13th Scientific/Research Symposium with International Participation
„METALLIC AND NONMETALLIC MATERIALS“ B&H, 27th May 2021

CHAMOTTE REFRACTORY CASTABLE PROPERTIES ENHANCING BY OPTIMIZING PARTICLE SIZE DISTRIBUTION

Marina Jovanović, Adnan Mujkanović
University of Zenica, Faculty of Metallurgy and Technology
Zenica
Bosnia and Herzegovina

Key words: refractory castable, chamotte, milling, particle size distribution, Andreasen equation

ABSTRACT
The paper examined the changes in properties of conventional castables composed of a mixture of calcium-aluminate cement and chamotte *caused by changes in the particle size distribution. Properties of castable with 20 % cement and „as received“ chamotte were compared with castableofparticle size distribution adapted to the calculated distribution using the Andreasen equation. Porosity, water absorption, density and strength of samplesafter three-day curing and samples fired at 1100 °C were examined. It was found that samples with adjustedparticle size distribution gave better results than those prepared with „as received“particle size distribution, especially regarding strength.*

1. INTRODUCTION
Castable or refractory concrete isatype of monolithic refractories which can be molded or can be given any shape as per requirement.These are dry mix hydraulic compositions of graded refractory aggregates with a suitable bonding material (most commonly cement). By addition of the prescribed quantity of water to these compositions, a wet concrete-like mass is produced which forms useful castables. At room temperature a hydraulic bond develops due to reaction of cement with water, but when it is fired at a certain high temperature ceramic bond is developed.Conventional refractory castables contain 15 – 30% of calcium-alumina cement.

Calcium aluminate cements are the most important hydraulic binder used in castables. Castables with these binders develops strength very rapid, and maximal strength is obtained 6 - 24 hours after casting. In addition to the fact that cement in castables has the function of a binder, it is consisted of fineparticles and thus affects the rheological properties of fresh concrete mix by providing a long enough time required consistency for concrete installation. Nevertheless, the main role of cement is to create hydrated cement phases that provide the strength of castable. Cement also can take part in high temperature reactions. The role of the cement in the context of particle size distribution is merely as a finely ground fraction [1,2].

Chamotte is fireclay fired at 1000 - 1200 °C which contains 35 – 50 % Al_2O_3, while other oxides are impurities whose quantity depends on the purity of the raw materials. The higher the content of Al_2O_3, the better the refractory properties of the chamotte. The main minerals in chamotte structure are mullite (which provides high refractory properties) and cristobalite. Chamotte as an aggregate is most commonly used in conventional refractory castables [1].

Conventional castables show that their physical, mechanical and thermal properties depend on the density of components packing in concrete mix specially on filler content. Particle size distribution has become an effective tool in manufacturing of dense castables[2-5]. There are certain theories on particle packing which may be used to determinethe optimum particle size distribution. One of the mostcommonly used is the Andreassentheory expressedthrough equation:

$$CPFT = \left(\frac{d}{D}\right)^q. \qquad (1)$$

where is:
CPFT - Cumulative Percent Finer Than
d -particle size
D -maximum particle size
q - distribution coefficient (q-value).

For castableswith maximum particle size 4mm it was foundthat vibra flow is constant when the q-value islower than 0.30, and good free flow is obtainedwhen the q-value is lower than 0.25 [4].

A q-value of 0.28 was selected in this paper because examined castable is vibrating type.

2. EXPERIMENTAL

2.1. Materials and methods

The raw materials used were refractory cement containing 50% alumina REFRO 50, CIMSA and recycled chamotte. Chamotte was obtained from previously fired bricks that were crushed, ground and sieved. Atomic absorption spectrometry (AAS) is used for determination of chemical composition of chamotte. The analysis was run on Perkin Elmer instrument. In order to determine the grain size distribution of „as received" chamottethe procedure of dry sieving was used. The sieves 5 mm, 4 mm, 2 mm, 1 mm, 0,5 mm, 0,3 mm, 0,15 mm and 0,075 was applied. The sieving was performed on sieve shaker for 10 minutes.

Dry castable mixture was consist of 80% „as received" chamotte and 20% cement. In actualparticle size distribution of mixture cement was considered as fraction -75 µm.The target particle size distribution of mixture for q = 0.28 was calculated using the Andreasen equation.By comparing the actual and the target particle size distribution a deficit of 6 % fraction – 75 µm was identified. In order toobtain the target grain size distributionin the simplest way possible, 6% of chamotte fraction+1 mm was milleduntil all particles pass sievewith diameter 75 µm.In this way, anadjusted particle size distribution was obtained.

Two batches of samples were prepared. The first batch contained samples with „as received" chamotte and the second batchsamples with partially milled chamotte. Both types of aggregatewere mixed with 20 % cement and water. The water/cement ratio was 0.5 in both batches.The mixed batches were casted into cubes of 70 mm side length using a vibrating table for 3 minutes at a frequency of 50 Hz and 1 mm amplitude. The samples were left in the molds for 24 hours, and then demolded and placed in a container with water. After 3 days of curing in water the cubes were dried in oven at a temperature of 105 ± 5 ºC until reached constant mass. A half of the samples were tested under these conditions and a half were fired at 1100 °C and then tested. The heating rate below 1000 °C was 10 °C/min and over 1000 °C 5 °C/min.

Dried and fired samples were tested for water absorption, bulk density and apparent porosity.For each test, the average measurements of two samples were calculated.The samples for each test were weighed to get the dry mass. The samples were immersed in water for 1 hour to 1/3 of height, 1 hour to 2/3 of height and completely immersed until constant mass was achieved.The calculation of water absorption, apparent density and apparent porosity is performed as follows:

$$U_v = \frac{m_3 - m_1}{m_1} \cdot 100 \qquad (2)$$

$$\gamma = \frac{m_1}{m_3 - m_2} \cdot \rho_v \qquad (3)$$

$$P_p = \frac{m_3 - m_1}{m_3 - m_2} \cdot 100 \qquad (4)$$

where is:

m_1 – mass of dry sample [g]

m_2 - mass of sample saturated with water in water (hydrostatic weighing) [g]

m_3 - mass of sample saturated with water in air [g]

γ – apparent density [g/cm^3]

ρ_v – water density [g/cm^3]

U_v – water absorption [%]

P_p – apparent porosity [%].

After determination of water absorption, bulk density and apparent porosity samples were dried. Each sample was placed between two plates of the compression strength tester. This was followed by the application of an axial uniform load. The load at which destruction of the sampleoccurs was noted, and strengthwas calculated according to equation:

$$\sigma_c = \frac{W}{A} \qquad (5)$$

where is:

σ_c – cold crushing strength [MPa]

W – maximum load [N]

A – gross area [mm^2].

3. RESULTS AND DISCUSSION

3.1. Characteristics of raw materials

Table 1 shows the AAS results related to the chemical analysis of the chamotte. The physical properties and chemical composition of cement are summarized in Table 2.

Table 1. The chemical composition of the chamotte

Component	*SiO_2*	*Al_2O_3*	*Fe_2O_3*	*CaO*	*MgO*	*K_2O*	*Na_2O*
Chemical composition (wt. %)	*57.3*	*37.6*	*1.82*	*0.01*	*0.20*	*1.03*	*0.15*

Table 2. Properties of calcium aluminate cement [6]

Characteristic	***Value***
Blaine fineness	*≥ 3000 cm^2/g*
Thermal resistance	*1450°C*
Specific gravity	*≤ 3,0 g/cm^3*
Initial set time	*> 120 min*
Final set time	*> 150 min*
Compressive strength after 6h	*≥ 18 MPa*
Compressive strength after 24h	*≥ 60 MPa*
Chemical composition	
Al_2O_3	*≥ 49.0 %*
CaO	*≤ 40.0 %*
SiO_2	*≤ 6.0 %*
Fe_2O_3	*≤ 3.0 %*
TiO_2	*≤ 4.0 %*
MgO	*≤ 1.0 %*

3.2. Particle size distribution

Figure 1 shows particle size distributions for first and second batch as well as target curve.It can be seen that the grain size distribution of second (adjusted) batch is more closely to target curve than first batch.

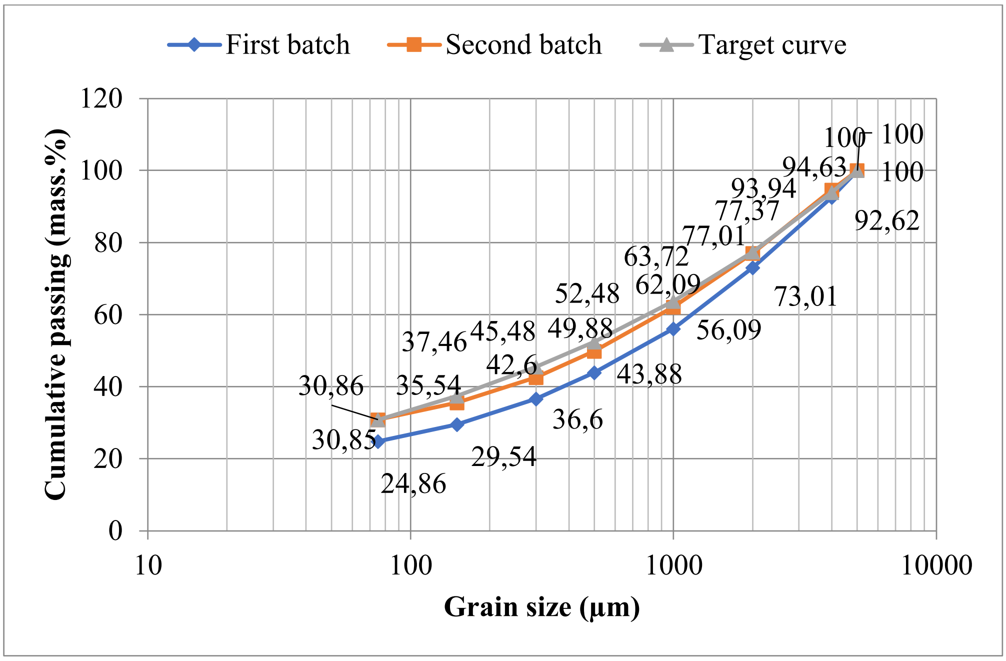

Figure 1. Particle size distribution of mixturein the first and second batch and target particle size distribution

3.3. Properties of castables

Table 3 shows bulk density, apparent porosity, water absorption and cold crushing strength of the castables with different grain size distribution.

Table 3. The results for tested castables

Thermal treatment	***Property of castable***							
	Bulk density *γ[g/cm³]*		***Apparent porosity*** P_p*[%]*		***Water absorption*** U_v*[%]*		***Cold crashing strength*** $σ_p$*[MPa]*	
	I	*II*	*I*	*II*	*I*	*II*	*I*	*II*
Dried	*2.09*	*2.14*	*14.2*	*13.2*	*6.8*	*6.2*	*48*	*60*
Fired at 1100 °C	*1.98*	*2.05*	*22.2*	*20.0*	*11.1*	*9.7*	*42*	*51*

I – first batch, II – second batch

3.3.1. Effect of particle size distribution on bulk density

Table 3 and Figure 2 show the relations between bulk density and particle size distribution for dried and fired castables. It can be seen that the bulk density increases withchange in particle size distribution which ultimately was the point. Second batch contains more fine grains that fill voids and thus increase the density. The increase in density is evident in both dried and firedsamples. For dried samples this increase is 2.4% and for fired samples 3.5%.

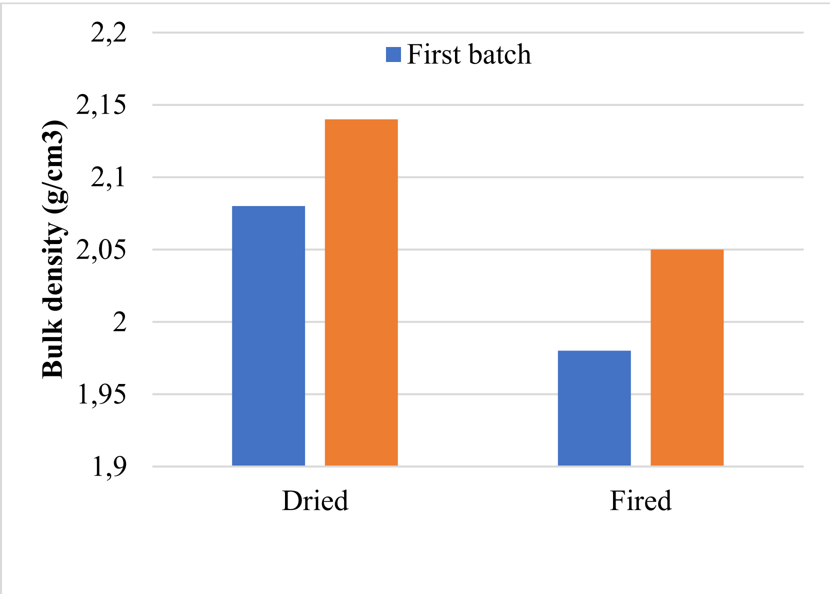

Figure 2. Effect of particle size distribution and thermal treatment on bulk density

3.3.2. Effect of particle size distribution on apparent porosity

Table 3 and Figure 3 show the effect of particle size distribution on apparent porosity for dried and fired castables. Apparent porosity decreases with change in particle size distribution. Porosity of dried samples is less than 20% indicating that used chamotte is not too much porous because porous chamotte gives a porosity of 25 – 30 % [7]. Increasing the density decreases the porosity. For the dried samples the decrease in apparent porosity isabout 7% and for the fired samples is more pronounced and is about 10%. Increasing porosity in fired samples occurs because the hydraulic bond is destroyed upon heating and new mineral phases are formed. During this change the open porosity increases [8].

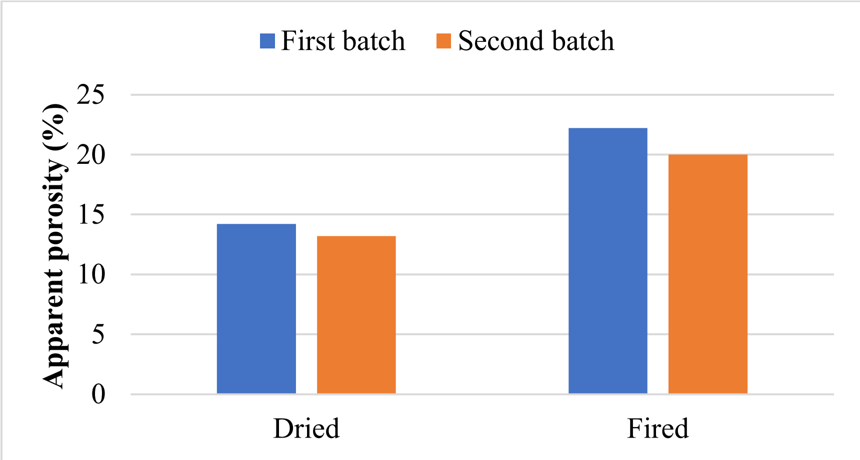

Figure 3. Effect of particle size distribution and thermal treatment on apparent porosity

3.3.3. Effect of particle size distribution on water absorption

Table 3 and Figure 4, which show the relations between water absorption and particle size distribution, point that castables from second batch have lower water absorption in both dried and fired state. For dried samples decreaseis 9% and for fired samples even 14%.

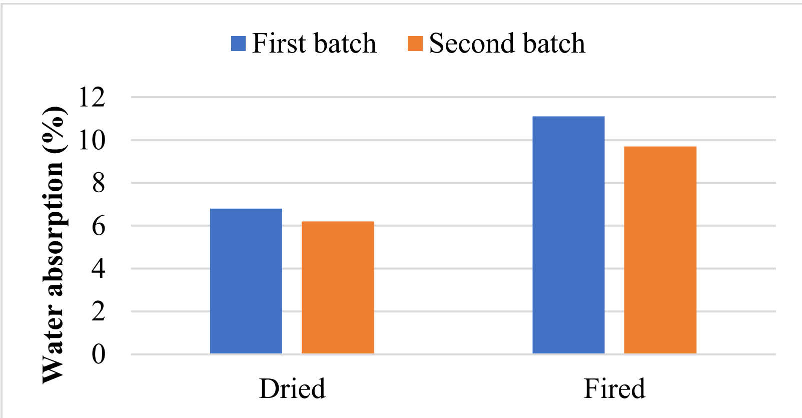

Figure 4. Effect of particle size distribution and thermal treatment on water absorption

3.3.4. Effect of particle size distribution on cold crushing strength

Table 3 and Figure 5 show the effect of particle size distribution on cold crushing strength for dried and fired castables. Cement provides strength of castable at room temperature, but at the temperatures preceding sintering, irreversible destructive processes occur in the cement – a liquid low-soluble phase is created, hence fired samples have less strength than dried once [5,9,10]. Cold crushing strengthincreases with change in particle size distribution. For dried samples theincrease in cold crushing strength isabout 25% and for fired samples is about 21.5%.

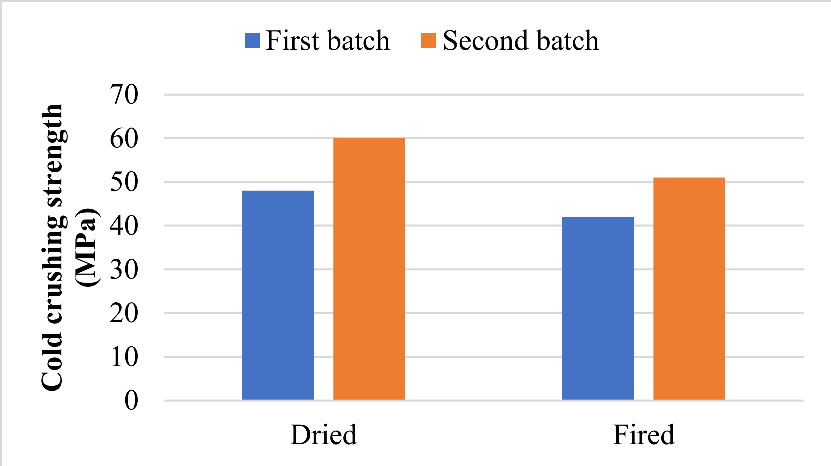

Figure 5. Effect of particle size distribution and thermal treatment on cold crushing strength

4. CONCLUSION

Conventional refractory castable is still widely used. Most of them use chamotte as aggregate and calcium-aluminate cement in the amount of about 20% as binder. Particle size distribution affects almost all properties of castable. In this paper it is shown that a small intervention on the particle size distribution, that is, by increasing the fine fraction by 6% at the expense of coarse fractions, can improve the properties of castable. Improvements are evident in both dried and fired specimens. The greatest positive effect is on the compressive strength, especially in dried specimens.

5. REFERENCES

[1] Hayase M.: Refractories handbook, Introduction to Refractories, The Technical Association ofRefractories, Japan, 1998.
[2] MyhreB.: Particle size distribution and its relevance in refractory castables, 2nd India International Refractory Congress, New Delhi, 1996.
[3] MyhreB.: The effect of particle size distribution on flow of refractory castables, 30th Annual Refractories Symposium, St. Louis, 1994.
[4] MyhreB., HundereA. M.: The use of particle size distribution in development of refractory castables, XXV ALAFAR Congress, San Carlos de Bariloche, 1996.
[5] GhonaimS.A., GhazalH.B.G., AbadirM.F.: Effect of Type of Aggregate on the Properties of Refractory Concrete, Journal of American Science, 2010, 6(12), 1015-1027
[6] Technical data sheet for REFRO50
[7] Montgomery R.in: Advanced Concrete Technology Processes, Edited by Newman J. and ChooB.S., Chapter: Heat-resisting and refractory concretes, Elsevier, 2003.
[8] ParrC., BierT.A., BuntN.E., SpreaficoE.: Calcium Aluminate Cement (CAC) Based Castables for Demanding Applications, 1st Monolithic Conference, Teheran, Iran, 1997.
[9] BanerjeeS.: Recent developments in monolithic refractories, American Ceramic Society Bulletin, 77 (10),1998, 59-63
[10] Volkov HusovićT.:Vatrostalnimaterijali – svojstva I primena, SavezinženjerametalurgijeSrbije, Beograd, 2007.