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ScienceDirect
Journal of the European Ceramic Society 34 (2014) 3217–3227
www.elsevier.com/locate/jeurceramsoc

Effect of binding system on the compressive behaviour of refractory mortars

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Received 6 December 2013; received in revised form 4 April 2014; accepted 8 April 2014
Available online 10 May 2014

Abstract

In refractory masonry lining of industrial furnaces the compressibility of mortars is critical for the thermo-mechanical integrity of the structure. Compressive stress–strain behaviour of refractory mortars has been measured during drying at room temperature and in the service temperature range of 300–1400 °C. The results have been explained using fractographic analysis and distinct element method computer modelling. The mortar failure has been shown to occur due to formation of shear bands of micro-cracks. The propagation of cracks preferably follows the shortest path between larger pores and is influenced by grain cohesion and interlocking. Tests with mortars featuring calcium aluminate cement, mono aluminium phosphate, water glass and bentonite clay binders have indicated that besides increasing the cohesion between the grains the binder reduces the internal friction that promotes higher compressibility. It has been found that the mortar with clay has the highest compressibility. The mortar with cement shows the most stable behaviour.

Keywords: Refractories; Mortars; Thermo-mechanics; Binder effects; Microstructure

1. Introduction

Mortars are widely used to bind bricks in refractory ceramic linings of high temperature aggregates and furnaces.[1,2] Refractory mortars are predominantly water based. Depending on the application, grains of various composition and coarseness are used. The binding system can feature one component, e.g. calcium aluminate cement, phosphate, clay, or a combination of those.

Compressibility of the mortar is a significant factor in the analysis and design of a lining.[3] Temperature gradients between hotter refractory bricks and colder steel shell of the furnace result in the conditions of constrained thermal expansion and compressive loads. Mortar which is too stiff can be responsible for increased stresses, brick cracking and spalling. In cyclic operation, when the lining heats-up and cools down on a regular basis, mortar which is too soft may develop high plastic strains, which will cause joint opening and instability upon cooling.

Parameters influencing the compressive behaviour of refractory mortar are expected to be similar to those of granular materials, in general, and to those of civil engineering mortars, in particular. The critical role of binder in the development of compressive strength is shown on the example of early age calcium silicate mortars.[4] The binder increases the adhesion between the grains and strengthens the mortar. There are three main factors determining the strength of the adhesion of the binder to the aggregate: chemical affinity, mechanical bond and physical bond between the molecules (van der Waals forces).[5] Apart from the binder, the porosity and the interaction between the grains are the factors determining the compressibility of the mortar. The compaction stiffness of civil engineering mortar and concrete is shown to be reversely proportional to the initial porosity. As a rule the porosity is determined by the initial water content[6–8] in the mortar. The contact network and the interaction between the grains have a strong effect on stress transition and local failure.[9–11] In soils, particle rearrangement

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http://dx.doi.org/10.1016/j.jeurceramsoc.2014.04.016
0955-2219/

in more compact configuration is achieved by overcoming interparticle friction through interparticle slip and rotation. In some cases the rearrangement can take form of particle damage. This can involve particle abrasion, breaking or grinding the particle surface protrusions or fracturing of the whole particle.[9]

Several set-ups for testing of mortars have been reported.[6,7,12] For testing mortar compressibility, samples of prismatic and cylindrical shapes are most frequently used. In practice, the mortar joint features a very low ratio between the joint thickness and its length. To account for this aspect, the laboratory tests on civil engineering mortar have been performed on real size brick-mortar assembly and on flat laboratory samples with the real thickness of a mortar joint.[13,14] For refractory mortars the effects of temperature are often assessed at room temperature after firing cylindrical samples at specific temperature.[1,15] The tests at a high temperature have been reported in,[16] where the high temperature shear strength of mortars featuring several bonding agents (phosphate, clay) was measured. Besides the static compressive tests, ultra-sound measurements have been used to assess the mortar properties.[8] It has been shown that the porosity and degree of damage in the mortar correlates well with the ultra sound velocity.

In the present investigation the role of the binding system on the compressibility of refractory mortar is studied. The emphasis is placed on performing the tests at thermal conditions representing the service temperature range and using sample geometry of realistic width-height ratio. Compressibility of refractory mortars with phosphate, cement, water glass and clay is quantified. The mechanisms of mortar deformations are explained using the information on known transitions in the binders, fractographic analysis and by the distinct element method (DEM) computer analysis. The results of the investigation are to be used in the optimisation of refractory linings and as input data for computer models.

2. Materials and experimental procedures

2.1. Materials

Mortars with binders most frequently used in refractory linings were prepared for investigation. These binders included calcium aluminate cement, water glass, mono aluminium phosphate (MAP), and bentonite clay (Table 1). Also, a mortar without any binder was prepared and tested. For all the tested mortars, with and without binder, the same grains were used. Those featured 99.7% of Al_2O_3 and 0.3% of Na_2O. The grain size distribution is shown in Fig. 1. Irrespectively of the binding system 17 wt.% of water was added to prepare the mortars. This corresponds with the industrial practice, where some 15–20 wt.% of water is used for mortar of any binding system. The water amount is in significant surplus to what is needed to activate the binding agent. The surplus is required to ensure proper flowability and workability of mortar. For majority of tested mortars, the amount of the binding agent was representative for commercially available mortars. A limited series of tests was performed with samples of variable binder amounts. In case when binding agents were in aqueous solution, the water added with the solution was included in the total water balance.

Table 1
Binding agents.

Binder	Composition	Amount added (wt.%)
Calcium aluminate cement	69% Al_2O_3, 31% CaO Phases: CA (primary), CA2 (secondary)	4.5% of powder
Water glass	70% SiO_2, 30% Na_2O, Density 1.33 g/cm^3	8% of 24% solution
Mono aluminium phosphate (MAP)	9% Al_2O_3, 37% P_2O_5 Formula $[Al(H_2PO_4)_3]$	7% of 50% solution
Bentonite clay	SiO_2 60.50%, Al_2O_3 18.20%, Fe_2O_3 5.25%, MgO 3.26%, CaO 3.14%, Na_2O 0.20%, K_2O 0.14% Phases: montmorillonite (primary), feldspar, calcite, quartz (secondary) $(Na, Ca)_{0.33}(Al, Mg)_2(Si_4O_{10})(OH)_2 \cdot nH_2O$	0.3% of powder

2.2. Experimental procedures

Mortars are prepared in standard rotary blade mixer. Samples are formed using dense ceramic discs. One sample consists of 4 ceramic discs and 3 layers of mortar. The discs are of the material Alsint (99.9% Al_2O_3). According to the data sheet the porosity of the disc is 0% and its Young's modulus at 20 °C is 370–400 GPa. The disc height and diameter are 5 mm and 50 mm, respectively. The mortar layer thickness is 3 mm. During the sample preparation the exact thickness of the mortar layer is guaranteed by the distance holders installed between the disks on their periphery. Using several layers in one sample allowed increasing total sample displacement during the compressive tests, thus reducing the relative error weight in displacement

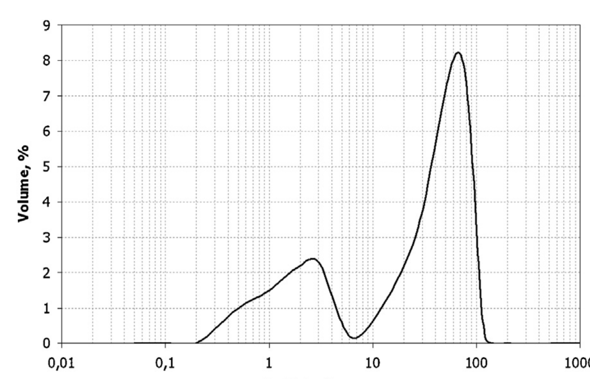

Fig. 1. Grain size distribution.