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The effect of curing temperature on the properties of different types of refractory concrete

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Abstract

At different curing temperatures, in alumina cement-based concrete, various crystalline hydrates are formed such as CAH_{10}, C_2AH_8, C_3AH_6, AH_3. While developing or modifying compositions of refractory concrete, it is necessary to take into consideration the impact of curing temperature on the process of formation of the structure and operating characteristics of concrete. This study investigates the properties of the following refractory concretes: the conventional concrete, the concrete modified by microsilica additive and the medium-cement concrete based on chamotte filler with alumina cement, of the grade Gorkal 70, at the curing temperatures of 10 ºC, 20 ºC and 30 ºC. Using the ultrasonic method of investigation, the differences were revealed in formation of the structure of concrete at its hardening in the course of 48 hours. It was established that the differences formed in the structure at hardening of concrete exert influence on properties of concrete after its firing at temperatures of 1100 ºC and 1200 ºC.
Keywords: Refractory concrete, Alumina cement, Hydration, Curing temperature, Properties of concrete.

WPŁYW TEMPERATURY DOJRZEWANIA NA WŁAŚCIWOŚCI RÓŻNYCH TYPÓW BETONU OGNIOTRWAŁEGO

W różnych temperaturach dojrzewania w betonie opartym na cemencie glinowym tworzą się różne krystaliczne wodziany, takie jak CAH_{10}, C_2AH_8, C_3AH_6, AH_3. Podczas opracowywania i modyfikowania składów betonu ogniotrwałego konieczne jest wzięcie pod uwagę wpływu temperatury dojrzewania na proces formowania struktury i charakterystyk pracy betonu. W niniejszej pracy zbadano właściwości następujących betonów ogniotrwałych: beton tradycyjny, beton modyfikowany dodatkiem mikrokrzemionki i średniocementowy beton oparty na wypełniaczu szamotowym z cementem glinowym w gatunku Gorkal 70, przy temperaturach dojrzewania wynoszących 10 ºC, 20 ºC i 30 ºC. Wykorzystując metodę ultradźwiękową w badaniach, ujawniono różnice w tworzeniu się struktury betonu podczas jego dojrzewania w ciągu 48 h. Ustalono, że różnice powstałe w strukturze podczas dojrzewania betonu wywierają wpływ na właściwości betonu po jego wypaleniu w temperaturach 1100 ºC i 1200 ºC.
Słowa kluczowe: beton ogniotrwały, cement glinowy, hydratacja, temperatura dojrzewania, właściwości betonu

1. Introduction

The temperature, at which the alumina cement-based concrete should be cured, is regulated by manufacturers' technical documents of refractory concretes. Thus, according to the standard UOP [1], such a temperature should not be below +10 ºC and above +35ºC. The type of hydration products formed in hardening concrete depends considerably on the curing temperature. According to [2], the main products of hydration of calcium-alumina cement are crystalline hydrate CAH_{10}, which forms at the temperature < 21°C, crystalline hydrate C_2AH_8 and amorphous AH_3 (21–35 ºC), crystalline hydrates C_3AH_6 and AH_3 (> 35 °C). CAH_{10} and C_2AH_8 are metastable and, subjected to various conditions (temperature, W/C ratio, etc.) can change into C_3AH_6 and AH_3. Naturally, the concreting in winter conditions mostly results in formation of hydrates CAH_{10}, while in summer - C_2AH_8 and C_3AH_6.

In deflocculated concretes (MCC, LCC, ULCC), the ultra-dispersed additives influence the process of hydration significantly. In the presence of microsilica, besides the above-mentioned products of hydration, the phase CASH is forming [3].

The quantitative and qualitative composition of hydration products is also slightly influenced by heat of hydration and, therefore, during the process of hydration the temperature of concrete increases for a certain period of time.

Subject to composition of hydration products, the properties of fresh concrete may differ. It is underlined in [4-6] that the mechanical strength of concrete (or of cementitious stone or mortar) cured at low temperatures is higher versus concrete cured at higher temperatures. This can be explained by increased porosity of material at conversion of hydrates $CAH_{10} \rightarrow C_2AH_8 \rightarrow C_3AH_6$ [4].

According to the production technique for monolithic refractories, after hardening of concrete, it is necessary to conduct the procedure of drying and first burning. The high pace of heating can cause the mechanical destruction of refractory what is most likely for concrete cured at low temperatures (< 21 ºC) [7]. The process of dehydration ends at temperature of heating of approximately 550 ºC. Hydrates, which formed at low temperatures and which contain much water, are destroyed within interval of temperatures from 100 ºC to 200 ºC [4]. To make the removal of water vapour safe, the long-duration procedures of drying have been developed considering peculiarities of dehydration process meant for specific concrete. Obviously, the operating characteristics of produced concrete will depend on quality of drying procedure.

The purpose of this study is to determine the impact of recommended interval of curing temperatures on properties of the following concretes: the conventional concrete, the microsilica-modified concrete and the medium-cement concrete not only after hardening, but also after firing.

2. Methods and experiment

For investigations, the following materials were used, i.e. cement Gorkal-70 (content of Al_2O_3 not less than 70%) and chamotte filler of grade BOS-145 (Al_2O_3 not less than 38%), both of Polish manufacture; microsilica of grade RW-Füller of the firm RW SILICIUM GmbH (SiO_2 - 96.1%), calcined alumina of grade CTC-20 of the firm ALMATIS (Al_2O_3 – 99.7%), deflocculant – polycarboxylated ether CASTAMENT FS 20 made by the firm BASF (all manufactured in Germany).

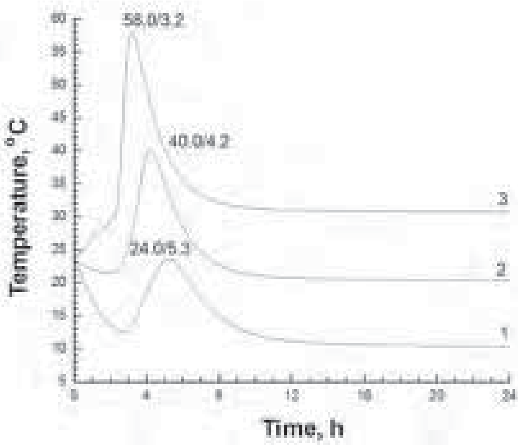
The refractory concretes of three types were subjected to investigation (Table 1), i.e. conventional concrete (CC), modified concrete (MC) and medium-cement concrete (MCC).

Table 1. Compositions of concrete in %.

Components	Type of concrete		
	CC	MC	MCC
Chamotte filler	75	72	78
Alumina cement	25	25	12
Microsilica	-	3	5
Calcined alumina	-	-	5
Polycarboxylated ether	-	0.1	0.15
Water	14	11	11

The temperature of preparation of samples and the temperature of components at their mixing was as high as 20±1 °C. After preparation, samples of individual series were placed into the climatic chamber 3401 RUMED (Ruberth Apparate GmbH, range from -30 °C to 80 °C) and cured for 3 days at temperatures of 10±1 °C, 20±1 °C and 30±1 °C. During the curing of concrete in the chamber, the temperature of exothermal effect and rate of ultrasound propagation in samples of concrete were measured. For measurement of temperature of exothermal effect in hardening concrete, the method developed by the firm ALCOA was applied. Changes in structure of hardening concrete were observed from ultrasound propagation rate measured by the special equipment (Schleibinger Geräte GmbH [8]), which enabled to fix changes in ultrasound propagation rate occurring in concrete mix immediately after mixing with water.

The parameters of firing (at 1100 °C and 1200 ºC) of samples of concrete sized 70 mm × 70 mm × 70 mm and 40 mm × 40 mm × 160 mm), as well as the main physical-mechanical properties were established according to the requirements of LST/EN1402.



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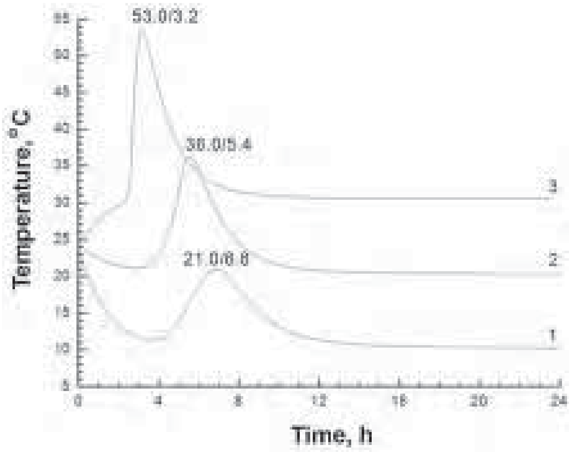

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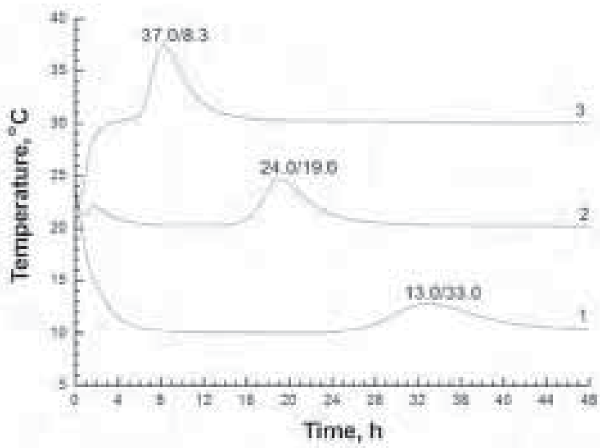

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Fig. 1. Temperature of exothermal reaction in concrete mixes: a) CC, b) MC, c) MCC; 1,2,3 – curing temperature of 10 ºC, 20 ºC and 30 ºC, respectively; ciphers above the curves are temperature/time.

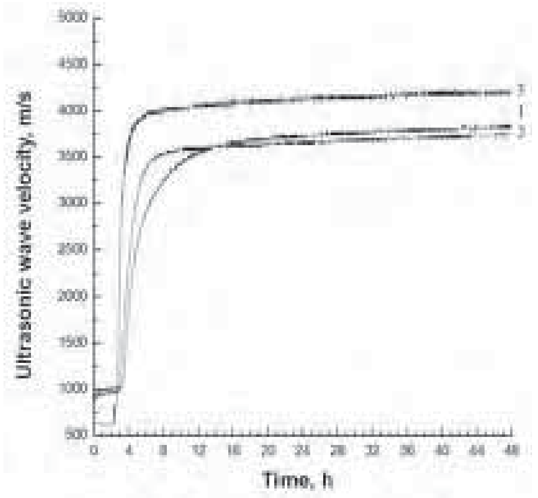
3. Results and their discussion

The impact of curing temperature on the process of hydration of a concrete mix was assessed by determining time and temperature of a maximum of exothermal reaction. This revealed (Fig. 1) that regardless of the type of concrete, along with increase in the curing temperature, the time of for appearance of the maximum of exothermal reaction decreases, i.e. for CC, from 5.3 h to 3.2 h, for MC from 6.8 h to 3.2 h, for MCC from 33 h to 8.3 h (Fig. 1). It should be noted that for concretes of higher cement content (CC, MC), the maximal temperature of exothermal reaction exceeded by 1.8-2.4 times the curing temperature, and in MCC by 1.2-1.3 times only.

The obtained results mean that, due to high heat of hydration, which evolutes in concretes of high cement content, the products of hydration possibly have a tendency to form more stable hydrate phases. In concrete of low cement content, the low curing temperature considerably retards the process of hydration (the maximum to be observed after 33 h only), while a slight increase in maximum of exothermal reaction versus respective curing temperature influences to a lesser degree metastable hydrate phases, the composition of which depends significantly on curing temperature.

By the ultrasonic method of investigations, the differences were revealed in formation of the structure of concrete at its hardening for 48 hours (Fig. 2).

It was established that the impact of curing temperature on the process of concrete consolidation, subject to type of concrete, differs considerably. For concrete of high cement content (Figs. 2a and 2b), along with decrease in temperature, a slight retardation in consolidation of the structure is observable and lower values of the maximal rate of ultrasound propagation are fixed in samples of concrete (approximately 3800 m/s) versus samples cured at higher temperature (> 4200 m/s). For medium-cement concrete such retardation along with a decrease in temperature is



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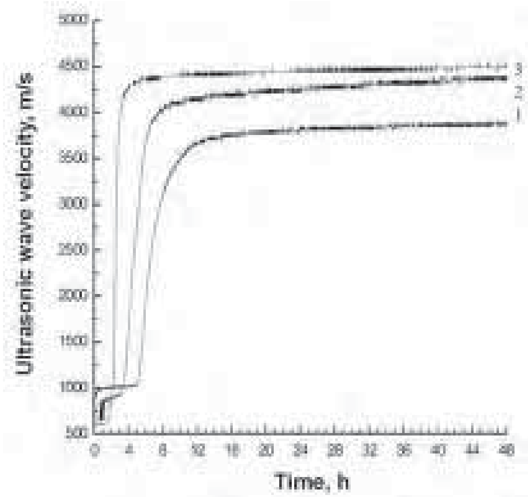

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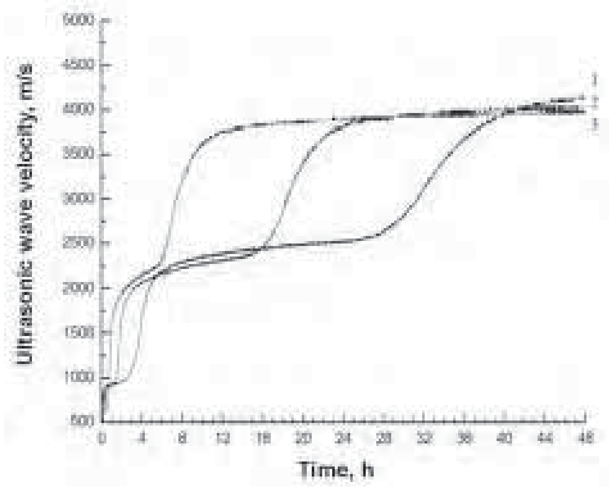

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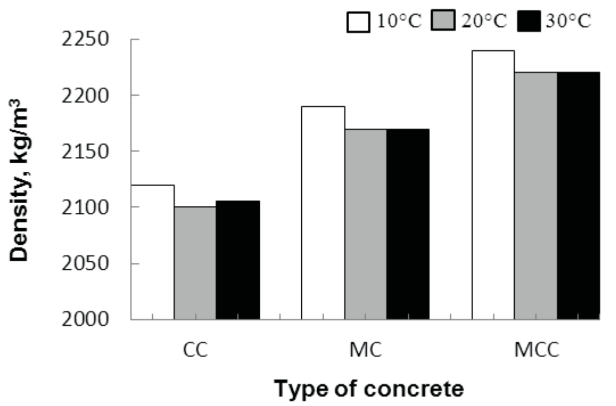
Fig. 2. Change in rate of ultrasound propagation at hardening of concrete: a) CC, b) MC, c) MCC; 1,2,3 – curing temperature of 10 ºC, 20 ºC and 30 ºC, respectively.



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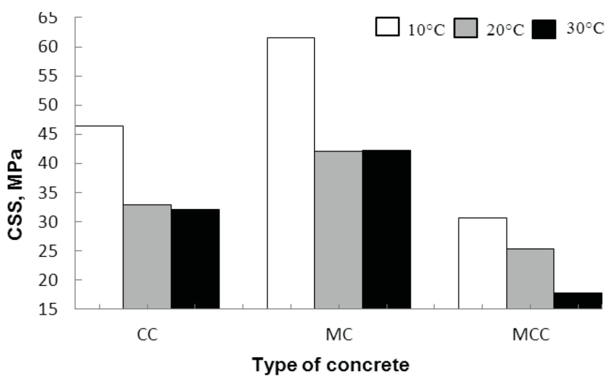

b)

Fig. 3. Properties of concrete after 3-day hardening: a) density, b) cold compressive strength.

significant (from 12 h to 32 h, Fig. 2c), though the maximal rate of ultrasound propagation in samples of such concrete after 48 hours, regardless of curing temperature, becomes practically the same (approximately 4000 m/s).

The differences in formation of the structure of concrete established by ultrasonic investigation, as well as dynamics of exothermal reaction show that, subject to composition of concrete, the curing temperature can influence differently the process of hydration.

The analysis of data on density and strength of concrete after 3-day hardening (Fig. 3) showed that at the curing temperature of 10 ºC, concretes of all types are denser and stronger versus those cured at higher temperatures. It should be noted that the strength of concretes under investigation cured at the temperature of 30 ºC decreased by (32–42)% (Fig. 3b).

After determination of differences in the properties of hardened concrete, it is of importance to assess how much such differences influence the properties of concrete after its firing. For concretes under investigation, the following temperatures of firing were selected: 1100 ºC and 1200 ºC.

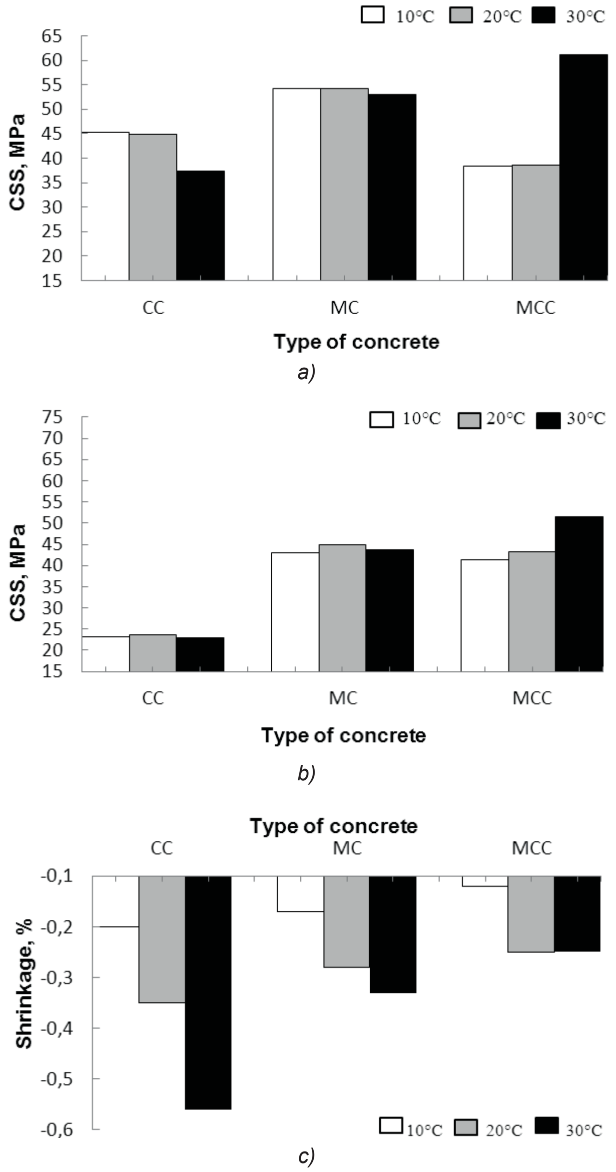

Fig. 4. Properties of concrete after firing: a) cold compressive strength after 1100 ºC, b) cold compressive strength after 1200 ºC, c) shrinkage after 1200 ºC.

The difference in compressive strength of concretes with high cement content (CC and MC), subject to curing temperature (Fig. 4), makes (2–21)% after firing at the temperature of 1100 ºC, and only (1–4)% after firing at 1200 ºC. Nevertheless, one should note higher (by (24-60)%) values of compressive strength of fired samples of MCC cured at the temperature of 30 ºC (Fig. 4).

The maximal impact of curing temperature, as well as structure formed in this connection may be observed upon analysis of shrinking deformations of fired concrete (Fig. 4c). It was established that the higher curing temperature was used for hardening of concrete, the higher was the shrinkage of concrete after firing at 1200 ºC, i.e for concretes with high cement content cured at the temperature of 30 ºC it reached (0.35–0.55)%, for MCC 0.25%.

The obtained results show that the curing temperature of concrete exerts influence not only on the process of hydration and properties of hardened concrete, but also on the properties of concrete after its firing.

4. Conclusions

There were investigated properties of the following refractory concretes: the conventional concrete, the concrete modified by additive of microsilica and the MCC based on chamotte filler with alumina cement of grade Gorkal 70 at curing temperatures of 10 ºC, 20 ºC and 30 ºC.

By ultrasonic testing and investigation of exothermal temperature, it was established that the process of hydration and the consolidation of concrete with high cement content, along with decrease in curing temperature, slows down by 1–3 hours. In MCC concrete a considerable retardation of hydration is observable (more than by 10 hours).

It was established that after 3-day curing at the temperature of 10 ºC, the investigated concretes of all types were denser and stronger than those cured at higher temperatures. The cold compressive strength of investigated concretes cured at the temperature of 30 ^{o}C decreased by (32–42)%.

The investigations showed that the curing temperature has an impact on properties of concrete after its firing. The higher curing temperature was used at hardening of investigated concretes, the greater was the shrinkage of concrete after firing at 1200 ºC. The difference in cold compressive strength after firing at 1200 ºC in concretes of high cement content, subject to curing temperature, is insignificant. However, the cold compressive strength of fired samples of MCC preliminarily cured at the temperature of 30 ºC is higher by ~20% versus samples cured at lower temperatures.

Acknowledgements

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