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Microwave and conventional treatment of low-cement high-alumina castables with different water-to-cement ratio; Part II. Dehydration

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A R T I C L E I N F O

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A B S T R A C T

Modern refractory castables contain between 3.5 and 5 wt.-% water that is necessary for sufficient flow during emplacement and for the formation of hydrate phases, necessary for the green strength of the material. Prior to the high temperature use of this material, it must be dried very carefully to avoid explosive spalling.

This paper will demonstrate that beside conventional drying of pre-shaped materials in resistance furnaces microwave radiation is an energy saving and rapid method to remove pore water as well as hydrate bond water from the castable. In comparison to resistance furnaces, the use of microwave radiation does not affect the castable properties as there are mechanical strength (MOR, CCS), open porosity and pore size distribution. This study proved microwave radiation as valuable alternative with a series of tabular alumina based low cement castables (LLC) in which the water-to-cement-ratio (wcr = 0.64, 0.75, 0.82 and 1.13) was systematically altered by changing the cement concentration at constant mixing water concentration of 4.5%.

1. Introduction

Calcium-aluminate cement containing refractory castables develop mechanical strength due to the formation of cement hydrate phases. Therefore after setting and curing these castables contain distinct amounts of chemically bound water. Water is not only added for the said chemical reaction but also to adjust the rheological properties of the readily mixed concrete slurry. Therefore, beside hydrate bonded water, pore water remains in structure. For the generic use of refractory concrete pore and hydraulic bond water must be carefully removed prior to the first use at high temperatures. The drying process of monolithic linings comprises at the initial stage the removal of pore water. Further heating of the castable leads to the decomposition of hydrate phases that are stable up to distinct temperature ranges. CAH_{10} ($CaO{\cdot}Al_2O_3{\cdot}10H_2O$) decomposes between 100 and 130 °C, C_2AH_8 ($2CaO{\cdot}Al_2O_3{\cdot}8H_2O$) dehydrates in the range of 170–195 °C, and C_3AH_6 ($3CaO{\cdot}Al_2O_3{\cdot}6H_2O$) starts to decompose between 300 and 450 °C. The calcium-free AH_3 ($Al_2O_3 0.3\ H_2O$) as far as it is crystalline (gibbsite) decomposes between 210 and 300 °C converting to boehmite (AH) that dehydrates at about 530 °C [1]. The water release from the hydrate phases occur at high temperatures that may result in an explosive vapor expansion if the dewatering rate of the hydrate phases is to high. Therefore, the heating procedure of the monolithic linings should be carried out very carefully to prevent an excessively fast release of water and explosive destruction of the castable. The dehydration process is finished at about 530 °C and further heating can be carried out faster in a safe way. If precast castables are used, a material treatment up to ca 600 °C is common practice. For the development of monolithic refractory products, the dehydration process is always identified as a key issue for proper use at high temperatures and has already been studied in detail [2–4]. It is a common practice to dry monolithic refractories by conventional heat addition by means of electrical energy or open flames whereat the material dry and dehydrates from the surfaces to the center or cold face of the lining.

The use of microwave appears to have certain advantages as an alternative energy supply, because the entire material is affected from the very beginning of the drying process. Microwaves are already applied for drying of tableware ceramics, sanitary and technical ceramics. The results show clear advantages in terms of secure drying and energy consumption [5,6]. Preceding investigations show that microwave drying is also suitable for the removal of water from calcium aluminate cement pastes without disadvantages for the material performance after drying [7]. In addition, Routschka concluded that a more rapid heating of refractory castables up to the temperature of 500 °C and higher is possible by microwave radiation and high frequency heating [8]. Its applicability for drying low-cement refractory castables was also confirmed in Part I of this article, where the properties of low-cement alumina castables with various water-to-cement ratios in the range of 0.63–1.13 investigated and the results gained were compared after conventional and microwave heating.

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Table 1
Composition of castables with different wcr.

Component	Composition [%]			
	wcr 0,64	wcr 0,75	wcr 0,82	wcr 1,13
Tabular alumina T60 0,02-3 mm	69	69	69	69
Tabular alumina T60 0-0,045 mm	**6.6**	**7.8**	**8.4**	**10.2**
Alumina CTC20	10	10	10	10
Reactive alumina RG4000	7	7	7	7
Cement Secar 712	**7**	**6**	**5,5**	**4**
Dispersant FS60	0.15	0.15	0.15	0.15
Deionised water	4.5	4.5	4.5	4.5

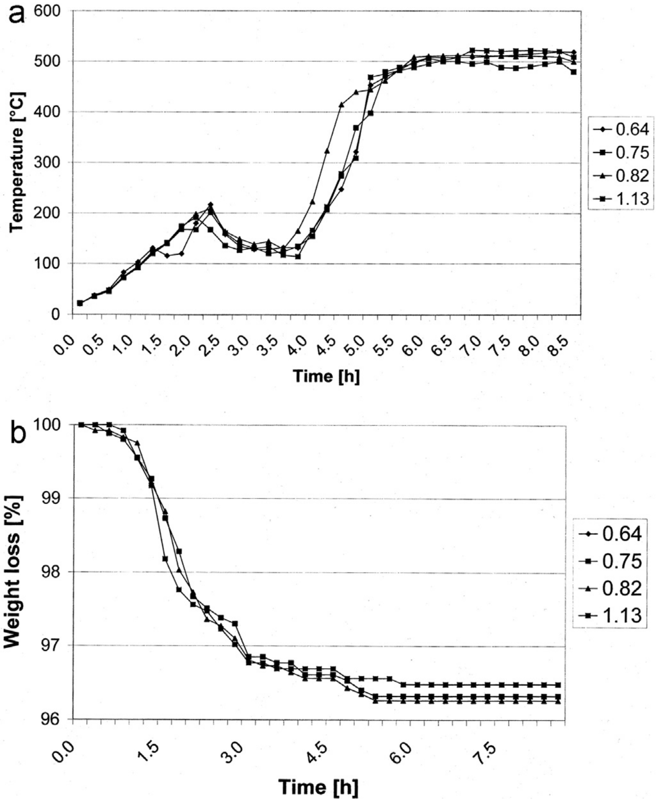

Fig. 1. Progression of microwave drying: a) temperature measured on the surface of samples, b) weight loss of samples.

While the first Part of this paper focus on the drying the aim of this part is to figure out the influence of microwave heating of low-cement alumina castables compared to the conventional dehydration process that carried out in an electric furnace. In order to obtain a comprehensive picture how microwaves affect the dehydration of cement hydrates in the castables the initial amount of hydrate phases was altered by adjusting distinct water-to-cement ratios by adding variable cement concentrations. The mixing water addition was kept constant. This approach keeps the castable formulations comparable in terms of material properties measured after conventional and microwave induced dehydration. Solely the proportion of pore and hydrate bond water was changed but not the bulk density that would clearly affect the dehydration process and mechanical properties measured after dehydration.

2. Materials and methods

2.1. Sample preparation and treatment

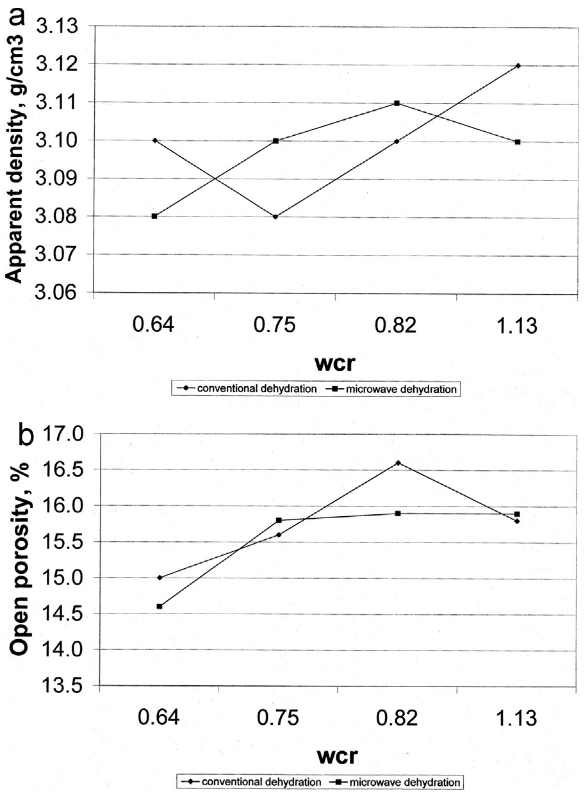

Fig. 2. Apparent density (a) and open porosity (b) of castables after dehydration.

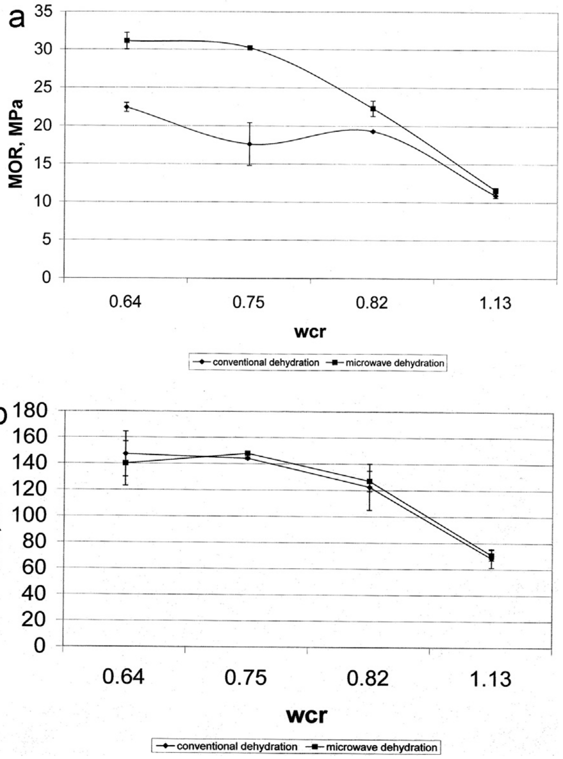

Fig. 3. MOR (a) and CCS (b) of castables after dehydration.

Based on a tabular alumina (T-60) low cement self-flow model castable four distinct recipes were derived by variation of the watr-to-cement-ratio (wcr = 0.64, 0.75, 0.82 and 1.13) as depicted in Table 1. The alteration of wcr was achieved by a volumetric replacement of cement (SECAR 712) with 0-0,045 mm tabular alumina that has a comparable particle size distribution. The water content in the whole composition was held constant at 4,5 wt.-%.