Unconventional methods of reclamation of used moulding sands

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Abstract

Analysis of the literature provides information on a constant search for new ways of regenerating of moulding sand deprived disadvantages of existing solutions, especially in the case of low efficiency of regeneration of a mixture of used masses of certain technologies, and high energy intensity of the high temperature heat recovery. In the advanced stage of the research are both attempts to apply a very high temperature (about 2200°C) for short-term impact on the surface of regenerated moulding sand, as well as support of thermal regeneration of oxygen addition in order to increase the temperature and direct combustion of organic components. At the second end of the scale are attempts to apply the extremely low temperatures to changes in physical properties of used binding material to reduce the work of crushing and recycling of other waste (e.g. bentonite).

The article presents the results of author’s own investigation of the regeneration process of mechanical and thermal carried out with the new, unconventional treatments which improve the reclaimability of used moulding sands.

Keywords: innovative reclamation systems, moulding sand, used sand, waste management

1. Introduction

Generally applied reclamation procedures comprise practically all used foundry sands with quartz sand grains and some with chromite base. In sands of the so called “new generation” - containing chemically hardened binding materials - the problem of their reclaimability is essential. The possibility of easy reclaiming of new moulding sands introduced into foundry industry is a measure of their modernity and industrial attractiveness. Economic aspects related to savings in buying new sands are not the only most important arguments motivating the introduction of reclamation processes in the given foundry.

2. Problems of scientific and development research concerning the reclamation of used foundry sands

Fields of scientific research and development concerning the reclamation process of used foundry sands can be systematised according to the research fields and the actual state of knowledge - based on the analysis of scientific papers.

2.1. General problems concerning reclamation of used foundry sands

Reclamation of used moulding and core sands is defined as a treatment of waste refractory materials allowing to recover at least one component of properties similar to the properties of the new
component and to reuse it for casting moulds and core production. In traditional technologies of casting moulds and core production on the basis of high-silica sands with binding agent addition, the reclamability consists mainly of a sand recovery and very seldom of a sand and bentonite recovery.

Analysis of data from several countries indicates that from 600 to 1200 kg of fresh sand is used for 1 tonne of ferrous casting alloys. In Poland it is 1000 kg of sand for 1 tonne of castings [1, 2]. Out of this amount approximately 20% of new sand is used for core production and the remaining amount for rebonding moulding sands.

Analysis of data from 20 largest Polish foundries, performed in 2005 [2] indicates that approximately 50% of waste foundry sands is reclaimed while the rest is directed to dumping grounds. Taking into account all remaining foundries it can be estimated that approximately 250,000-350,000 tonnes of waste foundry sands are sent to dumping grounds annually.

Important issue are costs of storage, which depend on the kind of wastes and on the ownership form of dump-sites (municipal dumping grounds, plant’s or own [belonging to the foundry]) as well as on their relation to the costs of purchasing fresh sands.

### 2.1.1. Kinds of new sands generated by the domestic foundries and ways of their management

Moulding and core spent sands are materials for various ways and types of reclamability. In consideration of their reclamability, they are divided into mono-sands (sands from single technology applied in the foundry) and mixed sands (mixture of sands from different technologies) — according to the reference document of the European Union (Integrated Pollution and Control. Reference Document on the Best Available Techniques in the Smitheries and Foundries Industry, European Commission, May 2005) [3]. Differentiation of operations preparing used sands for the reclamability was also introduced. A preliminary reclamability is described as the primary, while a reclamability treatment leading to final reclaimed materials is called the secondary reclamability.

Used sands, regardless of the reclamability method chosen, are subject to:
- treatment performed - most often - in the following sequence of operations:
  - preliminary separation of mechanical, mainly metallic, contaminations,
  - breaking up caked sands after their knocking-out,
  - sieving of sands and separating grain size ranges for the reclamability,
  - repeating separation of metal contaminations,
  - secondary reclamability, liberating sand grains from leftovers of spent binding materials by using ways allowing to remove binding material coatings from grain surfaces,
  - removing undesirable reclamability products by dedusting sand grains,

- separating sand grains of the determined size and uniformity (classification) according to the grain size).

Treatment of used sands based on applying the first four operations is called the primary reclamability process [3]. Its full realization is necessary to perform further processes of removal binding material coatings. At that stage grains are not yet satisfactorily separated from binding materials since this process rather allows separating large grain conglomerates and in effect reduces the amount of reclaimed material, which can be added to fresh sands for the casting production.

The secondary reclamability together with the primary reclamability constitutes the complementary treatment system for cleaning sand grains from the remains of spent binder coatings and from technologically useless fractions of sand bases. A task of more efficient liberating grains of the base requires more aggressive techniques than the ones applied during the primary reclamability.

Depending on the applied reclamability method the quality of reclaimed grains can be similar or sometimes even better than the fresh sand quality, which enables foundries to take advantage from all, mentioned earlier, values of the reclamability procedure.

### 2.2. Mechanism of liberating sand grains from envelopes of used binding materials

Research aimed at finding the mechanism of liberation of sand grains from envelopes of used binding materials in the dry reclamation method (mechanical and pneumatic) was initiated by H.W. Zimnawoda [4], D. Boenisch [5], W. Tilch with co-authors [6], D. Leidel [7] and others [8-10], consider processes of the mechanical reclamability as varieties of the way of releasing sand grains from envelopes of spent binding material, which occur independently of the kind of the reclamability treatment applied.

A model allowing for quantitative description of phenomena occurring in the process of liberating sand grains from coatings of binding material has not been practically developed until now.

Emphasised in literature [3] the separation of two stages of the reclamability procedure (primary and secondary reclamability) is of a conventional character useful for certain systematisation of analysed phenomena both at the interface: envelope of binding material – sand grain and at the contact zone of individual grains in spatial confinement.

It seems, that the variety of reclamability influences utilised in actual systems should be considered as a set of elementary operations, which have certain common features, regardless of the type of the reclamability process. Such an approach is presented in several papers [6, 11, 12]. Elementary operations are rubbing, abrasion and crushing.
3. Innovative developments in sand reclamation technologies

3.1. Unconventional mechanical-cryogenic reclamation

The general idea of mechanical-cryogenic reclamation is to use extra-low temperatures as a factor intensifying the process of the waste sand mechanical reclamation. It was assumed that by considerably reducing the temperature at which the process of reclamation is carried out, the envelope of sand binder, present on the surface of the sand grains, should become more brittle, and in the case of bentonite sands, the binding forces which are acting between the sand grains and the envelope of binder present on these grains should be weakened [14-16]. This should improve the sand reclaimability of the waste sands and release in quite an easy manner the sand grains from the sticking envelope of the used binding material.

3.2. Unconventional thermal reclamation

Thermal reclamation method is mainly aimed for the reclamation of spent sands containing organic binders [3, 13], but is also used for the deactivation of components of sands containing binders in systems, in which the selection of spent sands is not provided.

There are following advantages of the thermal method: accurate removal of binding agent, possibility of utilisation of total reclaimed sand for the production of fresh moulding and core sands and negligible chemical harmfulness of dust for the environment. The failures are: high costs of building and exploitation as well as – in certain cases – the necessity of the combustion gases neutralization.

In standard industrial thermal reclaimers reclamation is carried out in fluidisation bed, where air-gas mixture is burned to incinerate the used binding material from the sand basis.

The modification of this method is tested at Faculty of Foundry Engineering AGH-UST in Cracow. Modification consists on usage of sole oxygen or air-oxygen mixture as a fluidisation agent.

4. Tests and experiments

4.1. Laboratory stand for unconventional mechanical-cryogenic reclamation

The laboratory test stand is a reduced model of the mechanical reclamation unit with blades acting as a rotating abrasive element [9]. The test reclamation unit enables the reclamation process to be carried out with and without the use of a cooling agent. It has been provided with a feeding system for liquid nitrogen to carry out the reclamation process at extra-low (cryogenic) temperatures.

A temperature sensor, placed on the bottom of the sand container, enables current control of the temperature of the reclaimed waste sand.

The possibility of conducting in the same equipment either the mechanical reclamation alone, or a combination of the mechanical and cryogenic reclamation provides an excellent tool for comparison of the real efficiency of the reclamation process obtained in both examined cases.

4.2. Laboratory stand for unconventional thermal reclamation

The laboratory stand is a thermal reclaimer unit[9] with fluid bed mixing system. The mixing (fluidising) agent can be air, oxygen, or a mixture of these two, introduced in various ratios to the bed at intervals of every 1 minute. The time of feeding the fluidising agent was 10 seconds.

5. The testing procedure unconventional mechanical-cryogenic reclamation

Within the research described in this paper some tests have been made to improve the effectiveness of a mechanical reclamation process as applied to the most used type of the waste moulding sands typically produced during castings manufacture, namely:

- the used sand with bentonite,
- the process of the proper reclamation of the sand grains was conducted under the following operating parameters of the reclamation unit: rotational speed of the impeller blades - 300 rpm, time of reclamation - 1, 3, 5, 10 and 15 min, successively. A sample of the determined waste sand (circa 4 kg) was subjected to reclamation at ambient temperature; the second analogous sample was reclaimed with simultaneous feeding of liquid nitrogen to the sand in an amount enabling the temperature of the reclaimed batch to be reduced to about minus 70°C.

The effectiveness of releasing the sand grains from the envelope of the used binding material was evaluated by means of the tests below which, as a result of own studies carried out previously 2,3, were considered to be the tools reliable enough in evaluating the degree of the examined waste sand reclamation:

- clay binder content in bentonite reclaim,
- value of pH of the reclaim,
- compressive strength and permeability of the sand prepared with bentonite reclaim
- reclaims morphology

5.1. The results of the tests and its analysis

The results of tests for the waste sand with bentonite are presented in combined diagrams (Figures 1 ÷ 4). The analysis of the obtained data is given below.

In evaluating the effectiveness of a reclamation process of the waste sand with bentonite, as a main indication of the effectiveness of this reclamation has been adopted the content of
the clay binder present in reclaim. The waste sand without any reclamation treatment, subjected only to removal of tramp metal, preliminary crushing, and screening through a 3 mm mesh screen is characterised by the clay binder content amounting to about 8% (in present investigations it was 7.8% - see data in Fig. 1). In foundries, this sand is rebonded with an addition of about 0.8% bentonite and 0.1% coal dust, and next - after having been mixed - it is used for production of moulds for castings. Typically, in a standard system, when the thermal load in a moulding sand, determined by an average mould weight/casting weight ratio, is assuming a value of 4:1, about 15% of the unit sand should be subjected to reclamation after each cycle of the sand preparation.

After reclamation treatment, the content of the clay binder in the sand drops to a value of 4.20% and 3.5% for, respectively, the mechanical and mechanical-cryogenic reclamation conducted for a time of 15 minutes. The chemical analysis of reclaim (Fig. 2) also indicates a high degree of removal of the used binder from the sand grains; in the case of mechanical-cryogenic reclamation this effect is even more pronounced.

Fig. 1. clay content (used bentonite sand) vs. reclamation time and kind of reclamation treatment

Fig. 2. The pH value vs. reclamation time for reclaimed used sands and adopted kinds of reclamation treatment

SEM photographs of the waste moulding sand with bentonite before the secondary reclamation process (A) and the grain matrix – after 5 minutes of the mechanical reclamation (B) and the mechanical-cryogenic reclamation (C), at a magnification of 1000 times – are presented in Fig. 3.

It can be stated – on the basis of the presented scanning pictures – that under conditions of the mechanical-cryogenic reclamation the compactness of the binder envelope is disturbed and fragments of uncovered surface of matrix quartz grains are seen. Used binding material - in this case - is fuzzed and effects of a mechanical destruction are seen on grain boundaries, while on grains of the reclaimed material after the mechanical reclamation a relatively compact envelope of binding material remains. Thus, it can be assumed that an increased effect of the mechanical-cryogenic reclamation is caused by a higher brittleness of the binding material envelope due to being subjected to the treatment in extra-low temperatures.

Fig. 3. Morphology of grain surfaces: A – waste sand with bentonite before the reclamation, B – reclaimed material after 5 minutes of the mechanical reclamation, C – reclaimed material after 5 minutes of the mechanical-cryogenic reclamation

Figure 4 shows the results of testing the compressive strength and permeability of sands prepared with the obtained reclains. In these studies the obtained reclaim was treated as a replacement of the new sand. The sand composition included 7% of Zebiec bentonite and 3.5% of water content.

Fig. 4. Compressive strength and permeability of foundry sand prepared from reclaimed bentonite sands after various reclamation time subjected to mechanical or mechanical-cryogenic treatment

5.3. Conclusions – unconventional mechanical-cryogenic reclamation

The own, described here, experiences gathered during reclamation of bentonite sand in extra-low and ambient temperature indicate that the reclamation of used moulding sands with water glass conducted in the range of extra-low and cryogenic temperatures is fully justified from the technological point of view. The mechanical-cryogenic reclamation obviously improves the reclamation output in the case of both investigated sand types, subjected to reclamation in the same reclamation unit, which has all the features of a plant of the traditional design, commonly used for the mechanical reclamation process.

It can be stated that the currently used processes of reclamation with application of extra-low temperatures are the only ones, which among all other well-known techniques of the reclamation can effectively utilise the hygroscopic behaviour of moulding sands as a factor intensifying the process of releasing the sand grains from a binding material. The presence of a
“freezing” agent changes the volume of both binder and sand grains, leading to increased stresses on the grains surface and inside the grains, combined with higher brittleness of the binding material.

Compared to most of the currently used mechanical reclamation units operating under ambient conditions, the same equipment when adapted to operation at low temperatures, may in a short time produce the sand grains of better technological parameters. This is very advantageous not only in respect of the process economy but, first and foremost, in respect of the environmental protection, as it provides us with a tool making the use of larger amounts of the reclaim in the newly prepared sand possible, which quite obviously should reduce the volume of the post-production waste.

At this point, however, attention should be drawn to the fact that the mechanical-cryogenic reclamation of sands with either water glass or bentonite may, if not adequately controlled, lead to a much quicker wear of the sand grains and formation of large volumes of the dust.

**6. Test parameters – unconventional thermal reclamation**

In the present study attention was focussed on an assessment of the reclaimability of the sand used in the technology of loose self-setting mixtures. The trials were made on the sand which was not burnt down, considering this type of sand much more difficult for reclamation than the burnt down material.

The sand for the tests was prepared in a ribbon-type laboratory mixer, following recommendations of the resin producer. Urea-furan, Kaltharz U 404 U type resin was used together with an acid 500 T1 activator (trade names). The sand mixture had the following composition:

- dry silica sand 100 parts by weight
- resin 1.0 part by weight
- hardener 0.5 part by weight

The following techniques of reclamation were used in the study:

I. Mechanical reclamation carried out in a unit shown in Figure 5. Operating parameters of the reclamation process: time - 3 minutes, 5 minutes, 10 minutes, reclaim R1.

II. Thermal reclamation with periodical fluid bed mixing (frequency of fluidising – every 1 minute, time of fluidising – 10 seconds) carried out in an experimental thermal reclaimer unit shown in Figure 1B. The time of reclamation process 3 minutes, 5 minutes, 10 minutes, reclaim R2.

III. Thermal reclamation with preheating the surface of a steady bed of the used sand for a time of, respectively, 3 minutes, 5 minutes, 10 minutes, carried out in an experimental thermal reclaimer unit shown in Figure 5, followed by additional blowing of the sand with oxygen for a time of 1 minute – reclaim R3.

IV. Thermal reclamation with periodical fluid bed mixing (frequency of fluidising – every 1 minute, time of fluidising – 10 seconds) carried out in an experimental thermal reclaimer unit shown in Figure 5. The time of reclamation - 3 minutes, 5 minutes, 10 minutes, respectively. The fluidising agent – air + oxygen in ratio 1 : 1, reclaim R4.

V. Thermal reclamation with periodical fluid bed mixing (frequency of fluidising – every 1 minute, time of fluidising – 10 seconds) carried out in an experimental thermal reclaimer unit shown in Figure 5. The time of reclamation - 3 minutes, 5 minutes, 10 minutes, respectively. The fluidising agent – air + oxygen in ratio 1 : 2, reclaim R5.

The output of the reclamation process was evaluated measuring the following factors: loss on ignition (LOI), bending strength of specimens prepared from the reclaim ($R_g$) after the time of 1, 4 h and 24 h.

**6.1. Analysis of results – unconventional thermal reclamation**

Examining the results of the tests it can be noted that the loss on ignition of the reclaim obtained by the mechanical technique of reclamation differs quite considerably from the level obtained in the case of thermal reclamation carried out in its different variations. High values of the loss on ignition of reclaim R1 indicate weak effect of the rubbing-abrading action provided by the used reclamation unit as well as the fact that in the case of sands with organic binders the thermal reclamation is much more effective in removing the coating from the base sand grains.

The results of the loss on ignition measurements are shown in Figure 5. In the case of reclaim R1, the removal of the remaining resin from the sand grains was unsatisfactory even after 10 minute process duration. In the case of other reclaims, the effects can be considered satisfactory already after 5 minutes of the process duration.

Basing on the changing values of the loss on ignition in function of time in different techniques of the reclamation process it has been noted that the most effective is reclamation R5, which uses a 1 : 2 ratio mixture of air and oxygen for mixing of the fluidised bed. The next in respect of its effectiveness is reclamation R4, followed by similar, as regards output, reclaims R3 and R2.

Figure 6 shows the relationship between bending strength $R_g$ [MPa] of samples made from the reclaimed sand and time of their setting using various techniques of reclamation, referred to samples prepared from the new sand. The diagram also includes a plotted level of 80% strength value of the sand mixture prepared from new components, which can be used as a criterion for
evaluation of the reclaim and its applicability in being re-used as a base material in core sands. The reclaim which has not reached the required strength level can be used as a backing moulding sand, or for internal sand layers in the technology of making compound cores.

Basing on the collected data it can be stated that reclaims R3-R5 satisfy the imposed requirements and can be re-used in core sands. Reclaim R2 approaches the limit value and in the case of less responsible cores its re-use as a base material can be taken into consideration. Under industrial conditions, reclaim R1 is suitable in preparation of the backing sand or as an additive to the new sand.

6.3. Conclusions – unconventional thermal reclamation

The conducted studies confirm that the core sand-to-core sand or green sand-to-core sand reclamation creates a lot of technical problems. So far, to perform this process, mainly thermal reclamation has been used, which in industrial plants can last from about 25 to 30 minutes. The application of oxygen enables this time to be shortened quite considerably (by even as much as 60%), not deteriorating in any way the reclaim quality. This can be of particular importance for foundries which face some problems with throughput of the already existing thermal reclamation units, which can easily be improved without high investment outlays. At the same time, it creates the possibility of extending further the range of reclamation units which use the oxygen-enriched air to perform an even more efficient process.

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