresses. Contemporary we can find the effective successor to asbestos in using ceramic, carbon, glass, or basalt fibers [6, 7]. Application of basalt fibers characterizes lower price and consequent financial savings in comparison with carbon fibers [8].

The use of polyethylene fibers in structural concrete could contribute to the increase of its safety behavior during fire exposure due to its combustibility by the surface spalling reduction. Its phenomenon is based on the decrease of internal pressure induced by the originating steam by the creation of channel systems after the fibers are burned out, which create the escape of the originating steam [9, 10]. However, the polypropylene fibers may lead to a small reduction of the compressive strength (in room temperature) [11]. This solution does not improve mechanical properties after the action of high temperatures, what essentially limits their application.

Steel fibers are used for the strengthening of thermal resistance of the structural concrete as well [12]. However, steel fibers are not suitable for the purpose of refractory composite, due to the apparent decrease of mechanical properties at approximately 600°C and subsequent recrystallization [13].

An optimal amount of fibers, suitable for cement composite production, depends on the type of composite, used aggregate, cement, admixtures, and especially material of used fibers and their surface treatment. Dosage of 1.0% by volume of basalt fibers usually suffices to eliminate the crack formation on the surface even after exposure to cyclic load at 1000°C [14]. Also the drying process could cause cracks; therefore, the fibers limit the crack propagation [15]. The previous research confirmed that optimal dosage of basalt fibers, in terms of residual mechanical and fracture properties, in fine-grained cement-based composite lies between 1.0 and 2.0% by volume [16] or 4% of ceramic fibers, respectively [17].

Fracture energy is an important factor for the description of the thermal damage of refractory materials [18]. However, the test arrangement highly influences the final results and their interpretation. The fracture energy determination under uniaxial load is considerably a more suitable test organization in comparison with biaxial loading, which is noticeable especially in the softening part [19]. Fracture characteristics of refractory composites were thoroughly studied by Miyaji et al. [20], who found out that refractory castables characterized by the highest value of fracture energy did not show the highest resistance to thermal shock damage.

The production of refractory composites is extremely energy intensive, and that is why more environmentally friendly industrial processes are under the research. Besides advanced technologies, it is often solved by the incorporating of various secondary or waste materials [21, 22]. The philosophy of utilization of waste materials in the production of building materials denotes one of the current issues of materials engineering. The previous research [23] was focused on the study of high-performance composites additionally cured under hydrothermal conditions. Interesting increase of mechanical properties was confirmed. The main goal of performed experimental program lies in the analysis of advanced refractory cement composite with hydraulic bond. The response to elevated temperatures of composites of various composition and also incorporation of waste material was studied, for to obtain those with the optimal composition. Such selected set of samples was after the repeated production additionally cured under specific hydrothermal condition to exploit full material capacity of used components.

Figure 1: Studied ceramic fibers IZOWAT 12G.

2. Materials and Methods

2.1. Ceramic Fibers. Ceramic-based materials are commonly used for the production of insulation elements, such as blankets, paper, and boards [24]. Small diameter ceramic fibers have undergone great changes since their early development, due to the need for reinforcement in structural ceramic matrix composite (CMC) materials applied at temperatures above 1000°C [25].

Ceramic fibers are commonly used in ordinary structural concrete to improve resistance to dynamic load; Su and Xu [26] described the positive influence of 0.1% and 0.2% of ceramic fibers (volume %) on resistance to dynamic and impact load.

Ceramic fibers IZOWAT 12G (Figure 1) were used for the purpose of this experimental program. Their bulk density is 200 kg·m^{-3}, with an average diameter of fibers of 6 μm and an average length of approximately 5 mm. Its chemical composition, shown in Table 1, limits the maximum temperature of use to 1260°C, which reflects the maximum content of 55% (wt. %) of SiO_2 guaranteed by the producer.

2.2. Calcium-Aluminous Cement (CAC). The hydraulic bond was produced by calcium-aluminous cement Secar 71, which is produced by Lafarge. A detailed chemical composition of CAC that was studied is shown in Table 1. The crucial parameter of this type of cements is measured by the amount of aluminium oxide, which determines the final thermal resistance. Hardened CAC undergoes several processes during its gradual thermal exposure. The impact of high temperature starts with dehydration of metastable hydration products CAH_{10} ($CaO{\cdot}Al_2O_3{\cdot}10H_2O$) and C_3AH_8 ($3CaO{\cdot}Al_2O_3{\cdot}8H_2O$). According to XRD performed by [27], these hydration products (CAH_{10} and C_3AH_8) were not detected after exposure to 200°C. However, until 150°C, the evaporation of free

Table 1: Chemical composition of studied materials.

Chemical components	Secar® 71 % of weight	FGCP % of weight	IZOWAT 12G % of weight
Al_2O_3	70.8	13.98	44.00
SiO_2	0.58	64.45	53.70
K_2O	-	2.43	0.20
CaO	27.5	8.18	0.22
TiO_2	0.37	0.77	0.60
Fe_2O_3	0.42	5.39	0.66
SrO_2	—	—	0.01
ZrO_2	—	—	0.57
MgO	0.21	—	—
Specific surface	381 $m^2 \cdot kg^{-1}$	336 $m^2 \cdot kg^{-1}$	—

Note. Aluminous cement: Secar® 71; ceramic fibers: IZOWAT 12G; FGCP: fine ground ceramic powder.

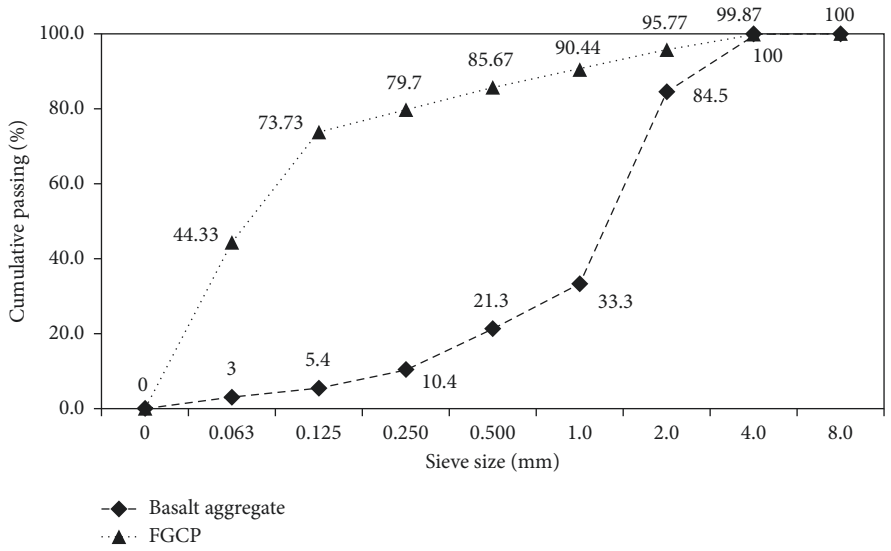

Figure 2: Gradation curve of used aggregate and FGCP.

and structural water of the AH_x gel also takes place. For temperatures between 200°C and 300°C, the remaining hydrates AH_3 and C_3AH_6 are almost completely dehydrated, but they can still be observed in the results at 400°C obtained by XRD [27]. We can say that $C_{12}A_7$ is the first observable dehydration product, which is formed from amorphous dehydrated CA at the temperature 400°C. After reaching 900°C, the CA is formed from the reaction between A (Al_2O_3) and C_2A. At a temperature of approximately 600°C, CA_2 is detected from the reaction with Al_2O_3 [28, 29]. The resultant aluminium oxide is a product from thermal decomposition of AH_3. Aluminous cement composites achieve the lowest strength in the range 800°C–900°C, due the final decomposition of CAH.

2.3. Fine Ceramic Powder. Increasing requirements for insulation properties of bricks resulted in the production of accurate brick blocks by grinding. The secondary waste material originating from this process is fine ground ceramic powder (FGCP). A portion of the volume returns to the production process, while the rest ends at the landfill. The pozzolanic properties of FGCP have been confirmed in ancient architecture, as well as various research works [30–32]. The utilization of FGCP as a filler for self-compacting concrete has been confirmed in [33], especially when the fresh state properties were improved. The addition of FGCP only slightly affects final mechanical properties (maximal dosage used in [33] was 25%). It must be noted that FGCP had already gone through exposure to elevated temperature during brick production, which could be successfully exploited in the composition formulation of refractory castables. This approach was confirmed in previous research [16, 34]. In addition, Table 1 shows the chemical composition of the studied FGCP, when the total amount of Al_2O_3 is 13.98% and SiO_2 is 64.45%. Particle size distribution of FGCP is shown in Figure 2.

2.4. Basalt Aggregate. Aggregate, or filler utilized in general, determines the temperature range of the composite application, which forms up to 80% of the volume. Natural aggregate commonly used for the refractory composites is presented by the basalt; however, for specific application, it is necessary to acknowledge its actual mineralogy and chemical composition, which determines the stability under thermal exposure [35, 36]. It has been recorded [37–39] that

Table 2: Composition of studied mixtures.

Ceramic fibers (volume %)			Basalt aggregate (kg·m^{-3})		Fine components (kg·m^{-3})		Liquids (kg·m^{-3})	
0.25% 5 kg	4.0% 80 kg	8.0% 160 kg	0/4 mm	2/5 mm	Aluminous cement	FGCP	Water	Plasticizer
I-0	II-0	III-0	880	220	900	0	224	22.75
I-5	II-5	III-5	880	220	855	45	224	22.75
I-10	II-10	III-10	880	220	810	90	224	22.75
I-15	II-15	III-15	880	220	765	135	224	22.75
I-20	II-20	III-20	880	220	720	180	224	22.75
I-25	II-25	III-25	880	220	675	225	224	22.75

basalt has a low thermal conductivity and great resistance to the action of elevated temperatures. For severe application, exceeding 1000°C, artificial aggregates such as chamotte, porcelain, and carborundum are used [40]. The composite that was investigated contains natural crushed basalt aggregate from Czech quarry, Dobkovičky. This supplier provides several combinations of grain sizes. Based on previous experiments [35, 36], the combination of two fractions, 0/4 mm and 2/5 mm, was chosen. Figure 2 provides the results of the sieve test.

2.5. Mixture Design and Composition. The fine-grained composites used in this study were designed with an increased portion of binder, which is typical for high temperature resistant composites containing additional fibers. The usual binder/filler rate is approximately 1.3/1.0 by mass. However, the cement content was decreased to 0.67/1.0 (binder/filler) to improve the economical parameters, while also respecting the selected requirements of thermal loading. Plasticizer SIKA 1035 (based on the polycarboxylate ether) was used to ensure sufficient workability of fresh mixtures, as well as reducing the water/cement ratio, which was set at 0.25. A low water/cement ratio is also important due to the hydration of CAC. Previous research did not confirm a negative impact on the subject organic compound, including its flammability [41]. Ceramic fibers were applied in doses 0.25%, 4.0%, and 8.0% by volume. Detailed composition of studied mixtures is introduced in Table 2.

Measurement of workability was in accordance with the Czech standard for mortars [42] on a flow table, which was equipped by the larger plate, because very high values of flow were expected. The value of flow is the average from two mutually perpendicular directions.

2.6. Thermal Loading. All produced specimens were stored in a wet environment until the age of 28 days, when all specimens were dried at 105°C for 72 hours to evaporate free water. After the drying process, samples were divided into three groups: one reference (dried at 105°C), and two groups for different thermal loading (600°C and 1000°C) in an automatic electric furnace. Each group consisted of three specimens from all mixtures (in total, 9 specimens from each mixture were tested). The temperature gradient in the electric furnace achieved a rate of 10°C/min, until the selected temperature was reached. The thermal loading, schematically described in Figure 3, took 240 minutes. After that, the electric furnace was cooled down naturally.

2.7. Hydrothermal Curing. Selected mixtures, which achieved optimal mechanical and residual properties resulting from the initial experimental program, were cured under hydrothermal condition. Specimens were stored for 36 hours in molds after repeated production, under wet conditions, which determines the age of hydrothermally cured mixtures. The curing process, lasting 240 minutes, was controlled by temperature; the pressure applied corresponded with the properties of saturated steam. The process of curing chosen is illustrated in Figure 4 and reflects previous experiences [23].

2.8. Mechanical Properties. Flexural and compressive strength were measured using prismatic specimens with dimensions of $40 \times 40 \times 160$ mm, in accordance with CSN EN 196-1 [43]. Flexural strength was determined using results from a three-point bending test, with a support span of 100 mm. Testing was performed using a universal loading machine MTS30, which allows test control by the deformation, with an automatic record of the test. Test speed was set to 0.2 mm/min up to crack initiation, and the test which followed was automatically controlled by crack opening, using a clip-engage extensometer fixed over the notch with the depth 15 mm. Fracture energy was calculated on the basis of the test record according to RILEM recommendations (1) [44]. The principle of fracture energy is explained in Figure 5. Deflection was measured using the couple extensometer, which eliminated pushing by supports.

$$G_f = \frac{\int_0^{\delta_{\max}} F(\delta)\, d\delta}{A}, \tag{1}$$

where cross section area $A = a \cdot (b - n) \cdot [m^2]$, G_f is the fracture energy (J·m^{-2}), a is the height of the prism (m), b is the width of the prism (m), n is the depth of the notch (m), F is the force (N), and δ is the deflection (mm).

Compressive strength was determined by using the EU 40 loading machine and measuring the fragments left after the bending test. The subjected area was demarked by a testing pressure device measuring approximately 40×40 mm. Bulk density was measured on the basis of actual dimensions and weight of the studied samples to

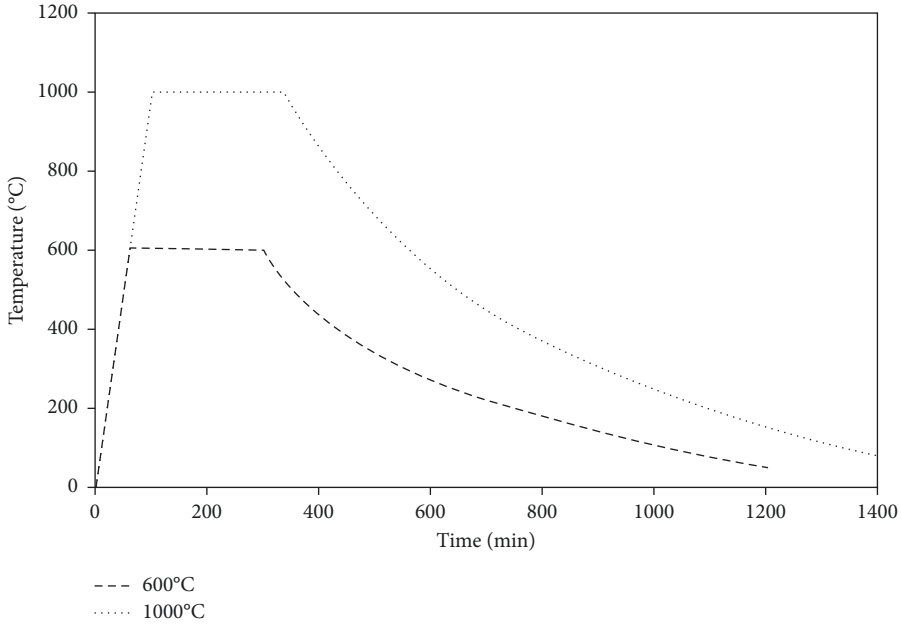

Figure 3: Illustration of used thermal loading (600°C and 1000°C).

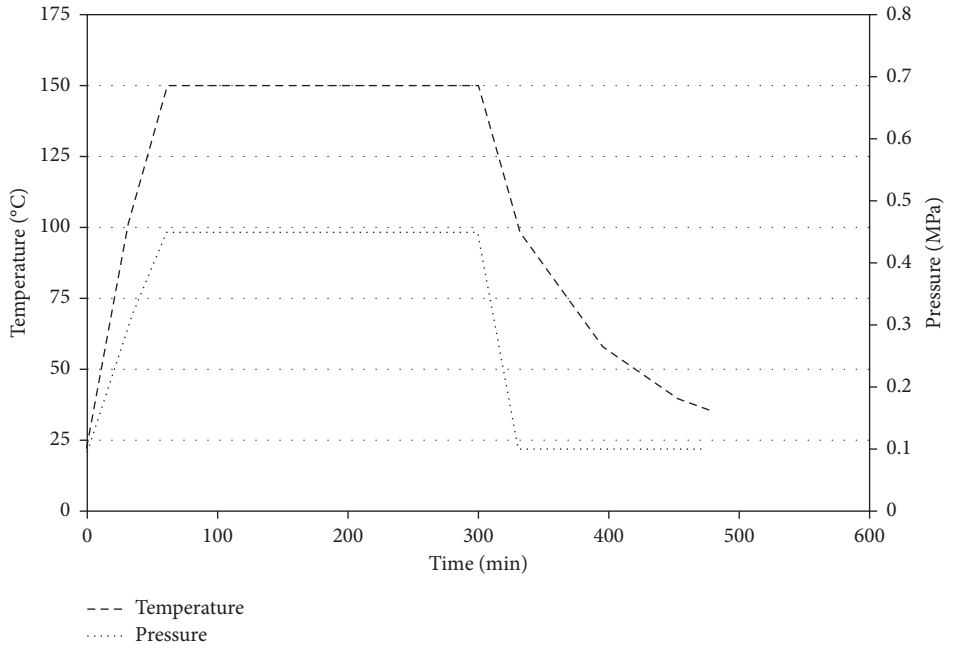

Figure 4: Illustration of applied hydrothermal curing.

predominantly monitor the impact of gradual thermal loading.

Possible damage can be described and quantified by utilizing the nondestructive ultrasonic pulse method [45, 46]. The pulse velocity of ultrasonic waves was measured by the Proceq Pundit Lab$^+$ testing device, and both the pulse transducer (54 kHz) and receiver were used. The test arrangement corresponded to the requirements of standard CSN EN 73 1371 [47], in accordance with (2). This nondestructive method is suitable for the monitoring of material transformation induced by thermal loading [48].

$$E_{\mathrm{cu}} = \rho \cdot v_L^2 \cdot \frac{1}{k^2} \cdot 10^{-3}, \tag{2}$$

where E_{cu} is the dynamic modulus of elasticity (GPa), ρ is bulk density of measured material (kg·m^{-3}), v_L is pulse velocity of ultrasonic waves (m·s^{-1}), and k is the characteristics of the environment (–) [47].

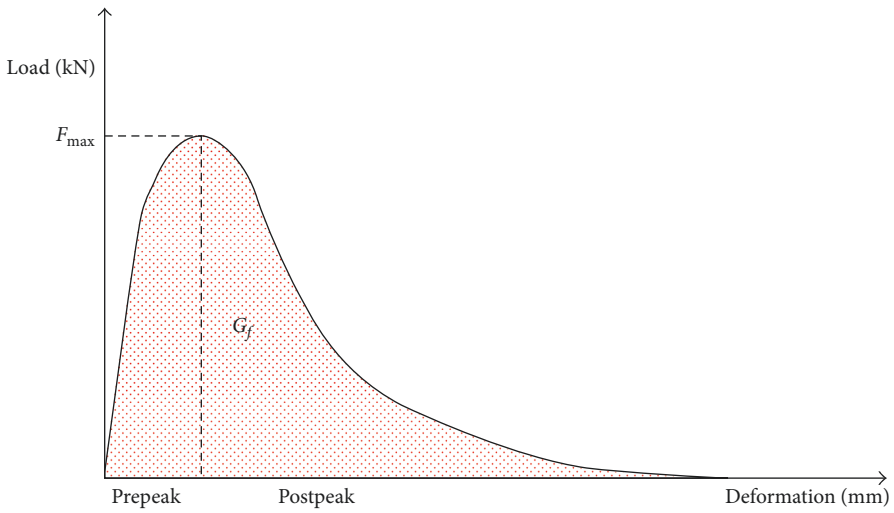

Figure 5: Principle of calculation of fracture energy.

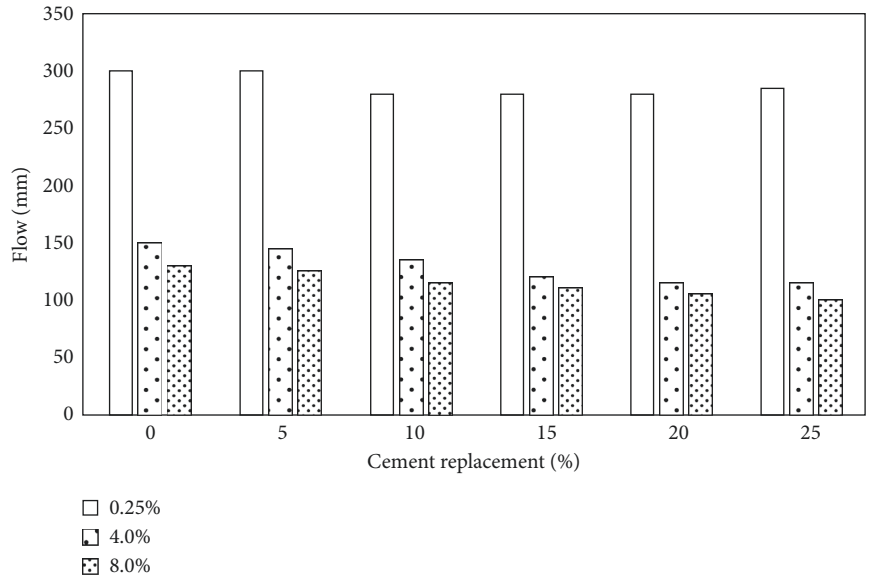

Figure 6: Workability of studied mixtures.

3. Results and Discussion

The initial part of the experimental program was performed to determine the optimal combination of ceramic fibers and cement replacement in terms of residual properties. The dependence of slump and flow on increasing amounts of FGCP can clearly be observed in mixtures with, respectively, 0.25%, 4.0%, and 8.0% of ceramic fibers. Values of flow show the decrease of workability due to increasing amounts of ceramic fibers. The evaluation of flow tests, and the dependence of workability on the total amount of fibers and FGCP, is described in Figure 6.

Detailed results are shown in Table 3. The graphical illustration of decay due to thermal loading in the selected properties is obvious in Figures 7 and 8.

3.1. Bulk Density. Exposure to thermal loading up to 600°C caused a decrease of approximately 5% in bulk density, in comparison to the dried state. An approximate 6.7% decrease in bulk density characterized the effect of temperature loading up to a level of 1000°C. The highest decrease of bulk density took place between drying and 600°C. It is caused by the evaporation of both physically bound and chemically bound water. The total dosage of ceramic fibers and FGCP had significant influence on the values of bulk density. The difference between 0.25% of ceramic fibers and 8.0% of ceramic fibers was quantifiable as 2.7% (the bulk decrease with increasing amount of ceramic fibers). The effect of FGCP dosages in the mixture of refractory composite resulted in an average decrease of 4.6% (increasing amounts of FGCP caused decreases in bulk density).

3.2. Flexural Strength. The highest decrease of flexural strength takes place after exposure to temperatures of 600°C

Table 3: Detailed results of bulk density, flexural strength, and compressive strength.

Mixture	105°C			600°C			1000°C		
	ρ (kg·m^{-3})	f_{tm} (MPa)	f_{cm} (MPa)	ρ (kg·m^{-3})	f_{tm} (MPa)	f_{cm} (MPa)	ρ (kg·m^{-3})	f_{tm} (MPa)	f_{cm} (MPa)
I-0	2300	8.2	59.8	2260	5.0	55.2	2190	4.4	19.9
I-5	2375	10.8	68.3	2250	4.8	47.1	2180	3.3	27.0
I-10	2340	9.0	66.8	2240	3.4	47.0	2200	2.5	23.6
I-15	2320	8.6	63.5	2210	3.4	42.5	2150	2.5	21.9
I-20	2310	8.0	54.5	2200	4.5	41.0	2160	2.4	30.3
I-25	2290	7.3	64.2	2180	4.0	36.7	2110	2.3	28.8
II-0	2350	8.2	78.1	2220	3.1	57.3	2215	2.0	20.9
II-5	2350	9.6	73.8	2220	5.0	58.4	2195	2.3	22.3
II-10	2300	9.1	63.4	2195	4.0	54.6	2170	2.8	24.2
II-15	2280	10.0	58.6	2170	4.8	44.0	2090	2.7	27.9
II-20	2260	8.2	56.0	2105	4.4	39.8	2070	4.0	32.8
II-25	2235	6.6	55.3	2135	4.4	48.4	2120	3.9	32.8
III-0	2310	8.5	47.5	2240	3.7	30.6	2170	2.1	27.9
III-5	2220	9.7	64.4	2100	4.2	42.4	2090	2.4	22.5
III-10	2200	8.5	64.7	2120	4.2	39.7	2060	2.2	20.6
III-15	2195	8.4	59.0	2090	3.7	40.2	2075	2.8	25.1
III-20	2180	8.9	60.2	2040	4.8	41.3	2040	3.1	25.7
III-25	2180	10.4	60.7	2050	4.7	42.1	2030	3.3	28.2

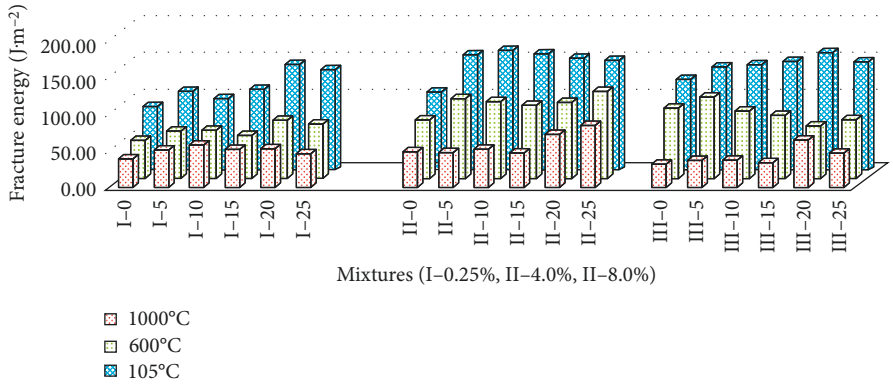

Figure 7: Fracture energy of studied mixtures.

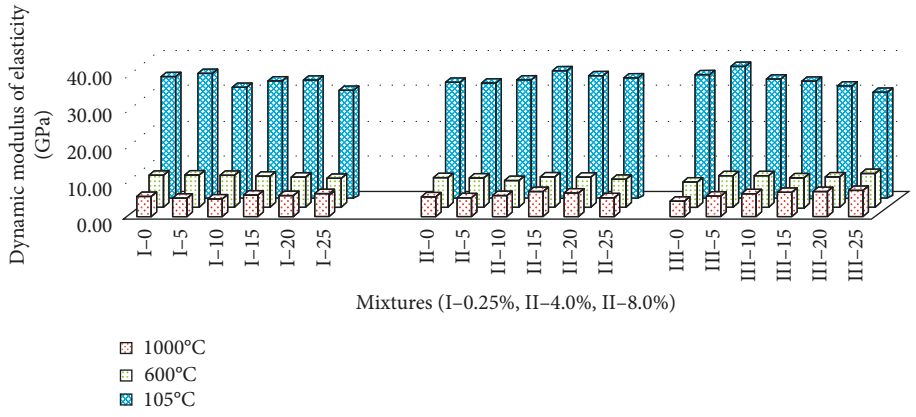

Figure 8: Dynamic modulus of elasticity of studied mixtures.

and above, resulting in an approximate level of 48%, which represents a 52% decrease. This phenomenon was not surprising, based on general knowledge available from several literature sources (e.g., [49]). The temperature of 400°C, usually mentioned as the limit, is the point at which the hydraulic bond begins to decompose. The results obtained at 600°C demonstrate an average decrease to 49% of the original values (48.9% for 0.25% of fibers, 50.3% for 4.0%

Table 4: Basic and mechanical properties of hydrothermally cured specimens.

	105°C				600°C				1000°C			
	ρ (kg·m^{-3})	f_{cm} (MPa)	f_{tm} (MPa)	G_f (J·m^{-2})	ρ (kg·m^{-3})	f_{cm} (MPa)	f_{tm} (MPa)	G_f (J·m^{-2})	ρ (kg·m^{-3})	f_{cm} (MPa)	f_{tm} (MPa)	G_f (J·m^{-2})
II-0HC	2400	91.3	20.4	294.5	2170	72.4	6.1	146.3	2130	53.0	4.6	137.4
II-5HC	2390	53.7	17.5	205.4	2145	46.5	4.1	178.8	2130	39.7	3.2	123.1
II-10HC	2380	64.9	16.8	184.6	2135	58.5	6.0	157.9	2110	42.6	3.9	143.6
II-15HC	2310	59.5	14.2	131.3	2105	40.8	5.0	160.6	2085	34.6	3.3	96.0
II-20HC	2305	46.8	15.9	142.3	2090	37.9	5.3	139.3	2085	26.0	4.4	118.2
II-25HC	2350	44.7	14.0	116.2	2155	35.6	5.7	116.6	2110	27.2	4.1	125.6

of fibers, and 47.0% for 8.0% of fibers). The results shown at 1000°C demonstrate an average decrease to 30.3% of the original values (33.9% for 0.25% of fibers, 35.7% for 4.0% of fibers, and 21.2% for 8.0% of fibers). The average values of flexural strength in the reference specimens are approximately on the same level and are not dependent on the total amount of fibers (from 8.6 MPa to 9.1 MPa).

3.3. Compressive Strength. Thermal loading did not affect the residual values of compressive strength to the same degree as was shown in tests of flexural strength. However, a small increase in residual values, with increasing replacement by FGCP, could be observed. A set of mixtures containing 4% of ceramic fibers by volume could be observed on the basis of compressive strength as optimal, which corresponds with the previous research [17].

3.4. Dynamic Modulus of Elasticity. The values of dynamic modulus of elasticity obtained are closely related to the values of bulk density. The highest decrease was observed after exposure to thermal loading at 600°C, while the influence of 1000°C does not have a significant effect on dynamic modulus. However, appearance of microcracks significantly worsened signal transmission during the measurement process.

3.5. Fracture Energy. The values of fracture energy are summarized in Table 3. The fracture energy corresponded with the amount of ceramic fibers that were used, and it also follows the trend of FGCP dosage. Generally, it can be concluded that this property increased with rising amounts of FGCP, especially in the reference specimens, which were not thermally loaded. The addition of elevated temperatures led to decreasing values of fracture energy. The maximal tested dosage of ceramic fibers (8.0%) caused the lowest values of fracture energy after exposure to a temperature of 1000°C.

The primary objective main of the initial experimental program was to obtain the most suitable material combination, which could be then be further improved in terms of residual properties using hydrothermal curing. The set of samples containing 4% of ceramic was selected as the optimal option with respect to utilization of ceramic fiber capacity. The mixtures with various levels of cement replacement by FGCP were subjected to additional testing.

3.6. Evaluation of Hydrothermal Curing. Additional hydrothermal curing produced the expected increases in almost all the parameters that were evaluated. The values of bulk density, compressive strength, flexural strength, and fracture energy of specimens cured in an autoclave device are introduced in Table 4. The higher values of bulk density after drying characterize autoclaved composites, while the bulk density slightly decreased after exposure, in comparison with specimens cured in the laboratory. The most significant benefit of hydrothermal curing was evident in the values of flexural strength. In some cases, this mechanical parameter achieved values that were twice as high as the values in reference specimens that were compared. Even after exposure to a temperature of 1000°C, the flexural strength of the autoclaved specimens achieved higher values in comparison to the reference specimens. This phenomenon corresponded to different hydration products, with improved cohesion to the surface of the fibers. The opposite phenomenon occurs in the case of compressive strength. In some situations, especially in mixtures with a higher dosage of FGCP, the values for specimens cured in an autoclave were lower than those cured in the laboratory. The fracture energy followed the trend of flexural strength. An increase of fracture energy values of hydrothermally cured specimens was observed.

4. Conclusion

Experimental development of fiber-reinforced composite suitable for the production of thermal barriers was documented by this paper. Energy consumption related to its production was partially reduced by incorporation of FGCP, which was applied as CAC replacement. An optimal composition, especially regarding dosage of ceramic fibers and CAC replacement, was determined. Suitable workability levels were also obtained, relative to both residual mechanical and physical properties. The experimental program confirmed that 4% by volume is the optimal material solution. Based on the results obtained from the experimental program performed, the following conclusions can be presented:

(1) The positive influence of hydrothermal curing was confirmed for the purpose of refractory cement composites reinforced by ceramic fibers. Flexural strength, both before and after being subjected to elevated temperatures, achieved an especially excellent level.

(2) Neither visual marks nor damage were observed following macroscopic observation of specimens after thermal loading. The applicability of the subject composite for environments with elevated temperatures was also confirmed.

(3) The dosage of ceramic fibers, along with the total amount of FGCP, significantly affected the workability of the fresh mixture. The mixture with 0.25% of fibers achieved the characteristics of self-flow; however, the fibers did not contribute to fracture properties. The combination 4.0% of fibers and 15% of FGCP resulted in the optimal combination in terms of workability. The maximum dosage of fibers studied, 8.0%, resulted in a mixture that had to be intensively compacted during casting.

(4) In terms of mechanical, especially residual, properties, the combination of 4.0% and 15% of FGCP resulted in optimal values.

(5) In the context of the environmental impact of cement-based composites, the utilization of waste material (FGCP) as an integral part of both composite and partial cement replacement had a positive effect on total cement consumption and the resulting production of CO_2.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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