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Characterization of high-alumina refractory bricks and modelling of hot rotary kiln behaviour

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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

Rotary kilns for iron-ore pellets production are highly dependent on a well-functioning refractory brick lining. To improve the long-term capability of the lining, in-situ observations of the bricks' performance are desired, however, the high process temperatures and the size of the kiln make it difficult to study the lining during operation. By using numerical simulations as a tool, some of the problems encountered by the brick lining can be studied. Knowing material properties of the refractory bricks as input in a numerical model is therefore necessary. However, material properties are poorly documented for this type of materials, especially, at elevated temperatures. In this work three commercial aluminasilicate bricks were tested in compression until failure for a temperature range of 25–1300 °C. The purpose was to evaluate compression strength and Young's modulus in compression of the fully burned bricks at a wide range of temperatures. The data was later used for modelling of a hot rotary kiln lined with bricks by using the finite element method, whereupon load state of the lining was evaluated at steady state after the expansion of the system. The objective of the numerical modelling was to investigate trustworthiness of the model and to give insight into the stress levels that can potentially arise. It was found that for all of the investigated brick types the compression strength increased with increased temperature, having a peak in the vicinity of 1000 °C. The maximum increase was between 50 and 150 % for the different brick types. After passing 1100 °C the compression strength rapidly and considerably decreased below its as-received compression strength. Young's modulus was measured to vary between 2 and 10 GPa in the range of up to 1000 °C. The numerical results indicate that severe boundary conditions (expansion of the lining is highly restricted) can potentially lead to compression stress of up to 34 MPa in the brick lining at steady state. However, at these boundary conditions the present tensile stress was only 0.5 MPa, while tensile stresses of close to 3 MPa could be observed in the lining with mild boundary conditions. The authors conclude that the created model is trustworthy and that it has high potential for being used as a tool in further investigations of the lining in hot state.

1. Introduction

Ceramic refractory materials have been used as barriers between hot and relatively cold zones for thousands of years and are still of great importance for mankind. This is especially noticed in the production of cement and iron – two of the most produced

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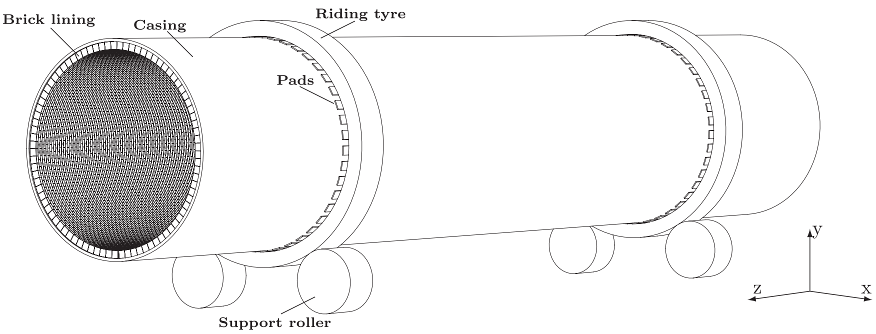

Fig. 1. Illustration of a typical short dry-kiln used in iron-ore pellets industry (true proportions).

materials on Earth [1,2]. Without insulating properties of refractories these and many other processes would not have been possible.

Manufacturing of iron-ore pellets is commonly made in the grate-kiln process [3] where sintering of the pellets is performed in a refractory lined rotary kiln. The kiln is a large cylinder-formed furnace rotating about its axis with typical dimensions of 30–45 m in length and 5–8 m in diameter, and operating at temperatures of up to 1350 °C, see Fig. 1. High-alumina refractory bricks are commonly used in the lining [4]. The service conditions inside the kiln are rough − requiring chemical, mechanical and thermal resistance of the bricks. Damage of the bricks is inevitable and regularly planned maintenance is needed. However, unplanned emergency stops due to failure of the lining are frequent. The need of slow cooling prior to the repairing followed by slow heating of the kiln, makes the process of maintenance time consuming (5–14 days) and expensive. A single kiln is commonly responsible for a large part of the company's production capacity, possibly the company's total capacity − therefore, it is important to minimize the risk of unplanned shut-downs.

There have been many improvements of rotary kilns in the last century regarding production capacity, reliability, energy efficiency and improved material properties of the lining [5]. Nevertheless, despite the improvements there are some gaps in knowledge behind mechanisms of the failure of the lining. An explanation to this is the difficulty to observe or study a kiln due to its size and harsh environment. Stjernberg et al. have contributed to the increase of the knowledge regarding chemical degradation of the aluminasilicate bricks [6–8]. Boateng [9], Saxena [5,10] and Schacht [11] are noticeable in the literature regarding rotary kilns. Shubin [12–15] gives valuable series of scientific papers on the subject of cement kilns with some focus on analytical calculations. Authors in [16] perform a rigorous work about refractory engineering covering description of materials, design theory, practical principles and more.

Today, computers can be of a great help for studying various issues without causing production delays, risking failures, or being limited by the extreme conditions found in a rotary kiln. However, academic research in this field has stagnated and very little documentation can be found regarding finite element analysis of the lining, especially of the thermo-mechanical character.

To numerically reproduce lining behaviour at production conditions it is necessary to know material properties of the lining as input for a numerical model. In this work three commercial alumina silicate brick types are tested in compression until failure in the range of 25–1300 °C. The purpose is to evaluate compression strength and Young's modulus of the bricks at elevated temperatures. The obtained data is used for numerical modelling of a rotary kiln at production temperature. The purpose of this part is to evaluate the load state of the brick lining in a rotary kiln after thermal expansion of the system. The model used in this work is based on a previous study [17] and can be regarded as a link from cold state analysis to hot state analysis. Contribution to the field are the rarely conducted high temperature tests for this type of materials and finite element simulation of the brick lining in a hot rotary kiln that has, to the authors' knowledge, never been reported before.

2. Materials

Three as-received brick qualities with trade names Victor HWM, Silox 60 and Alex were tested. These are high-alumina bricks [4] manufactured on the base of different raw materials. Victor HWM is based on bauxite, Silox 60 on andalusite and Alex on chamotte reinforced with bauxite. From here on Victor HWM, Silox 60 and Alex will be denoted as brick 1, brick 2 and brick 3, respectively. Table 1 summarizes some of the material properties and main chemical constituents found in the final burned products.

Fig. 2 represents optical light microscope and QEMSCAN (Quantitative Evaluation of Minerals by SCANning electron microscopy)

Table 1
Summary of brick properties provided by the manufacturer [18]. (AP - apparent porosity; CCS - cold compression strength).

	Material properties			Constituents (wt.%)					
	ρ (g/cm^3)	AP (%)	CCS (*MPa*)	Al_2O_3	SiO_2	TiO_2	Fe_2O_3	*CaO*	*Alkalis*
Brick 1	2.7 (2.65–2.75)	18 (17–21)	80 (60–100)	79	17	2.2	1	0.2	0.5
Brick 2	2.45 (2.40–2.50)	17 (15–19)	70 (50–90)	59	37	1.5	0.9	0.1	0.5
Brick 3	2.33 (2.25–2.40)	19 (17–21)	50 (30–70)	54	40	2.1	1.4	0.3	1.3