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Upright die pressing of refractory hollowware for steel ingot casting with reduced clay content

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Abstract

This phenomenological study investigated alumina-mullite refractories with a large height–diameter ratio bonded by 3 wt% clay and temporary additives. The temporary additives were categorized into binders, plasticizers, pressing aids and lubricants. The influence of the additive mixes on apparent and bulk density, open porosity, bending strength and exemplary density gradients was determined. Due to improved lubrication, one of the highest strengths (19 MPa) and lowest open porosities (18%) was achieved by combining a polysaccharide binder, a high-viscous cellulose derivative plasticizer, a fatty acid lubricant and a wax dispersion pressing aid. Mainly the polysaccharide and the fatty acid improved the lubrication due to their functional groups. Hence, upright die pressing was successful. The density gradient, however, was unaffected by the regarded additives.

Keywords: Density gradient; Steel ingot casting; Refractory; Runner brick; Lubrication

1. Introduction

Severe bending stresses occur at high temperatures during continuous casting of steel. Steel grades which are sensitive to such stresses are ingot cast discontinuously—usually in a bottom teeming process. Steel ingot casting is also applied when extreme block sizes are necessary for manufacturing forgings or thick plates [1,2].

During ingot casting, the steels are poured through a refractory pipe system into the ingot mould. The refractories of the pipe system like runner bricks are indicated as hollowware [1].

The hollowware is mainly produced by extrusion and increasingly also by upright die pressing [1,3,4]. In both processes friction in the mass and between mass and tool occurs. The friction causes a pressure drop, especially for high ratios of the height h in pressing direction to the diameter d orthogonal to the pressing direction. Consequently, an inhomogeneous compaction and a high density gradient arise [5–7]. A high h/d ratio, furthermore, increases the necessary ejection stress which can cause cracking. Therefore, lubricants are important to improve the pressure pass and to reduce the density gradient as well as the ejection force [8,9]. To decrease the friction and to attain the necessary plasticity of the refractory batch, high amounts of clay between 5 and 15% [10] are used in common dry pressing. For upright die pressing with larger h/d ratios even higher amounts are used [1,3].

Clay is a natural raw material which is generally plastic at appropriate water contents and hardens after a thermal treatment. The most important components are phyllosilicates [11]. Therefore, clay usually contains a considerable amount of SiO_2 [3].

The SiO_2 reacts with alloying elements of the steel such as manganese, chromium or aluminum [1–4,12,13] and thus causes non-metallic inclusions in the final steel product. Inclusions act as stress raisers and lower the mechanical properties of the steel significantly. Regarding the refractory corrosion and erosion, the amount and size of the inclusions

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Table 1
Properties of the additives according to manufacturer.

Category	Name	Chemical basis	State	Active substance (%)	Viscosity at 20 °C (mPa s)	Recommended addition (wt%)
Temporary binder	PS17	Polysaccharide	Dispersion	≈25	6000	1–3
	AC95	Polymer	Dispersion	50	2800	1–2
Plasticizer	C92	Cellulose derivative	Powder	100	600[a]	0.5–3
	C28	Cellulose derivative	Powder	100	20,000[b]	0.5–3
Pressing aid	WE52	Wax	Dispersion	50	100	2–8
	91/11	Tenside	Dispersion	≈50	1500	0.2–1.5
Lubricant	9002	Polyoxyethylen	Dispersion	50	25	0.2–2
	126/3	Fatty acid	Liquid	100	50	0.2–1.5

[a] 1% solution at 25 °C.
[b] 1.9% solution.

can be reduced by using high purity zirconia or alumina materials as well as lowering the silica content [1,2,13]. In the ceramic batch, therefore, the clay content should be reduced or avoided [1].

In general, clay can be substituted by organic additives which decompose completely [14,15]. Such temporary additives, however, may lead to a springback which can cause cracks and destruction of the body after ejection [8]. Therefore, the use of organic additives is limited. To our knowledge, no additive mix was reported to date which supplies the necessary lubrication in sufficient small amounts to enable upright die pressing with large h/d ratios.

The idea of the present study is to reduce the clay content to 3 wt% and to investigate the influence of different temporary additive mixes on the density and the internal density distribution. Besides common lubricants, cellulose derivatives as strong pseudoplastic additives will be used [16]. Pseudoplastic additives are force and pressure sensitive. Consequently, during pressing a good lubrication is expected due to a low viscosity whereas in the pressureless state a good bonding power is expected due to a high viscosity.

2. Experimental

The influence of additive mixes on properties of upright die pressed refractories with a clay content of 3 wt% was investigated. Subsequently, runner bricks were produced from exemplary batches and their density distributions were analyzed.

The used raw materials were alumina-mullite aggregates and a special clay with only ≈50 wt% SiO_2 content in line with Rettore et al. [3]. A reduced clay amount of 3 wt% was applied in all experiments. The investigated temporary additives were categorized according to their main function into temporary binders (TB), plasticizers (PL), pressing aids (PA) and lubricants (LU). All temporary additives were purchased from Zschimmer & Schwarz GmbH & Co. KG in Germany. The tested temporary binders were Optapix PS17 and AC95. The plasticizers Zusoplast C28 and C92 were used as well as the pressing aids Zusoplast WE52 and 91/11. The lubricants were Zusoplast 9002 and 126/3. Table 1 lists some properties of the tested additives as given by the manufacturer.

Table 2
Design of experiments for the additive selection.

Category/Factor	Levels (wt% Additive)	
Temporary binder	2.50 PS17	1.75 AC95
Plasticizer solution in water	1.25 C92	1.25 C28
Pressing aid	1.00 WE52	0.70 91/11
Lubricant	0.50 9002	0.50 126/3

A design of experiments was applied to investigate the effects of the additive selection and combination. In preliminary experiments, a basic composition for the experimental design was determined to assure the manufacturing feasibility of all experimental points of the design. The basic composition contained 2.5 wt% PS17 as temporary binder and 1 wt% of the pressing aid WE52. The total water amount was adjusted to 3.25 wt%. A part of the water was already included in the additive dispersions. The remaining water was added in a solution with 1.25 wt% of the plasticizer C28.

The experimental design was adapted from the basic composition. The used additive amounts were determined according to the recommended addition of the manufacturer (Table 1). Only in case of the pressing aids lower amounts in line with the basic composition were applied. The experimental design is presented in Table 2. The water content was 3.25 wt% for all batches and adjusted similar as for the basic composition.

The samples were mixed in a compulsory mixer. First, the fractions with particle sizes ≥0.5 mm were mixed for 1 min. Then the temporary binder was added and mixed with the coarse grains for 2 min. Afterwards, the finer fractions were added and the batch again mixed for 1 min. Thus, the fine particles adhered to the binder-coated coarse grains. Such a mixing type is referred to as ordered mixing [10,17]. Subsequently, the plasticizer solution, the pressing aid and the lubricant were added in this sequence whereby after each addition the batch was mixed for 30 s. During mixing the temporary additives are considered to intermix due to friction. Directly after mixing, the apparent density of the batches was measured according to the standard EN ISO 60 on at least three samples.