Analysis of effectiveness of used sands reclamation treatment – in various technological devices

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Abstract

The analysis of effectiveness of spent sands reclamation treatment performed in technological devices of various intensity of dry reclamation – during which used binding material is being removed from grain surfaces – is presented in the paper. Variety of reclamation influences was considered via the realization of the so called elementary operations such as: rubbing, grinding and crushing [1-5], which are realised mainly in dry mechanical reclamation devices but also appear in other technological devices for sand preparation. The model rotor reclaimer and two types of mixers used for preparing initial foundry sands with resin U 404 and hardener 100 T3 of the Hüttenes-Albertus Company were applied for tests.

The theoretical model for assessing the effectiveness of reclamation treatment developed by the author [3, 4], was experimentally verified [5, 7], with the application of standard testing procedures. The model can be considered a new tool enabling the selection of optimal reclamation times for the given used sand at the assumed intensity of silica sand matrix recovery. Sand mixture of a proper composition fulfilled needed technological properties after total hardening was used as charge material in experiments. The reclamation treatment consisted of mechanical and mechanical-cryogenic reclamation performed within a wide range of times and conditions influencing the treatment intensity.

Keywords: Waste management, Used sand, Reclamation treatment

1. Rittinger’s energetic model as the base of the reclamation effectivity assessment

The theoretical model of mechanical reclamation presented in authors own papers [3, 4] is based on the deterministic hypothesis of the material disintegration developed by Rittinger [1, 2] who assumed the proportionality of energy used for the disintegration of brittle material and the obtained increased surface of grains. He stated, among others, that for brittle materials: „Crushing works are related to each other in a similar way as their disintegration degrees”. In the case of the presented model the work introduced into the system is used for crushing used binding material being on the grain matrix.

According to the assumed model [3-5], a field contained in between integral curves of a feed grain composition and a product of reclamation processes – given by Equation (1), plotted in a system (1/d, \( \Phi(d) \)) and presented in Figure 1 is considered a measure of work used for disintegration of material clusters into grains.
\[ \Phi(d) = \int_{-\infty}^{\infty} f(x)dx = \int \frac{f(x)}{d}dx \]

where:
- \( \Phi(d) \) – grain composition function
- \( n \) – material before reclamation (feed)
- \( p \) – material after reclamation (product)
- \( d \) – representative grain diameter

\[ V_A = V_z - V_g \]
\[ \rho_g \] – density of coatings of used binding material; kg/m\(^3\) (or g/mm\(^3\)),
\[ \rho_z \] – density of sand matrix material; kg/m\(^3\) (or g/mm\(^3\))
\[ d_z \] – matrix grain diameter; m (or mm),
\[ L \] – mass fraction of binding material in relation to matrix (decimal fraction).

Knowing thickness of a binding material coating, which is to be removed from the grain surface, one can calculate surface increase of grain set caused by the process:

\[ \Delta F_o = \frac{12 \cdot g}{\rho_z \cdot d_z \cdot (d_z + 2 \cdot g)} \]

Having the calculated change of a specific surface of material, which occurs during the reclamation process of used moulding sands the work of removal of used binding material from grain surface can be determined by Equation (4).

According to the previously defined Rittinger’s hypothesis the specific work equals:

\[ L_R = L_0 \cdot \Delta F \]

where:
- \( L_0 \) - work necessary for obtaining a unit surface increase; J/m\(^2\) (or J/cm\(^2\)),
- \( \Delta F \) – increase of material surface as the result of crushing; m\(^2\) (or cm\(^2\)).

The presented considerations indicate that the specific work \( L_R \) calculated by means of granulometric analysis of used moulding sands before and after the reclamation process can be treated as the base for assessment the effectiveness of the reclamation treatment.

2. Characteristic of the experimental stand

Experimental rotor reclaimer and two types of mixers – being the equipment used in moulding sand laboratories in foundries - were applied for the research.

**Experimental rotor reclaimer**

The main systems, realising in this device the reclamation treatment, are rotating impact-grinding elements acting on the batch of used sands and causing successive thickness decrease of used binding agent due to elementary operations of crushing, grinding and rubbing. It was shown in previous investigations [3, 4] that the secondary reclamation effect can be flexibly changed by the proper selection of the rotor system rotational speed.

**Simpson type roller mixer**

During the preparation of moulding sands in the Simpson type roller mixers two essential elementary operations – kneading and grinding [5] occur in the space in between the mixer roller and the immobile mixer pan. In the dry roller mixer operation conditions favourable for the mechanical grinding-crushing reclamation exist, due to rollers moving over the material and due to slips and grinding characteristic for this type of devices. It can be assumed that all elementary operations of the mechanical reclamation occur in roller mixers, while the sequence of decreasing intensity of their occurrence is probably as follows: grinding, rubbing and crushing [6]

**Ribbon mixer LM-1 type**

Functional analysis of this mixer operation – performed in an aspect of a reclamation treatment – indicates less intensive influence on used moulding sands. Material for reclamation is fed into a cylindrical horizontally positioned container in which specially shaped mixing system attached to horizontal shaft rotates. Operation of mass switching with its simultaneous axial displacement in the container is the main operation [6]. Elementary reclamation operations in this type of mixer are reduced to mild rubbing and grinding due to small rotational speed of shaft with ribbon elements.
3. Methodology and conditions of examinations

Reclaimability examinations were performed on used sands with resin U 404 and hardener 100 T3 of the Hüttenes-Albertus Company. The applied resin is an urea-furan resin. Its density in 20 °C equals 1.175 – 1.185 g/cm³. It is specially suitable for casting moulds and cores for high quality castings from grey and nodular cast iron. Hardener 100 T3 is a water solution of paratoluenosulfonic acid. This activator is used for hardening furan resins and resins of Sinotherm type. Density of this hardener equals 1.225 g/cm³ [8].

An initial sand, so called fresh sand, was prepared in a laboratory ribbon mixer, LM type, according to the composition and procedure recommended by the resin producer. Fully hardened moulding sands were used in reclaimability investigations, however, without thermal treatment as it happens under industrial conditions. The fact that the reclamation treatment of unburned sands is much more difficult, from the point of view of matrix reclamation, but the most suitable for comparative tests – seems to be justifying such selection of conditions. An advantageous feature of such material preparation is homogeneity - in the entire sample - of a binding agent covering grains. Such situation is not to be expected in case of used sands from the foundry plant since various sand components are burned to various degrees.

After each stage of the reclamation treatment samples of the reclaimed material were taken for examination, what is shown in Figure 2.

On the bases of screen analysis of samples the assessment of the specific surface changes and the effectiveness of reclamation treatment by means of the developed theoretical model [3, 4] for the estimation (together with ignition losses) of the removal degree of used binder from grain surface, was carried on. In addition dust contents in the reclaimed matrix was checked since it influences the reclamation effectiveness assessment and value of \( W_4 \) grain shape indicator, showing an influence of treatment on grain matrix parameters.

4. Methods of examination

A secondary reclamation treatment, which aim was to remove - in the described devices - layers of used binding material from the matrix grain surface, was preceded by a mechanical disintegration of grain agglomerates, which satisfies the criteria of a ‘primary reclamation’.

The secondary reclamation treatment was done according to the procedural scheme shown in Figure 2. Three reclamation cycles of used sands were applied. Cycles No 1 and 2 were used when the examination of the reclamation process was performed in roller and ribbon mixers, while during cycle No 1 the sand was continuously reclaimed for the assumed time. After each minute of the reclamation treatment of cycle No 2 inter-operational dust extraction was done in a cascade classifier in order to determine influence of this operation for a further reclamation treatment – assessed by the quality of the obtained product. Examinations realised within cycle No 3 concerned the reclamation done in the rotor reclaimer. Times of reclamation treatment were analogical to the ones in cycle No 1, approaching gradually to a maximum value of 30 minutes.

Fig. 2. Block diagrams of the operations applied in the examined reclamation cycles: A–cycle 1 and 3, B– cycle 2
5. The obtained results

5.1. Percentage determination of increasing areas in the coordinate system \((1/d, \Phi(d))\)

Percentage increases of surface areas in between curves of grain composition of a feed (used moulding sands before the reclamation) and the reclaimed material (matrix after the reclamation but before final classification) were determined in examinations and plotted in the coordination system \((1/d, \Phi(d))\). The results are presented in Table 1.

Table 1.
Percentage increase of surface areas in between curves of the feed grain composition and the reclaimed material functions - plotted in the coordination system \((1/d, \Phi(d))\)

<table>
<thead>
<tr>
<th>Reclamation time</th>
<th>Reclamation in a ribbon mixer</th>
<th>Reclamation in a roller mixer</th>
<th>Reclamation in a rotor reclaimer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 min</td>
<td>4.19%</td>
<td>5.1%</td>
<td>7.01%</td>
</tr>
<tr>
<td>5 min</td>
<td>4.35%</td>
<td>10.727%</td>
<td>21.56%</td>
</tr>
<tr>
<td>10 min</td>
<td>7.05%</td>
<td>11.271%</td>
<td>28.02%</td>
</tr>
<tr>
<td>15 min</td>
<td>7.78%</td>
<td>11.9%</td>
<td>33.674%</td>
</tr>
<tr>
<td>20 min</td>
<td>9.75%</td>
<td>14.07%</td>
<td>36.12%</td>
</tr>
<tr>
<td>30 min</td>
<td>10.56%</td>
<td>18.51%</td>
<td>41.77%</td>
</tr>
<tr>
<td>60 min</td>
<td>11.75%</td>
<td>20.96%</td>
<td>X</td>
</tr>
</tbody>
</table>

The obtained results indicate that, when taking into account changes in specific matrix surfaces, the mechanical reclamation is the most intensive in a less intensive in a roller mixer, the Simpson type, and the slowest in a ribbon mixer, LM-1 type.

5.2. Estimation of the remnant binding agent removal on the basis of the experimentally determined reclamation work

Calculations of the reclamation work were done on the basis of Equation (4) and the Rittinger’s material data given in paper [4]. The obtained results are shown in Figure 3, together with the reclamation work determined under the assumption of a total removal of remnant binding material coatings (thickness \(g\)) from grains.

The presented results confirm previous observations that the reclamation treatment is the most intensive in the rotor reclaimer. The comparison of data allows to notice that for the reclamation performed in this device and in the roller mixer, after 5 and 34 minutes – respectively, the experimentally determined work value exceeds the work value determined theoretically. It may be related to an unfavourable phenomenon of crushing matrix grains. In order to confirm these observations investigations shown in Figures 4-5 were performed, where changes of average characteristic diameters \(d_l\) of used sands after the reclamation treatment done in the roller and ribbon mixers (cycle No 1 and No 2) as well as in the rotor reclaimer (cycle No 3).

In all analysed averaged diameters the decrease of their value when the reclamation time was prolonged - could be seen. The most intensive diameter decrease took place during cycle No 3, which indicates that the most intensive reclamation was in the rotor reclaimer. In such reclaimer a crushing of matrix grains occurs and their averaged diameters are decreasing (both \(d_l\) and \(d_a\)) below values of the fresh high-silica sand (of which the tested moulding sand was prepared).

When comparing the results obtained for the reclamation process performed in the roller and ribbon mixers – according to cycles No 1 and 2 – one can notice that more intensive removal of the remnant binder occurs in the roller mixer and the process of inter-operational dust extraction improves the removal effect. This effect is – specially visible after exceeding 15 minutes of the reclamation. Dusts covering material being reclaimed decrease friction between grains and structural elements and in between grains themselves, what unfavourably influences the final reclamation effects.

Fig. 3. Values of experimental and theoretical reclamation work

Fig. 4. Average grain diameters \(d_l\) after the given reclamation time in various types of mixers
The results of examinations of the grain shape coefficient \( W_k \), are presented in Figure 6. They indicate that changes of coefficient \( W_k \) in the range up to 20 minutes is in the roller and ribbon mixers slower than in the rotor reclaimer. A shape of reclaimed material grains is the most similar to fresh sand grains occurs after approximately 10 minutes of reclamation done in the rotor reclaimer. Later on the coefficient increases, what is related to crushing of grain matrix by the rotors system.

5.3. Estimation of the reclamation effects on the basis of ignition losses

Ignition losses of the reclaimed material after the given time in various reclaiming devices are presented in Figure 7. An ignition loss is one of the most important indicators of a quality assessment of the reclaimed used sands with an organic binder. The obtained results justify the repeated statement that the most effective reclamation treatment occurs in the rotor reclaimer, less effective in the roller mixer and the least effective in the ribbon one. This corresponds to the character and intensity of elementary operations realised in those technological devices.

6. Conclusions

The performed analysis of the obtained results allows for the following conclusions:
1. The analysis of the obtained results of the reclamation treatment of used moulding sands – performed according to generally assumed assessment criteria – indicate that the most intensive reclamation takes place in the rotor reclaimer, less intensive in the roller mixer and the least intensive in the ribbon one. This corresponds to the character and intensity of elementary operations realised in those technological devices.
2. Valuable information is obtained from the determination of the removal degree of remnant binding materials on the basis of the experimentally determined reclamation work, which allows to find the permissible reclamation time limits at which the actual reclamation work achieves the one theoretically calculated for complete removal of the spent binder from the grain matrix surface.
3. Technological methods of the effectiveness estimation of the reclamation treatment indicate the same succession of the investigated devices – in respect of the operation intensity - and bring additional important information concerning granulometric composition, grain shapes and ignition losses.

4. Application of inter-operational blowing away of dusts – in all examined devices – is advantageous for the effectiveness of the reclamation treatment estimated by means of ignition losses.

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References


