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Evaluation of Synthetic Gypsum Recovered via Wet Flue-Gas Desulfurization from Electric Power Plants for Use in Foundries

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Abstract

This article investigates possible use of waste gypsum (synthetic), recovered via flue-gas desulfurization from coal-fired electric power plants, in foundries. Energy sector, which in Eastern Europe is mostly composed from coal-fired electric power plants, is one of the largest producers of sulfur dioxide (SO_2).

In order to protect the environment and reduce the amount of pollution flue-gas desulfurization (FGD) is used to remove SO_2 from exhaust flue gases of fossil-fuel power plants. As a result of this process gypsum waste is produced that can be used in practical applications.

Strength and permeability tests have been made and also in-depth analysis of energy consumption of production process to investigate ways of preparing the synthetic gypsum for casting moulds application. This paper also assesses the chemical composition, strength and permeability of moulds made with synthetic gypsum, in comparison with moulds made with traditional GoldStar XL gypsum and with ceramic molds. Moreover examination of structure of synthetic gypsum, the investigations on derivatograph and calculations of energy consumption during production process of synthetic gypsum in wet flue-gas desulfurization were made.

After analysis of gathered data it's possible to conclude that synthetic gypsum can be used as a material for casting mould. There is no significant decrease in key properties, and on the other hand there is many additional benefits including low energy consumption, decreased cost, and decreased environmental impact.

Keywords: Innovative foundry materials, Flue-gas desulfurization (FGD), Waste gypsum (synthetic), Gypsum moulds, Ceramic moulds.

1. Introduction

Production of precision castings using the lost wax method is an important and widely used technique of manufacturing parts [1]. In addition, precision castings made in the vacuum [2] or in the backpressure process [3, 4] outweigh the reliability of products manufactured by using many other metal forming techniques. An important area in which the lost wax method is used is a production of aluminum alloy castings, this is visible in the industries around the world, especially in the U.S. and the UK.

Competition for the lost wax method in the production of aluminum alloy castings is the investment casting in plaster moulds, both in the manufacturing of industrial castings and in art. In addition to lower cost of manufacturing plaster moulds, they also require lower energy consumption for production, which further affects the environmental impact of manufacturing goods (environmental improvement).

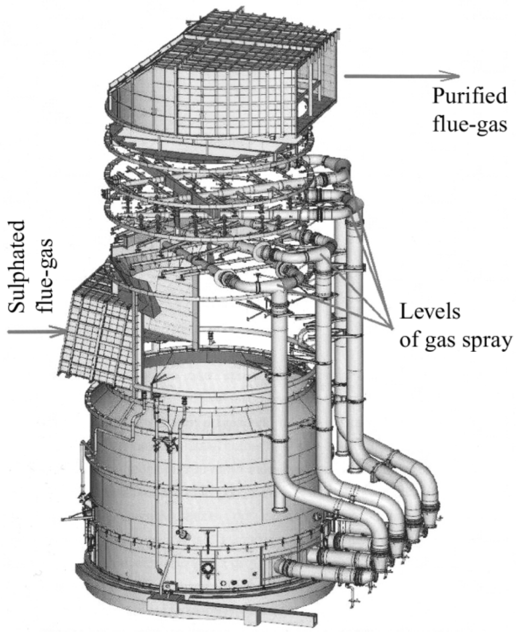

Fig. 1. Absorber used for flue-gas desulphurization in power plants

Research related with the performance of the investment casting of aluminum alloys was carried out so far mainly based on cristobalit gypsum for industrial castings [5, 6, 7, 8], and for artistic castings [9, 10].

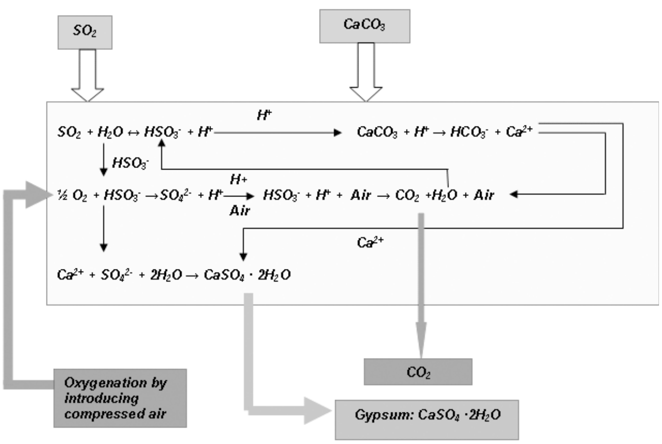

Fig. 2. The basic reactions in the absorber flue-gas desulfurization

In our study presented in this paper, we used synthetic gypsum, which is a waste product of plants produced in the wet flue-gas desulfurization. This was done as follows:

1) Preparing a slurry - sorbent (limestone flour in an aqueous solution),
2) Introduction of absorption slurry into circulation in the absorber (Fig. 1), which acts on sulfur oxides SO_x,
3) Absorption in the absorber with a capacity of 5700 m^3 proceeds according to the reactions shown in Fig. 2, the basic response to $CaCO_3$+SO_2 resulting in a gypsum $CaSO_4 \cdot 2H_2O$,
4) Meanwhile oxygenation process is carried out by a suitable air supply,
5) Crystallization of gypsum.

2. Evaluation of selected materials used for expendable moulds, which are used to produce high-quality AlSi alloy casts

These types of castings usually are made in plaster or ceramic moulds in lost wax method.

A comparison of high-quality gypsum GoldStar XL with synthetic gypsum (waste) obtained in the process of flue-gas desulfurization was made. Chemical studies have shown that gypsum GoldStar XL contains over 20% more Si than gypsum waste, and waste gypsum contains over 20% more Ca than GoldStar XL. The remaining components are in similar quantities, percentagewise in both types of gypsum.

High-quality gypsum have similar structure to spherical (Fig. 3a), and gypsum waste has the structure of small plates shape (Fig. 3b) unfavorable due to the lower strength of the mould.

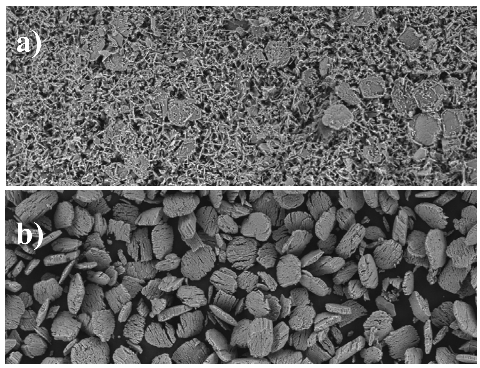

Fig. 3. Images from a Scanning Electron Microscope: a) gypsum GoldStar XL; b) waste gypsum (synthetic) ; (x250)

The quality of both gypsums was also examined on derivatograph. Synthetic gypsum was annealed at 170 ° C for two hours before the test. Despite this, on the diagram (Fig. 5) it is possible to observe a significant endothermic reaction, which is possibly associated with the disposal of water. Other exothermic and endothermic reactions are small, that's why generally it is possible to state that in sense of those properties both gypsum materials are comparable to each other (Fig. 4a and Fig. 4b).

In order to make a full comparison of gypsum materials, which will be used for casting moulds, further studies assessing bending R_g and permeability need to be made. Permeability is related to the filtration of gases through the walls of the form and has an effect on mould filling by the liquid metal. In previous studies [11] the impact of the permeability P_F on the quality of AlSi alloy casts was determined.

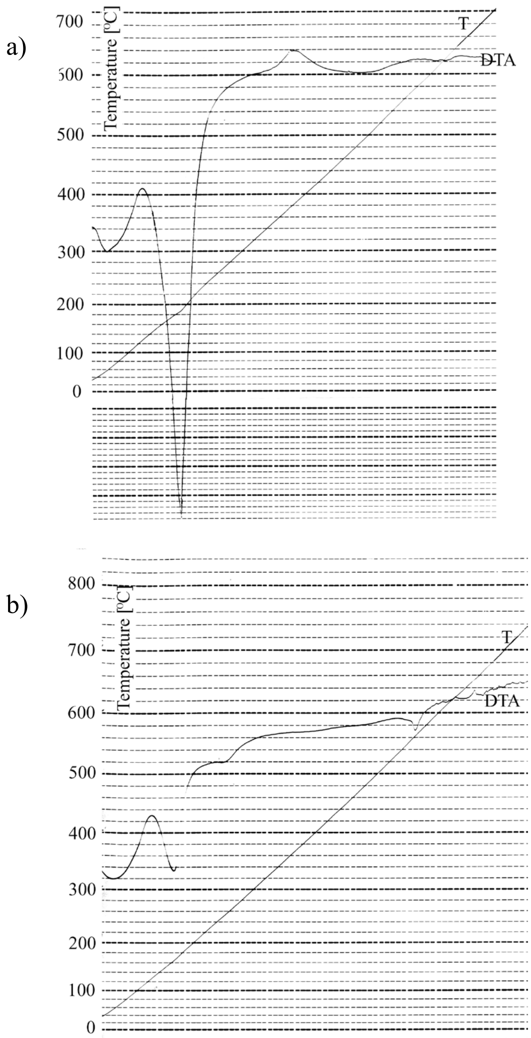

Fig. 4. Diagrams from derivatograph: a) waste gypsum (synthetic); b) gypsum GoldStar XL

2.1. Bending tests R_g of mould samples

Bending resistance R_g of gypsum samples were compared with those taken from ceramic mould. Strength tests were carried out in the system of three points with a distance between supports – 50 mm. Transverse dimensions of the samples of gypsum nests made of a mixture of PSW_p wax (paraffin wax, stearin and polyethylene wax) were 19 x 5 mm. Samples were prepared from four-layer ceramic moulds (dimensions 15 x 4 mm) and nine-layer (measuring 20 x 9 mm). Moulds were made from aqueous silicate binders and aluminosilicate ceramics.

Average values were determined for at least six samples, resistance R_g was:

1) Samples from GoldStar moulds – about 0.67 MPa,
2) Samples from synthetic gypsum (waste) mould with additives – 1.4 MPa,
3) Sample from 4-layered ceramic moulds – 1.68 MPa,
4) Sample form 9-layered ceramic moulds – 2.12 MPa.

Samples from synthetic gypsum mould contained at least 60% of waste gypsum, the addition of quartz sand, a small amount of gypsum GoldStar and around (1%) of cement GÓRKAL 40.

2.2. Permeability test of moulds samples

Permeability examination was performed by comparison. The reference point for the permeability coefficients was determined for ceramic moulds in previous studies [11]. As a result of these studies it was found that achieving high quality AlSi castings is contingent upon the permeability coefficient of ceramic molds above P = 0.5 m^2/Pa*s (specified at 20 ° C temperature). In Figure 5 castings made in mould with permeability about 0.3 m^2/Pa*s [11] are presented. There are visible misruns.

Fig. 5. Castings made in the low permeability ceramic mould

As a result of comparative studies it was found that the flow time of 400 cm^3 of air flow through a sample of synthetic gypsum is higher than for samples of the ceramic mould. For this reason, in subsequent stages of research, new procedures for the production of synthetic gypsum moulds need to be developed. The main emphasis need to be placed on increasing permeability of those moulds. The study was conducted for samples made of the same materials that were used to test the strength R_g (Fig. 6).

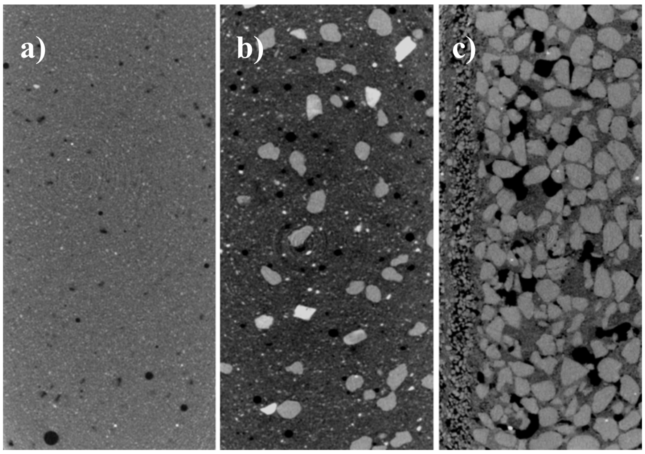

Fig. 6. Images from CT (Computed tomography) scan Metrotom 800: a) GoldStarXL gypsum mould b) synthetic gypsum mould, c) ceramic mould

3. Energy consumption of the materials acquisition for moulds in terms of environmental impact

Energy consumption of producing ceramic materials for moulds was compared with the energy consumption for the synthetic gypsum (waste) obtained during the FGD.

According to the literature [12] the energy consumption of achieving ceramic material used for making moulds for lost wax process is 2.35 MJ / kg.

Analysis of wet flue-gas desulfurization at power plants (Fig. 2) allowed obtaining the following data:

$E_G = E_{SS} + E_{AD} + E_N + E_{KR} + E_{PS} + E_S$

where:

E_G - energy consumption of obtaining gypsum,

E_{SS} - energy consumption needed for preparation of sorbet suspension (which is needed to absorb sulfur and put it into circulation),

E_{AD} - energy consumption of sulfur oxides absorption,

E_N - energy consumption of the aeration (as shown in Figure 2),

E_{KR} - energy consumption of gypsum crystallization,

E_{PS} - energy consumption of gas heating in desulphurization installation,

E_S - energy consumption of wastewater treatment in flue gas desulphurization installation.

Sum of all the available data allowed achieving the value of the useful energy consumption in wet flue-gas desulfurization, necessary for the production of waste gypsum. This value is about 80 600 MJ per 1 hour of work. Plant efficiency is 68 Mg / h, which calculated for 1 kg of waste gypsum gives about 1.2 MJ, at several times lower selling expenses of synthetic gypsum in comparison to GoldStar gypsum.

4. Conclusions

1. Synthetic gypsum is a suitable material for casting moulds.
2. Bending strength of synthetic gypsum moulds is similar to the strength of ceramic moulds.
3. Energy consumption of producing materials for synthetic gypsum moulds is much smaller than energy needed for producing materials for ceramic moulds.

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