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TESTING MECHANICAL PROPERTIES OF THE PHOSPHATE-BONDED REFRACTORY MATERIALS BASED ON CHAMOTTE

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ABSTRACT
Samples of the phosphate-bonded refractory materials were prepared and investigated. Raw materials for preparation of the samples were: chamotte, kaoline and monoaluminium phosphate. In this investigation, chamotte was used as refractory filler, kaoline was used as plasticizer, and monoaluminium phosphate was used as binder. The following mechanical properties were investigated: subsequent shrinkage and subsequent expansion, compressive strength and bulk density. Before testing, it was necessary to carry out synthesis of the phosphate binder and the samples preparation, as well as the heat treatment of the prepared samples. The obtained results indicate that the investigated properties change depending on temperature.
Keywords: Refractory material, Phosphate binder, Chamotte

1. INTRODUCTION
Phosphate-bonded refractory materials based on chamotte actually belong to the group of refractory concrete. Refractory concretes are thermally untreated compositional materials whose refractoriness is above 1850°C. These materials harden at normal or increased temperature, and have a limited shrinkage property at the temperature of application. The main difference between refractory concretes and ordinary refractory materials is that the use of special bonding material in refractory concrete forms the strong bond within the structure of refractory concretes under normal conditions or at higher temperatures and the bond is not destroyed at exploitation temperatures. Refractory concrets consist of refractory filler, binder and pores. Materials used as refractory filler have to be resistant to high temperature conditions, and in principle, it can be any refractory material that does not have the property of shrinkage. There are two basic conditions for selecting a type of binder material: volume stability of refractory concrete and strength for all temperature ranges from normal temperature to exploitation temperature. Volume stability is the basic requirement for refractory concrete, and the change of volume during the exploitation should not exceed 3%. Shrinkage is the most dangerous property of refractory concrete and it can lead to destruction of refractory lining. The most widely used binder for refractory concretes are phosphate binders, more precisely phosphoric acid and its salts. In comparison with shaped refractory materials, refractory concretes have great advantages. Refractory concretes offer great possibilities of their application and installation in various high temperature devices. In order to provide the adequate strength at different temperature conditions, it is necessary to elaborate the technology of refractory concrete that will provide the desired properties.

2. MATERIALS AND METHODS
The aim of the experimental part is testing mechanical properties of phosphate-bonded refractory materials based on chamotte. The following mechanical properties are investigated: subsequent shrinkage and subsequent expansion, compressive strength and density. Before testing, it is necessary to carry out synthesis of the phosphate binder and the sample preparation, as well as the heat treatment at different temperatures of the prepared samples.

2.1. Synthesis of the phosphate binder

It is necessary to prepare the phosphate binder, more precisely: 50% monoaluminium phosphate (MAP), with chemical formula $Al(H_2PO_4)_3$, whose density is 1,525 $g \cdot cm^{-3}$. Monoaluminium phosphate is obtained by dissolving aluminium hydroxide, $Al(OH)_3$, in phosphoric acid, H_3PO_4, heating the mixture at temperature of about 100°C, according to the following reaction:

$$Al(OH)_3 + 3H_3PO_4 \longrightarrow Al(H_2PO_4)_3 + 3H_2O \quad (1)$$

2.2. Preparation of the samples

It is necessary to prepare the samples of refractory concretes. Raw materials for preparation of the samples are: chamotte, kaoline and previously prepared binder - monoaluminium phosphate. In this experiment, chamotte is used as refractory filler, kaoline is used as a plasticizer, and monoaluminium phosphate is used as a binder.

2.2.1. Preparation of the raw mixture

Two different kinds of raw mixtures are prepared:

I raw mixture: 90% chamotte, 10% kaoline and 12% monoaluminium phosphate (MAP)

II raw mixture: 80% chamotte, 20% kaoline and 12% monoaluminium phosphate (MAP)

2.2.2. Shaping the samples

The samples are shaped in a form of cylinders, the height, h ≈ 50 mm; diameter, ϕ≈50 mm and weight, m≈180 g. It is necessary to make eight samples from each raw mixture.

2.3. Heat treatment of the samples

After three days, samples are subjected to the heat treatment at four different temperatures: 120°C, 400°C, 800°C and 1200°C.

2.4. Testing mechanical properties of the investigated samples

The following mechanical properties of the prepared samples are investigated: subsequent shrinkage and subsequent expansion, compressive strength and density.

3. RESULTS AND DISCUSSION

Subsequent shrinkage and subsequent expansion of the investigated samples are presented in Table 1 and Figures 1 and 2. It can be observed that both kinds of the investigated samples show similar results. Samples subjected to the heat treatment at the temperatures of 120°C and 400°C show subsequent shrinkage. Samples that were heat treated at the temperature of 800°C show subsequent expansion, while samples subjected to the heat treatment at the temperature of 1200°C show subsequent shrinkage.

Table 1. Dimensions of the investigated samples before and after heat treatment

Sample	Dimensions before heat treatment				Dimensions after heat treatment					Δ		
	$Φ_1$ (mm)	h_1 (mm)	m_1 (g)	V_1 (cm^3)	$Φ_2$ (mm)	h_2 (mm)	m_2 (g)	V_2 (cm^3)	A (mm^2)	ΔΦ (mm)	Δh (mm)	ΔV (cm^3)
12 % MAP, temperature 120 °C												
CK10	50,50	47,40	176,91	94,89	50,30	47,20	168,47	93,74	1986,12	0,20	0,20	1,15
CK20	50,10	47,20	177,68	93,00	50,10	47,10	169,68	92,80	1970,36	0,00	0,10	0,20
12 % MAP, temperature 400 oC												
CK10	50,20	47,50	177,17	93,97	50,10	47,50	167,04	93,59	1970,36	0,10	0,00	0,37
CK20	50,00	47,40	178,20	93,02	50,10	47,30	167,14	93,20	1970,36	-0,10	0,10	-0,18
12 % MAP, temperature 800 oC												
CK10	50,50	49,50	177,36	99,10	50,50	49,60	160,01	99,30	2001,95	0,00	-0,10	-0,20
CK20	50,30	49,80	177,26	98,91	50,30	50,10	158,49	99,50	1986,12	0,00	-0,30	-0,60
12 % MAP, temperature 1200 oC												
CK10	50,10	48,50	172,22	95,56	49,10	47,50	154,95	89,89	1892,49	1,00	1,00	5,67
CK20	50,30	50,70	178,39	100,70	48,90	49,20	159,08	92,35	1877,10	1,40	1,50	8,34

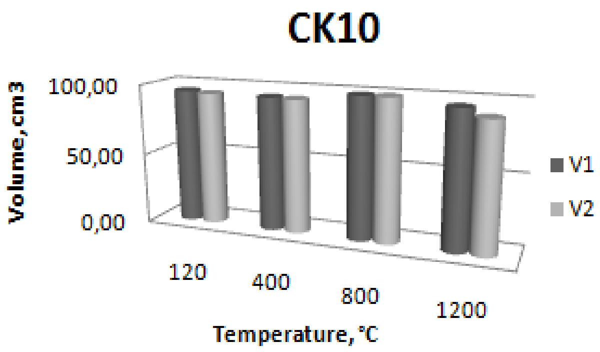

Figure 1. Subsequent shrinkage and subsequent expansion of the samples CK10

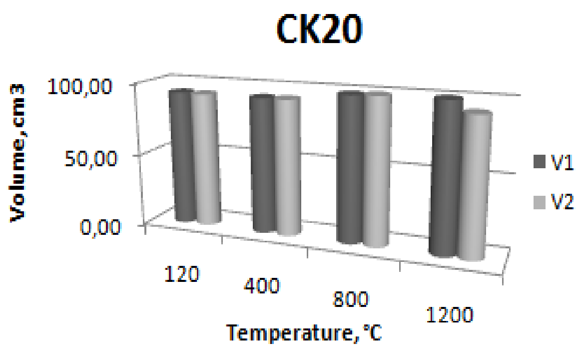

Figure 2. Subsequent shrinkage and subsequent expansion of the samples CK20

Compressive strength of the investigated samples is shown in Table 2 and Figures 3 and 4. It can be observed that both kinds of the investigated samples have the highest value of compressive strength at the temperature of 1200°C. Compressive strength of the samples CK10 initially increases with increasing heat treatment temperature, precisely at 120°C and 400°C, then at the temperature of 800°C slightly decreases, and finally at the temperature of 1200°C increases again. Compressive strength of the samples CK20 initially decreases at the temperature of 400°C, but further increasing of heat treatment causes the increasing of compressive strength.

Table 2. *Compressive strength of the samples CK10 and CK20*

Specimen	Φ [mm]	h [mm]	P [mm²]	F [N]	σ [N/mm²]
	Temperature 120°C				
CK10	50,30	47,20	1986,12	4602,96	2,32
CK20	50,10	47,10	1970,36	3835,82	1,95
	Temperature 400°C				
CK10	50,10	47,50	1970,36	5370,12	2,73
CK20	50,10	47,30	1970,36	3068,66	1,56
	Temperature 800°C				
CK10	50,50	49,50	2001,95	4602,96	2,30
CK20	50,30	49,10	1986,12	6904,44	3,48
	Temperature 1200°C				
CK10	50,10	49,50	1970,36	16877,52	8,57
CK20	50,40	50,40	1994,03	20713,32	10,39

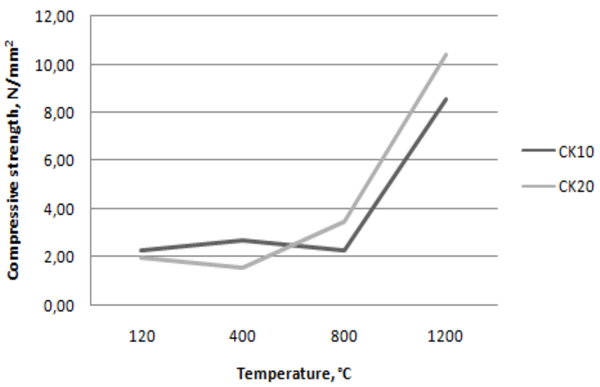

Figure 3. Compressive strength of the samples CK10 and CK20

Density of the investigated samples is shown in Table 3 and Figure 5.

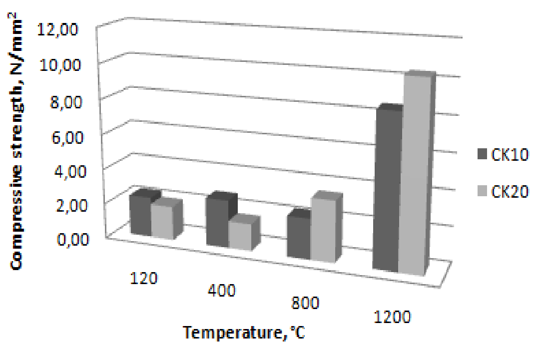

Figure 4. Histogram of compressive strength of the samples CK10 and CK20

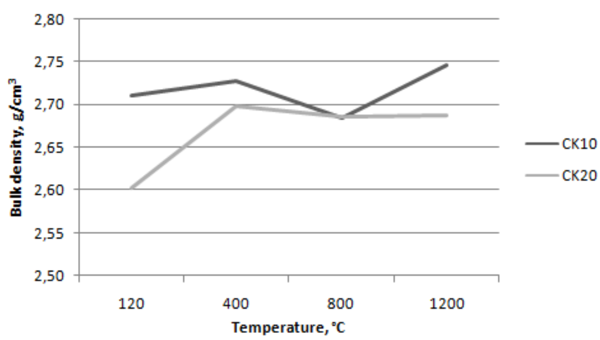

Figure 5. Bulk density of the samples CK10 and CK20

It can be observed that both kinds of the investigated samples show similar results. Density of the investigated samples initially increases with increasing heat treatment temperature, precisely at 120°C and 400°C, then at the temperature of 800°C slightly decreases, and finally at the temperature of 1200°C density increases again.

Table 3. *Bulk density of the samples CK10 and CK20*

Samples	m_p (g)	m_{p+s} (g)	m_1 (g)	m_2 (g)	m_3 (g)	ρ_w(g/cm^3)	γ_s(g/cm^3)	γ_z(g/cm^3)
12 % MAP, temperature 120°C								
CK10	28,697	46,148	17,451	89,447	78,404	0,9956	2,711	1,797
CK20	39,936	72,265	32,329	159,281	139,329	0,9956	2,601	1,828
12 % MAP, temperature 400°C								
CK10	27,841	41,414	13,573	86,210	77,592	0,9956	2,727	1,785
CK20	24,528	40,197	15,669	84,644	74,757	0,9956	2,698	1,793
12 % MAP, temperature 800°C								
CK10	28,699	41,456	12,757	86,564	78,548	0,9973	2,684	1,611
CK20	24,505	36,180	11,657	82,147	74,818	0,9973	2,686	1,593
12 % MAP, temperature 1200°C								
CK10	24,504	39,017	14,513	84,070	74,828	0,9973	2,746	1,724
CK20	28,696	43,642	14,946	87,940	78,541	0,9973	2,687	1,723

4. CONCLUSIONS

Testing mechanical properties of the phosphate-bonded refractory materials based on chamotte shows the following:

- Samples subjected to the heat treatment at the temperatures of 120°C and 400°C show subsequent shrinkage. Samples that were heat treated at the temperature of 800°C show subsequent expansion, while samples subjected to the heat treatment at the temperature of 1200°C show subsequent shrinkage.
- Strength of the investigated samples changes depending on temperature. Thus, at relatively low temperatures, for example up to 400°C, strength is increased. In the interval of 400 – 1000°C dehydration of binder occurs and strength is decreased. Above the temperature of 1000°C sintering process occurs and thus strength of the specimens is increased, as shown by the test results.
- Density of the investigated samples initially increases with increasing heat treatment temperature, precisely at 120°C and 400°C, then at the temperature of 800°C slightly decreases, and finally at the temperature of 1200°C bulk density increases again.

On the basis of the investigations, it can be concluded that the phosphate-bonded refractory materials based on chamotte, that actually belong to the group of refractory concretes, provide enormous range of application and installation in a variety of high temperature devices, and their advantages and disadvantages should be used according to application in these high temperature devices.

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