Reclamation of material from used ceramic moulds applied in the investment casting technology

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Abstract

Investigations on utilisation of reclaimed materials from used ceramic moulds applied in the investment casting technology, are presented in the hereby paper. This reclaim was used as a matrix for the preparation of the test moulds. Rheological properties as well as tensile strength at a room temperature of such ceramic sands were even better than of sands made of fresh components. However, ceramic sands with a reclaimed material exhibited worse properties at higher temperatures. The second direction of utilizing the reclaim was using it as the so-called powder topping when making ceramic moulds (for the IIth and successive layers). Tensile strength values at high temperatures of moulds made with the reclaim participation were comparable (and in some cases even higher) to values of moulds made of fresh components (Al₂O₃). These results encourage the further investigations in this field.

Keywords: environment, foundry, coal dust, green sand, bentonite, BTEX, PAHs

1. Introduction

Waste materials and emitted gases mainly from the wax model melting constitute an environment hazard in the process of making castings in the technology of investment casting [1, 2, 3]. Basic wastes of an investment casting house implementing the technology of investment casting are: used shell moulds, insoluble waxes, gypsums, refractory plastics (mixtures of binders and basic ceramic materials), soluble waxes and fibrous insulation materials. The balance of main wastes generated by the French investment castings is shown in Table 1.
Table 1. Balance of the waste in investment casting foundries in France [1]

<table>
<thead>
<tr>
<th>Waste</th>
<th>Amount Mg/year</th>
<th>Mass fraction, %</th>
<th>Procedure, Mg/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insoluble waxes</td>
<td>1100</td>
<td>18</td>
<td>Recovery 700</td>
</tr>
<tr>
<td>Gypsum</td>
<td>850</td>
<td>14</td>
<td>Treatment 50</td>
</tr>
<tr>
<td>Used ceramic moulds</td>
<td>3800</td>
<td>62</td>
<td>Storage 300</td>
</tr>
<tr>
<td>Refractory ceramic mixture</td>
<td>312</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Soluble waxes</td>
<td>80</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Fibrous insulating materials</td>
<td>74</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

The largest waste, quantitatively above 60%, from the investment casting technology constitute used ceramic moulds. According to the binding regulations concerning the environment protection, endeavours - to minimize the waste amounts and to their recycling and management in other processes - should be undertaken. Therefore investigations on possibilities of recycling of used ceramic moulds from the investment casting technology of the castings which are producing nickel alloys, were undertaken. The most advantageous solution would be recycling of those used moulds into the process of the ceramic moulds production either in a form of suspension or as powder toppings for moulds [4]. Fresh materials used for this purpose are very expensive, which significantly increases costs of the casting production in this technology. Additional advantage of such recycling would be an avoidance of transport and storage costs of these wastes. Another solution could be the utilization of used ceramic moulds outside the foundry industry (ceramic industry, roads building). However, in this case an essential parameter is an assessment of wastes influence on the environment [5, 6, 7]

2. Preparation of the reclaimed material from used ceramic moulds

Breaking up of used ceramic moulds, obtained from the production of investment castings, was carried out at various work parameters of the crushing installation. Schematic presentation of crushing tests of used ceramic moulds is shown in Figure 1. The applied disintegration process consists of three main stages (Fig. 1):

- **Preliminary crushing** in a jaw crusher. As a result of this operation broken up mould pieces are obtained. Dimensions of elements are within the jaw crusher clearance, which in the performed tests was in the range: 0.5-1 cm;
- **Crushing** in roll mixer. After this operation the product is ready for further, appropriate treatment;
- **Secondary disintegration** performed in the experimental device, which is characterised by wide possibilities of changing rotational speed of the rotating disintegration element and the possibility of measuring the engine power input.

The reclaim obtained from used ceramic moulds was divided into two basic fractions: fine-grained and coarse-grained.

The possibility of applying the reclaim, obtained from the reclamation process of used ceramic sands, in two directions was assumed in investigations:

- ‘Fine’ fraction as a matrix for a preparation of liquid ceramic sands,
- ‘Coarse’ fraction as a material for powder topping of ceramic moulds when preparing their successive layers.

As the applicability measure of the material, obtained from the reclamation in the described testing cycle, the ceramic moulds strength estimated in the 1st stage of making these moulds, it means the so-called ‘green strength’ and the strength after heating at temperatures: 400 – 1000°C (tensile strength Rm), were assumed. Since the investigations were of a comparable character, each time parallel samples were made from fresh materials and from the reclaimed ones.
3. Investigations with the application of the reclaimed material for the preparation of ceramic sands

3.1. Preparation of a liquid ceramic sand

It was assumed that the prepared ceramic sands will be applied for the second and successive mould layers. Compositions of ceramic sands applied for these layers in test ceramic moulds as well as materials applied for powder toppings, when making successive layers, are listed in Table 2. Components of ceramic sands and as well as powder toppings were substituted – in the performed tests - by the reclaimed material.

Colloidal silica Ludox AM was used as a binding agent in all tests.

Table 2. Composition of individual layers of a ceramic mould

<table>
<thead>
<tr>
<th>Layer</th>
<th>Composition of a ceramic mould</th>
<th>Powder topping</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Ludox AM - 1 dm³ (1200 g)</td>
<td>Al₂O₃ #80</td>
<td>Viscosity from 11 to 13 s. (measured by the Zhan’s cup)</td>
</tr>
<tr>
<td></td>
<td>Al₂O₃ #200 - 1710 g</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Al₂O₃ #325 - 1710 g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>Powder topping M1 (mullite of a finer grain-size)</td>
<td>Viscosity from 11 to 13 s.</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>Powder topping M2 (mullite of a coarser grain-size)</td>
<td>Viscosity from 11 to 13 s.</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>Powder topping M2 (mullite of a coarser grain-size)</td>
<td>Viscosity from 11 to 13 s.</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>Powder topping M2 (mullite of a coarser grain-size)</td>
<td>Viscosity from 11 to 13 s.</td>
<td></td>
</tr>
<tr>
<td>VI</td>
<td>Powder topping M2 (mullite of a coarser grain-size)</td>
<td>Viscosity from 11 to 13 s.</td>
<td></td>
</tr>
<tr>
<td>VII</td>
<td>Powder topping M2 (mullite of a coarser grain-size)</td>
<td>Viscosity from 11 to 13 s.</td>
<td></td>
</tr>
</tbody>
</table>

3.2. Investigations of strength Rₘ of the fresh moulds, ‘green strength’, with using the reclaimed material

The ceramic sand was used at preserving a mass proportion: Ludox AM (1200 g) and fine-grained reclaim fractions (3420 g). The obtained ceramic sand is characterized by good rheological properties and is easy to be deposited on a wax model and on successive layers. The sand had the proper viscosity determined by means of the Ford cup (dₜ = 4.0 mm) – outflow time: 20 – 30 s. Similar values of an apparent viscosity are characteristic for ceramic sands - intended for the second and successive layers - based on fresh materials. The concept of investigating strength Rₘ of ceramic moulds in a ‘fresh’ condition was developed in the Laboratory of Casting Moulds Technology. The ceramic layer (one or several) is deposited on the divided sleeve, and after the selected drying time, is undergoing a tensile test performed by means of the universal machine for moulding sands testing.

The results of the comparative tests in the ‘fresh’ condition of moulds performed when using two kinds of ceramic sands: sand with a reclaim as a matrix and sand with Al₂O₃ as a matrix are shown in Figure 3. Moulds made with using the reclaimed material had slightly higher tensile strength. Samples were dried at a temperature of 30°C for approximately 24 hours, without a ‘forced’ air circulation. The process of drying and hardening of moulds deposited on a wax model can be accelerated only by a forced air circulation (blowing).

The intensification of drying and hardening processes by increasing an ambient temperature can lead to a deformation of wax models. However, at the accelerated drying in certain systems: ceramic sand – matrix applied for powder toppings the micro-cracks can be formed in a layer, which in turn can decrease a sample strength Rₘ in a ‘fresh’ condition. In order to assess whether the described effect of micro-cracks formation really occurs in sands with the reclaimed material matrices - some additional investigations were carried out. Thus, samples of sands were in parallel dried under various conditions: one part under normal conditions, another part with an application of a forced air circulation (Fig. 2).
Fig. 2. Tensile strength of the ‘fresh’ ceramic mould made of a ceramic sand with a matrix:
1- Reclaimed material ; 2 – Al$_2$O$_3$

Drying under conditions of a forced air circulation causes an increase of strength ‘in fresh condition’, $R_m$, and not cracking of layers (and a strength decrease) of the mould prepared with the reclaimed material. It also helps in a better redrying of successively deposited layers.

3.3. Investigations of strength $R_m$ of ceramic moulds after heating

Ceramic moulds produced in the investment casting technology, are subjected to a heat treatment, after a wax model removal (melting, burning etc.). This treatment is aimed at burning wax leftovers and removal of water (introduced by a colloidal binder) as well as other materials which - after heating - could be emitting gases. In addition, the purpose of the high temperature treatment is to transform a silicate binder from a silicit acid sol into a high-strength gel, providing a high strength for the mould at increased temperatures. Holding at high temperatures is specially important for self-supporting moulds, which are required to have respectively high strength during pouring into moulds. The most often moulds are heat treated in two stages: heating and holding at a temperature app. 700 - 750°C for 2 h., followed by burning in a temperature of app. 1100 – 1150°C also for 2 h. Heating and cooling rates are matched to the mould thickness – those processes should be the slow ones. Ceramic moulds are poured in a heated state, to limit the possibility of a thermal stress occurrence leading to a mould cracking and also to enable performing of extra thin-walled castings (e.g. turbine engine blades). Without heating the filling of the moulds cavities would be impossible. Due to these reasons (from a functional quality point of view), a usefulness of new materials for ceramic moulds must be estimated on the basis of their strength at high temperatures.

Appearances of samples prepared for the tensile test is shown in Figure 4.

Fig. 3. Strength of a ‘fresh’ ceramic mould made of a ceramic sand on the reclaim matrix and with the reclaim as a powder topping. Drying in a temperature of 25°C, 1 – with a forced air circulation, 2 - without a forced air circulation

Strength of moulds - at a temperature of 525°C - made of ceramic sands with Al$_2$O$_3$ or the reclaimed material as matrices, being previously roasted at a temperature of 1150°C, is shown in Figure 5.

Fig. 4. Samples made of ceramic sands on the basis of fresh components (on the left-hand side) and of ceramic sands with the reclaimed material (on the right-hand side)

Fig. 5. Strength $R_m$ at $T = 525°C$ of ceramic moulds made of sands: 1- on a basis of fresh materials, 2 – on a basis of the reclaimed material
Conclusions

The following conclusions can be drawn on the grounds of the performed investigations:

1. Liquid ceramic sands made of fine-grained fractions of the reclaimed material and a binder – colloidal silica Ludox AM – are characterised by good rheological properties, are easy to be deposited on a wax model and on successive layers of a ceramic mould as well as have a proper tensile strength at a room temperature.

2. Moulds made of liquid ceramic sands of a matrix of the reclaimed material are characterised by a lower strength $R_m$ at an increased temperature (~500°C) as compared to moulds made of fresh ceramic sands ($\text{Al}_2\text{O}_3$).

4. Investigations with using the reclaimed material as a powder topping for ceramic moulds

The second direction of investigating the usefulness of the reclaimed material from used ceramic moulds comprised tests of its application as a granular material for powder toppings of successively deposited layers of liquid ceramic sands. The reclaim of grain-sizes: $d > 0.315$ mm (collected on sieves: 0.315 and 0.40 mm (Fig. 6) was used in investigations.

The results of tensile strength $R_m$, at a temperature of 525°C, of ceramic moulds made of ceramic sands on the basis of fresh components and at an application of various materials for powder topping are presented in Figure 7.

The obtained results indicate that at a temperature near 500°C the moulds made with an application of mullite, as a granular material for powder topping of moulds exhibit the best behaviour. When the reclaim was applied as a powder topping a slightly lower strength, however similar to the one when $\text{Al}_2\text{O}_3$ was applied – was measured. Currently mullite is being used for outside layers of moulds.

Fig. 6. Appearance of samples made of ceramic sands on the basis of fresh components and mullite as a granular material for powder topping. Heat treatment: 700-750°C – 2 h and then 1100 – 1150°C - 2 h.

Fig. 7. Strength $R_m$, at a temperature of 525°C, of ceramic moulds made of ceramic sands on the basis of fresh materials, when various materials were applied for powder topping

As it was already mentioned, the self-supporting ceramic moulds must exhibit a high strength at temperatures above 1000°C. The additional test run at a temperature range near this value was performed, to estimate the mould strength when the reclaimed material was used for powder toppings of successive layers of ceramic moulds.

Sometimes, to obtain a higher strength of a ceramic mould the more complex multistage heat treatment is carried out. In this test series a slightly longer heat treatment cycle, composed of four stages according to the following schedule: 400°C – 2 h, 700°C – 2 h, 900°C – 2 h and 1100°C – 2 h, was applied. The samples were cooled together with the furnace, while still being inside it. Samples after such heat treatment underwent strength tests $R_m$, at temperatures: 800 – 1000°C. The obtained results are presented in Figure 8.

Fig. 8. Strength $R_m$, at T = 800 - 1000°C, of ceramic moulds made of ceramic sands on the basis of fresh materials, when various materials were used as powder topping

The performed measuring series (at T = 800 – 1000°C) indicate that samples made with the use of a reclaim as a powder topping have at least equivalent and at a temperature ~ 1000°C
even higher tensile strength than samples in which a mixture Al₂O₃+mullite was used for a powder topping.

The presented above results seem to indicate that utilising the reclaim as a material for moulds powder topping, is the proper direction of waste management. While the obtained results are promising, they should be considered cautiously when the final results are taken into account. Further investigations in this field are still necessary.

Conclusions

The performed investigations allow to state that:
1. Utilisation of "coarse-grained" materials originated from the reclamation of used ceramic moulds for a powder topping - due to the obtained results - is justified. Moulds made with the reclaimed material are achieving a high strength, especially in a temperature range near 1000°C. This strength reaches: \( R_m = 3.0 \, \text{MPa} \) and is not lower than the one when fresh materials are used.
2. It will be possible to assess the general usefulness of the reclaimed material as a powder topping when the ceramic mould is made, poured with liquid metal and the quality of the obtained casting estimated.

References


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