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FEM investigation of global mechanisms affecting brick lining stability in a rotary kiln in cold state

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ABSTRACT

Severe degradation of refractory lining in a rotary kiln often leads to very costly production delays. Use of finite element analysis for understanding the mechanisms behind the failure of the lining is poorly reported in this field. To increase the knowledge and to update the field a simplified model of a kiln and a new methodology for studying stability of the lining are suggested. Behaviour of the lining in cold state – in static and dynamic cases – is studied. Influence of ovality, brick's Young's modulus and friction coefficient on stress and brick displacement are evaluated at two rotational speeds. It was found that the induced loads in the lining are harmless regardless of the tested conditions — challenging the traditional beliefs. On the other hand, recorded brick displacements were found to be significantly affected by rotational speed and ovality. Gaps as large as 80 mm could be observed between the bricks and the casing in a worst case scenario. An integrity coefficient was defined in order to quantify overall integrity of the lining.

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1. Introduction

Rotary kilns are important in a variety of different manufacturing areas for e.g. calcination and sintering of materials. In fact, two of the most produced materials in the world [1,2], cement and iron, are likely to start their journey in a rotary kiln. The kiln simply consists of a cylindrical steel casing lined with refractories. As the kiln is heated and rotates during production, it is subjected to a complex stress/strain condition. Availability of it is highly dependent on the state of the refractory lining. If the lining is significantly deteriorated and can no longer protect the casing from the heat – the production is shut-down – leading to high production losses.

There has been many improvements of rotary kilns in the last century. Production capacity of a single kiln has been increased from earliest 300 metric ton/day up to 20,000 metric ton/day today. The lifetime of the earliest linings in hot zones did not exceed more than 10–15 days, today 200–300 days is expected. Energy efficiency has been improved by 50–75 % compared to the early wet kilns [3]. However, despite these improvements there is still little knowledge behind the 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. Another is the slow adaptivity of the users who are, understandably, not willing to take the risk of practising new ideas that might become expensive. Today, a part of the problem can be moved to the computer clusters where behaviour of the lining can be simulated and studied. In this matter there is a contribution to be made.

Little attention is paid to the field of refractory lining and its failure, especially that of a non-chemical character [4,5,6,7]. Schubin [8,9,10,11] gives comprehensive and valuable series of scientific papers on the subject of cement kilns. These papers

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discuss the development of refractory materials and service conditions influencing the lining. The effect of temperature oscillations, the slag and the need of expansion joints are discussed. Analytical solution for the temperature profile in the lining at different conditions is proposed. The mechanical stresses in the lining caused by the ovality of the steel casing are analysed analytically and some data is presented. Other mechanical aspects affecting the lining are discussed. Saxena [3] gives a good overview on the problems encountered in the field of cement rotary kilns. In [12] authors perform a rigorous work about refractory engineering covering description of materials, design theory, practical principles and more. Como [13] presents a new comprehensive, unified theory of statics of masonry constructions, where similarities with refractory linings can be find. Use of Finite element method (FEM) for the simulation of rotary kilns is poorly reported in scientific journals. Some information can be gathered from the researches working in the field of steel-making industry, where refractory materials are extensively used. Damhof et al. [14] present a FE-model of thermal shock damage in the refractory lining of steel-making installations. Some authors [15,16,17,18] have presented a number of articles on the subject of FE-simulation of thermomechanical behaviour of refractory linings. Andreev et al. [19,20] discuss behaviour and importance of dry joints in refractory linings of BOF (basic oxygen furnace) converters. Del Coz Diaz et al. [21] make a Finite Element Analysis (FEA) of a cement rotary kiln evaluating ovalization and stresses in the steel casing. To the authors' knowledge there is currently little attention from academic research on FE-simulation of rotary kilns especially that includes brick lining and evaluates its mechanical response in static or dynamic cases, in cold or hot state.

Producers of iron-ore pellets for iron making are common users of rotary kilns. The size vary between 30 and 45 m in length and 5–8 m in diameter. The service temperature in the hottest zone is locally approximately 1300 °C. The kiln is resting on two pairs of support rollers. It is equipped with massive steel tyres for stiffening purpose that are riding on the support rollers. Between tyres and the main body (the casing) filler pads are placed as sacrificing abrasion material. The thickness of the steel casing is typically 50–100 mm depending on the diameter and the axial position (e.g. the casing is thicker close to the tyres). The inner part of a rotary kiln is typically lined with a single layer of refractory bricks. This is required for heat protection of the steel casing and surroundings, reduction of heat losses and maintaining of desired temperature. Fig. 1 illustrates a typical rotary kiln for iron-ore pellet production.

In this work some general aspects and basic concept of rotary kilns are discussed. Contribution of this paper is to, by means of FEA, study the effect of ovality, rotational speed, Young's modulus of the bricks and friction of the bricks on the load state and behaviour of a single layer brick lining in cold condition in static and dynamic cases. For this, a new methodology for studying the brick lining is proposed. The commercial FE-software LS-DYNA [22] is used for FE-calculations. The used parameters (geometries, material data etc.) are typical for rotary kilns in iron-ore pellets production.

2. Theory

Brick lining of a rotary kiln is directly or indirectly in symbiosis with the rest of the system. To some important factors influencing brick lining's life can be included ovality of steel casing, burner conditions, fit of the tyres and alignment of the kiln. Too high ovality of the steel casing can cause unhealthy load peaks in the brick lining during rotation. Misaligned burner or badly controlled power output of the burner can cause critical temperature peaks in parts of the lining leading to mismatched thermal expansion. Too tight riding tyre can inhibit thermal expansion of the brick lining leading to failure of the lining or even the tyre. Misalignment of the kiln can cause unnecessary stresses to the rollers, tyres and the brick lining [3,8].

Severe damage of the lining is usually presented by the fall outs or essential thickness reduction of the bricks. This leads to the formation of “hot spots” on the steel casing, indicating local temperature increase due to worsen heat insulation. The “hot spots” risk permanently damage the casing and making it less perfect (e.g. indents). Bad perfection of the steel casing worsen integrity of the brick lining, which additionally augments the risk of future lining failure. The damaged areas risk also crack formation followed by corrosion and other problems decreasing life of the casing. Thus, when “hot spots” are detected the production is commonly stopped for emergency maintenance. Due to the need of slow cooling and heating of the kiln, and repairing, the kiln can be out of service for 5–14 days [3,8].

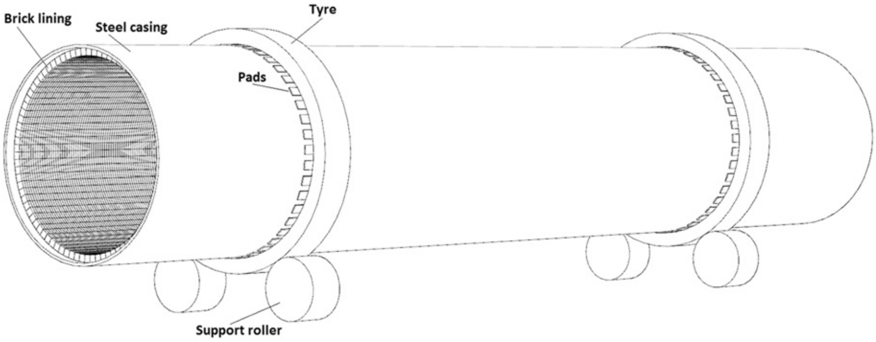

Fig. 1. Illustration of a typical short dry-kiln used in iron-ore pellet industry (true proportions).

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