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EFFECT OF FOUNDRY WASTE CONTENT ON TECHNOLOGICAL PROPERTIES OF CERAMIC BRICKS

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Abstract

A change from linear to cyclical production processes, as proposed by Industrial Ecology, is investigated in this paper. The feasibility of introducing Waelz slag (Ferrosita®) into a ceramic manufacturing process had been assessed in previous studies. In this work, the influence of incorporating Waelz slag and a Waelz slag/Moulding sand mix into a clayey matrix has been evaluated through the analysis of the physical and mechanical properties of fired bodies. A mathematical model has been developed in order to optimize the Waelz slag content in the clay mixture. The results demonstrate that the introduction of Waelz slag or slag/sand mix may improve the physical and mechanical properties of resulting ceramic bodies.

Keywords: Ceramic, Optimization, Moulding sand, Valorisation, Waelz slag.

INTRODUCTION

The recuperation of zinc from electric arc furnace (EAF) dust by means of Waelz process generates large amounts of an industrial by-product called Waelz slag. On the other hand, the management of waste sand derived from moulding processes has been identified as the most important problem in casting foundries. The valorisation of Waelz slag and Moulding sand by their incorporation into ceramic materials is regarded to be a better option than controlled disposal. The incorporation of waste or by-products into ceramic products avoids the depletion of natural materials resources, while reducing overall energy consumption [1].

In a previous work the sintering behaviour of Waelz slag was studied [2]. The results obtained have shown the feasibility of incorporating Waelz slag into ceramic processes for the production of quality building materials, as it improves the melting character of the clay.

The aim of this work is to study the influence of the proportion of Waelz slag and Waelz slag/Moulding sand mix in the physical (firing shrinkage, bulk density, water absorption and loss on ignition) and mechanical (modulus of rupture) properties of ceramic bodies. In order to optimize the Waelz slag content in clayey bodies, a mathematical model has been developed using General Algebraic Modelling System (GAMS) software

EXPERIMENTAL

The clay employed in this work was supplied by a local brick manufacturer from the north of Spain. The Waelz Slag, of commercial name Ferrosita®, was supplied by Befesa Zinc Aser (Abengoa Group), an EAF dust recycling plant located in Erandio (Basque Country, Spain).

The flow chart of the ceramic manufacturing process is shown in Figure 1. The original ceramic matrix consists of natural clay and Wood pulp (8 %wt). Two kinds of fired samples (of size 100 mm x 80 mm x 20 mm) were developed. In a subsequent study, the natural clay was replaced with different proportions of either Waelz slag (10, 20, 25, 30, 35 and 40 wt%) or Waelz slag/Moulding sand mix (20, 30 and 40 wt%). In each mixture, the content of both materials, slag and sand, varied as it can be observed in Table 1. The mixtures were homogeneized and then moulded in a laboratory clay extruder VERDÉS, 050-C to obtain the pilot specimens. Once moulded, they were dried at 100 ºC in a drying room and then fired in an industrial oven located in the brick factory using a low temperature cycle, 850 ºC.

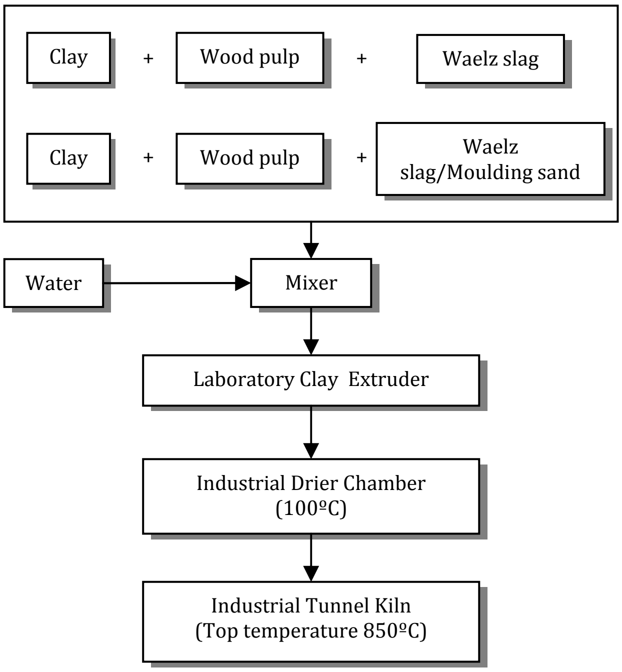

Figure 1: Flow chart describing the manufacturing process employed to produce the ceramic products.

Physical and mechanical characterisation of the fired specimen were performed according to the procedures stated in Council Directive 89/106/EEC (EU, 1989) in order to test the following properties: Firing shrinkage; Bulk density (UNE-EN 772-13) [3]; Water absorption (UNE-EN 67027) [4] and Weight loss on ignition (LOI). Analyses of physical properties were conducted in quintupled. Flexural strength (modulus of rupture) was conducted according to standard method UNE-EN 771 [6] using a mechanical servohydraulic equipment with a stress cell SUZPECAR MES-150 of 15 Tm of capacity, equipped with module of electronic control MIC-101 H. Experimental values were fitted to polynomial curves that represented the different properties as a function of the Waelz slag content. In order to optimize the Waelz slag content, the resulting polynomial regressions were analysed using GAMS software.

RESULTS AND DISCUSSION

In general, the firing process produces a densification process related to the shrinkage of the ceramic body. That effect reduces the open porosity and therefore the water absorption capacity of the samples[1].

Figure 2 plots the technological properties, both physical and mechanical, of Clay/Waelz slag bodies. Due to the phase transformation that occurs in the Waelz slag with temperature [2], the experimental results show that higher Waelz slag content result in lower firing shrinkage (FS) and loss on ignition (LOI). In spite of this effect, the introduction of Waelz slag produces a slight increase in bulk density (BD) that reduces the water absorption (WA) capacity of the final products. The incorporation of Waelz slag improves the mechanical properties of the ceramic products, as evidenced by a slightly increase of their modulus of rupture (MOR).

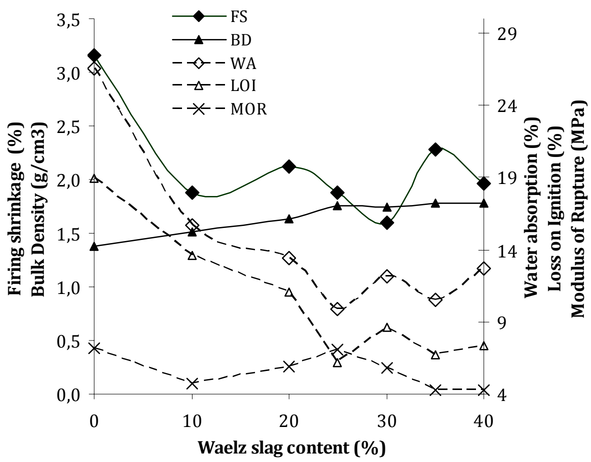

Figure 2: Physical and mechanical properties of Clay/Waelz slag/Wood pulp bodies

The technological properties, both physical and mechanical, of ceramic bodies containing slag/sand mix are shown in Table 1. The effect of the replacing the clay with the sand/Waelz slag mix is very similar to that observed in the case of Waelz slag. The presence of moulding sand increased slightly the firing shrinkage (FS) and the modulus of rupture (MOR) of the fired bodies, compared to Clay/Waelz slag bodies. On the other hand, the sand appeared to reduced bulk density (BD), water absorption (WA) and loss on ignition (LOI) in the resulting ceramics.

Mathematical regressions of technological properties as a function of their Waelz slag contents were calculated using the Kaleidagraph software and the results were subsequently analyzed using the GAMS model, which incorporated a range of high/low quality criteria for ceramic products obtained from published in the literature and in industry quality standards. Quality standards for commercial bricks, as employed in these analyses, were as follows: firing shrinkage below 8%; the bulk density below 2 g/cm^3; and loss on ignition between 15% and 5% [7]. Brickmakers admit up to 16% of water absorption. According to UNE EN 772-1 [8], the modulus of rupture of light brick must be higher than 5 MPa.

Table 1: Physical and mechanical properties of Clay/Waelz slag/Moulding sand/Wood pulp bodies

Mix (%)	Walez Slag (%)	Moulding sand (%)	FS (%)	BD (g/cm^3)	WA (%)	LOI (%)	MOR (%)
	5	35	2,56	1,71	10,14	7,10	3,62
	10	30	2,56	1,75	10,25	6,56	4,77
	15	25	2,12	1,74	11,31	5,48	5,85
40%	20	20	2,44	1,67	12,83	8,46	4,78
	25	15	2,36	1,72	10,96	6,62	4,86
	30	10	2,32	1,77	10,01	4,27	5,02
	35	5	1,76	1,90	8,15	4,79	4,98
	5	25	2,80	1,74	9,73	6,51	5,76
	10	20	2,68	1,66	12,60	9,49	6,24
30%	15	15	2,24	1,68	12,45	9,27	7,76
	20	10	2,36	1,74	10,33	6,07	5,85
	25	5	1,96	1,72	11,84	7,57	6,41
	5	15	2,48	1,65	12,42	10,45	6,25
20%	10	10	2,40	1,67	10,64	8,17	6,19
	15	5	2,44	1,68	11,95	10,48	7,12

FS: Firing shrinkage, BD: bulk density, WA: water absorption, LOI: Loss on ignition, MOR: modulus of rupture.
Wood pulp: 8wt%. Total content of solid: 100wt%

Table 2 illustrates the results obtained from the GAMS model for different replacement values (between 5-40 % of the original clay replaced either by slag or by a mixture of sand and slag). The results showed that, in the absence of moulding sand, ceramic products containing up to 32 wt% Waelz slag would still comply with the quality standards indicated above. When sand was also incorporated into the mixture, the results show that an even higher proportion of Waelz slag (34 %) could be added to the mixture before failing the quality tests. This suggests that addition of moulding sand favors the incorporation of Waelz slag into the ceramic matrix. In the case of lower replacement values (20 and 30 %), quality standards were met even at the highest Waelz slag concentrations (15 and 25 %, respectively).

CONCLUSIONS

In this work, the technological properties, both physical and mechanical, of ceramic materials containing either Waelz slag or a Waelz slag/Moulding sand mix have been investigated. In addition, mathematical models have been developed in order to optimize the Waelz slag content in the ceramic products.

The results show that the addition of Waelz slag and Waelz slag/Moulding sand mix into ceramic bodies improves the technological properties, physical and mechanical. Taking into account the quality standards and industry requirements, optimum Waelz slag content for light bricks is 32%. This proportion could be increased up to 34% if Waelz slag is combined with Moulding sand.

Table 2: Maximum Waelz slag content of fired bodies.

Total Replace Mix (%)	Walez Slag (%)	Moulding sand (%)	Maximum Waelz slag (%)
	10		
	15		
	20		
10-40%	25	0%	32%
	30		
	35		
	40		
	5	35	
	10	30	
	15	25	
40%	20	20	34
	25	15	
	30	10	
	35	5	
	5	25	
	10	20	
30%	15	15	25
	20	10	
	25	5	
	5	15	
20%	10	10	15
	15	5	

Replace mix = Waelz slag + moulding sand
Natural clay contains 8 wt% wood pulp in all cases. Total content of solid: 100wt%

REFERENCES

[1] M. Romero, A. Andrés, R. Alonso, J. Viguri, J. Ma. Rincón (2008) Sintering behaviour of ceramic bodies from contaminated marine sediments, *Ceramics International*, 34, 1917-1924.

[2] N. Quijorna, R. Alonso-Santurde, G. San Miguel, J.R. Viguri, A. Andrés (2008) Implementing industrial ecology through the incorporation of Waelz slag into clay bricks: thermal characterization of the slag, Abstr, p. 399-400. Abstr. 1st International Conference Hazardous Waste Management,

[3] EU (1989) Council Directive 89/106/EEC of 21 December 1988 on the approximation of laws, regulations and administrative provisions of the Member States relating to construction products.

[4] EN- 772-13:2001. Methods of test for masonry units - Part 13: Determination of net and gross dry density of masonry units (except for natural stone).

[4] EN-67027:1984. Burned clay bricks. Determination of the water absorption.

[5] EN-771:2003. Specification for masonry units - Part 1: Clay masonry units.

[6] P-H. Shih, Z-Z. Wu, H-L. Chiang (2004) Characteristics of bricks made from waste steel slag, Waste Management, 24 (10) 1043-1047.

[7] EN-772-1. Methods of test for masonry unit. Part 1. Determination of compressive strength.

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