CASTABLES BASED ON CHAMOTTE WASTE WITH ADDITION OF FLY ASH AND CLAY

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ABSTRACT
The paper examined the conventional vibrating castables composed of a mixture of high alumina cement and chamotte waste with addition of fly ash and clay. The influence of particle size distribution on density, porosity, water absorption, cold crushing and flexural strength of castables was investigated. Particle size distribution was determined by the Dinger and Funk equation, using four different coefficients q. Three series of samples were investigated. In the first series as the smallest fraction was used high alumina cement only and chamotte waste in other fractions. In the second and third series the amount of cement was 20.6 % for all mixtures with different coefficient q. Instead part of cement and instead the finest fraction of chammotte waste it was used fly ash in second and clay in third series. Fly ash and clay do not significantly change the properties of castables and can be used as replacment for part of cement and for finest fraction of chamotte waste.

Keywords: conventional castables, chamotte waste, fly ash, clay, particle size distribution

1. INTRODUCTION

Castables are refractory concretes which belong to the group of monolithic refractories. Nowadays they are increasingly replacing shaped refractory materials. Castables are composite materials from complex mixture of refractory aggregates, binders, fillers, additives and water. Physical, mechanical and thermal properties of castables depend on the packing density of components in the concrete mix so that the particle size distribution is one of the most important factors in castable technology [1-4]. The most destructive component in conventional castables is CaO, which enters with calcium aluminate cement. Conventional castables containing 15 - 30% calciumaluminate cement introduce 3 - 8% CaO. In order to reduce the amount of cement and water a new group of refractory concrete called deflocculated castables is developed. In this group a portion of cement is replaced by fine particles of another material [5].
In this study, we examined the castables of four different particle size distribution. In addition to the influence of particle size distribution the impact of replacing part of the cement and the finiest fraction of chamotte waste with fly ash and clay was studied.

2. EXPERIMENTAL WORK

For the preparation of castable mixtures the following raw materials were used: high alumina cement Gorkal 70, chamotte waste ("Šamoter" d.o.o. Zenica), fly ash (Power plant „Kakanj"), clay "Rapajlo" with chemical composition shown in table 1. Sodium hexametaphosphate was used as deflocculant and it was added in the amount of 0.97 % in regard to cement amount. Particle size distribution is determined based on the formula Dinger-Funk for selected coefficient q [1-4]. Three series of tests were carried out. In the first series, high alumina cement fraction from 0.3 to 75 microns was used and in the other fractions was used chamotte waste. The fraction of chamotte waste 75-150 microns is replaced by fly ash in the second series and by clay in third series. In second and third series cement quantity is constant for all values of q and amounted to 20.6%, a difference between the calculated amount of fractions from 0.3 to 75 microns and cement was fly ash or clay below 75 microns respectively. To create three prisms according to JUS B.C8.022 it was required 1800 g of material for each series. The calculation results for the types and quantities of materials for selected values of *q* are given in table 2.

Table 1. The chemical composition of the raw materials

Component	Chemical composition (wt. %)			
	Cement	Chamotte waste	Fly ash	Clay
SiO_2	< 0.5	49.75	39.8	67.6
Al_2O_3	69 - 71	42.8	20.48	12.9
Fe_2O_3	< 0.3	1.93	7.15	6.86
TiO_2	-	1.35	0.66	0.55
CaO	-	< 0.01	25.6	0.03
MgO	-	0.12	1.64	0.76
MnO	-	0.04	0.01	-
$Na_2O + K_2O$	< 0.3	2.84	2.01	3.87
L.O.I.	-	-	0.95	7.28

Table 2. The amount and type of material

Fraction [μm]	**Amount of fraction [g]**				**Raw material**		
	q=0.37	**q=0.34**	**q=0.31**	**q=0.28**	**1st series**	**2nd series**	**3rd series**
0.3 – 75	380.7	380.7	380.7	380.7	Cement	Cement	Cement
0.3 – 75	0	39.96	82.98	129.42	Cement	Fly ash	Clay
75 – 150	124.56	128.7	132.84	136.08	Chamotte	Fly ash	Clay
150 – 300	160.92	163.26	164.52	165.42	Chamotte e	Chamotte	Chamotte
300 – 500	147.96	147.24	146.16	144.0	Chamotte	Chamotte	Chamotte
500 – 1000	251.28	245.7	239.04	231.66	Chamotte	Chamotte	Chamotte
1000 – 2000	324.72	310.86	296.28	281.16	Chamotte	Chamotte	Chamotte
2000 – 4000	419.76	393.48	367.38	341.46	Chamotte	Chamotte	Chamotte

Mixing the prepared materials and filling metal molds was carried out in a laboratory mixer for cement paste according to JUS B.C8.022. Afterwards the samples were left in the molds for 24 hours, and after 24 hours were demolded and placed in a container with water for 3 days. After 3 days they were removed from the water and allowed to dry first in air for one day, and then in an oven for another day at 110 ± 5 °C. The following properties of refractory concrete are investigated: apparent density, apparent porosity, water absorption, cold crashing strength and flexural strength.

3. RESULTS AND DISCUSSION

The results of testing castables are shown in Table 4 and on figures 1 and 2. The amount of coarse fraction above 300 microns is reduced by reducing the coefficient q, and increased the amount of fine fraction below 300 microns. These changes also affect the examined properties. In the series with cement only, all properties were increased with increasing coefficient q. Increased strength can be explained by increasing the amount of hydraulic binder (cement). The increase in porosity can be explained by increasing the amount of water added with the

reduction of the coefficient q. By increasing the amount of fine fractions, improves the packing of particles which increases density.
Addition of fly ash in the second series of tests almost no effect on the bulkt density and cold crashing strength for coefficient q 0.37 to 0.31, but it reduces the apparent porosity and water absorption. Fly ash particles are generally round, and they get better mobility and cen be easily placed between the larger grains, filling the pores, in comparison to chamotte waste particles that are irregularly shaped. With the increasing amount of added fly ash increases the porosity, water absorption and modulus of rapture. When the coefficient q is 0.28 it leads to a slight decline of bulk density and strength, which probably indicates that this amount of fine particles becomes unfavorable for vibration.

Table 4. The results for tested castables

Coefficient q	Property of castable														
	Bulk density γ [g/cm^3]			**Apparent porosity** P_p [%]			**Water absorbtion** U_v [%]			**Modulus of rapture** σ_s [MPa]			**Cold crashing strength** σ_p [MPa]		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
0.37	2.2	2.2	2.25	9.2	6.9	10.05	4.3	3.1	4.46	11.06	11.3	14.7	78	77	80
0.34	2.22	2.21	2.24	9.4	7.1	10.17	4.64	3.2	4.53	11.35	12.6	13.7	83	83	79
0.31	2.23	2.23	2.23	9.7	7.7	9.99	4.71	3.4	4.47	11.93	13.9	12.9	85	84	64
0.28	2.24	2.22	2.21	10.5	7.9	10.9	5.0	3.5	4.95	12.6	13.3	12.2	87	82	61

A – castables with cement only, B – castables with fly ash, castables with clay

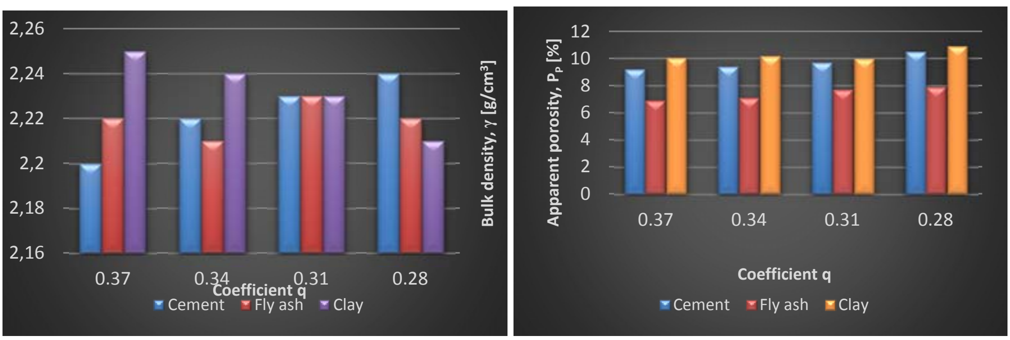

Figure 1. Bulk density and apparent porosity vs coefficient q

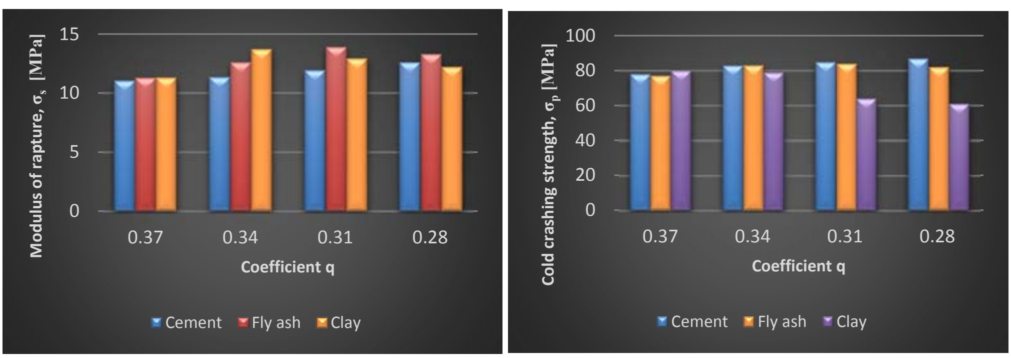

Figure 2. Modulus of rapture and cold crashing strength vs coefficient q

Addition of clay in fraction 75 to 150 μm (q = 0.37) slightly increase density because the clay in this fraction contains a lot of fine particles which ensure better packaging. Fractions of clay and chamotte are obtained by dry sieving. However, the clay is very difficult to dry disperse, because it is easy moistened exposure to air so that its particles agglomerate. Therefore, the results of porosity and water absorption disproportionate with changing coefficient q. With the addition of the clay fraction below 75 μm there is a decreasing density and cold crashing strength of the castable. Clay minerals have sheet structure and when they come in contact with water, water is placed between the sheets and leads to an increase in volume, or swelling, so that the samples with the increased amount of clay fractions under 75 microns show reduced density. The reduced density of the material leads to a reduction of cold crashing strength. The density and modulus of rapture of samples with clay are generally higher compared to samples without clay. Clay below 75 microns contains more clay minerals that water probably create a structure with a small number of internal defects that affect the modulus of rapture.
The strength, apparent porosity and density of the tested castables are as at par or even better than some commercial refractory concretes similar composition (table 5).

Table 5. Strength and density of castables

Data source	Property of castable		
	Bulk density γ [g/cm^3]	Cold crashing strength σ_p [MPa]	Modulus of rapture σ_s [MPa]
RHI [6]	2.26	60	-
KSKM [7]	2.0 – 2.1	25	-
AGC [8]	2.05 – 2.15	-	4
SKG [9]	2.1	25	-
Tested castables	2.21 – 2.25	61 - 87	11.06 – 14.7

4. CONCLUSION

It has been shown that the decrease of factor q increases the amount of fine fractions and decreases the amount of coarse fractions leading to an increase of density and strength of the refractory castables. At the same time, there has been an increase in the apparent porosity and water absorpition. Increased strength was due to the increasing the amount of cement and increasing porosity was caused by increase in the amount of added water. Replacing chamotte waste by fly ash is not deteriorating properties of castable based on chamotte waste, but even improves modulus of rupture and reduces porosity, indicating that part of the cement can be replaced by fly ash. The clay can also be used instead of part of the cement and the finest fraction of chamotte waste, because it increases the bending strength and density. Although clay reduces cold crashing strength it is still better than castables which can be found on the market.

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