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

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Received 28.07.2010; accepted in revised form 02.08.2010

Abstract

In traditional technologies of casting moulds and core production on the basis of high-silica sands with binding agent addition, the reclamation 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]. Out of this amount approximately 20% of fresh sand is used for core production and the remaining amount for rebounding moulding sands. Analysis of data from 20 largest Polish foundries, performed in 2004 [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 250-350 000 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. Average charges for storage of moulding sands wastes on storage yards in Europe are within the range: 12.5 to 61 Eu, which means from 85% to above 400% of purchasing costs of 1 tonne of fresh high-silica sand. The contractual price accepted for such sand in the BREF UE document [3] is 14.56 Eu. Problems of scientific and development research concerning the reclamation 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.

Keywords: Waste management, Used sand, Reclamation treatment

1. General problems concerning reclamation of used foundry sands -

Moulding and core spentused sands are materials for various ways and types of reclamation. In consideration of their reclaimability 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 [3]. Differentiation of operations preparing used sands for the reclamation was also introduced. A preliminary reclamation is described as the primary, while a reclamation treatment leading to final reclaimed materials is called the secondary reclamation.
Spent sands, regardless of the reclamation 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 reclamation,
- repeating separation of metal contaminations,
- secondary reclamation, liberating sand grains from left-overs of spent used binding materials by using ways allowing to remove binding material coatings from grain surfaces,
- removing undesirable reclamation products by dedusting sand grains,
- separating sand grains of the determined size and uniformity (classification according to the grain size).

Treatment of spent sands based on applying the first four operations is necessary to perform further processes of removal binding material coatings. The secondary reclamation together with the primary reclamation, constitutes the complementary treatment system for cleaning sand grains from the remains of spent used 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 reclamation.

2. Functional characteristics of devices for typical reclamation methods

2.1. Devices used for dry mechanical reclamation

Dry mechanical reclamation process is currently the most broadly applied process in the foundry industry. This results from:

- possibility of sand bases reclamation practically from every spent used sands, assuming the limited reclamation degree,
- possibility of applying relatively simple devices, often of different previous destination (e.g. mixers),
- Lower costs of the process, in comparison with other methods.

The systems of the dry mechanical reclamation are applying solutions in which liberating of grains from the coatings of binding material is being done by a combination of the following elementary operations: rubbing, abrasion and crushing of binding material coatings from the sand surface [4, 5]. Vibratory reclaimers cooperating with crushers (vibratory or hammer), in which products of abrasion, free dusts and undersized particles are removed by means of air blown through a layer of material under treatment, are currently dominating.

A method of the pneumatic reclamation is mostly applied for sands containing water-glass and binding agents, while rarely for sands with synthetic resins. The pneumatic reclamation is used either as an element assisting the dry mechanical or thermal reclamation or as an independent method.

2.2. Secondary thermal reclamation

During the thermal reclamation spent used sands containing resins are heated to the temperature enabling total or partial burning of organic binder. In spent used sands containing binders the thermal treatment should cause partial or total degradation of inorganic components of a binder, which facilitates further liberation of sand grains from envelopes of the burned binder. The advantage of the thermally reclaimed sand – underlined in many papers – is a stabilisation of its volumetric expansion at an increased temperature related to the quartz allotropic transformation during previous warming of sand adjusted to casting. This stability enables applying the reclaimed sand in practically every moulding and core sand technology. The only limitation is the condition that, prepared with the participation of the reclaimed sand grains the initial sands must have similar pH value, since the thermal reclamation does not change the chemical properties of sand grains [10-12].

2.3. Wet reclamation

Wet reclamation is the most efficient reclamation method for spent used sands with binding agents and for sands containing water-soluble binders (high-silica sands, sands with water-glass hardened by CO\textsubscript{2}).

A negative feature of the wet reclamation is high energy-consumption of the process (due to the necessity of drying the reclaimed materials) and high water consumption, reaching 10-15 m\textsuperscript{3} for 1 tonne of material.

Thus, due to the above-mentioned reasons the wet reclamation is not currently applied, however there are still foundries where these installations are in operation [13].

Recent studies [14] suggest that post-processor processing of the reclaim from used sands with specified resin conducted in the wet conditions significantly affect the release of sand grain from binder and reduces the loss on ignition of about 30%.

2.4. Combined reclamation

Combined reclamation methods found their application especially for the reclamation of sand grains from a mixture of used foundry sands. Mixed used sands were practically not reclaimable in a single system of any kind. Their reclamation is possible due to utilising features and advantages of individual reclamation methods. Combining single methods depends on the composition of spent used sands and on the purpose, the reclaimed sands are intended for. The combined methods can be divided into three main types:

- combination of wet and thermal method,
- combination of thermal method and dry mechanic or pneumatic method,
- combination of wet and thermal method with dry mechanic method.
2.5. Reclamation by means of a chemical method

Chemical reclamation methods of used sands containing bentonite, enabling reusing of reclaimed sand grains, are based on the application of concentrated H₂SO₄. The obtained reclaimed material is characterised by a very low oil utilisation since practically the whole envelope of spent used binding material was removed from the grain surface. This system is currently at the stage of industrial testing, which is difficult due to the hazard of applying H₂SO₄ as substance acting on the spent used sands, and due to expected high costs of such reclamation.

3. Mechanism of liberating sand grains from envelopes of used binding materials

D. Boenisch [17], W. Tilch with co-authors [4, 11], D. Leidel [18] and others [1, 7, 11,19-21], consider processes of the mechanical reclamation as varieties of the way of releasing sand grains from envelopes of spent used binding material, which occur independently of the kind of the reclamation treatment applied. Identification of active forces dominating in known devices for the secondary reclamation process allows to indicate the following methods and techniques of liberating sand grains from coatings of spent used binding material:

- intensive mechanical influence of internal and external friction forces, when the process is carried on at various temperatures: ambient, increased and cryogenic,
- violent momentum change of sand grains or of the sand-air jet occurring most often in pneumatic or centrifugal reclaimers,
- thermal influence either individual or combined with an intensive mechanical influence occurring mainly in the fluidisation systems or in thermal-mechanical reclaimers with rotors,
- intensive mechanical influences of internal and external friction forces, when the process is carried on in a water medium.

It seems, that the variety of reclamation 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 reclamation process. Such an approach is presented in several papers [22-25, 36]. Elementary operations occurring during the mechanical reclamation, realised at the ambient temperature can be characterised as follows:

**Rubbing** – process, based on gradual thinning of a binding material coating being removed by a mutual frictional influence. Rubbing occurs in a cluster of loose sand grains being in a relative motion and directly contacting with each other.

**Abrasion** – process, based on gradual thinning of a binding material layer being removed from the grain surface by a mechanical influence of constructional elements of machines. Abrasion of coatings occurs in larger clusters or on individual sand grains being in a relative motion versus movable or stationary constructional elements of machines with which they contact.

**Crushing** – process, based on pitched change of binding material coatings thickness on sand grains and on diminution of its particles. Crushing is caused by pressure of external forces either dynamic or static, causing increase of contact loads transmitted onto coatings by sand grains. Cracking of coatings and breaking bridges joining individual grains is the result of such influence.

4. Influence of the kind of the reclamation treatment on the quality of reclaimed sand

Influence of the reclamation treatment carried by different methods, which enabled changes of intensity and time of the reclamation procedure, on the final reclamation effect obtained was described in several papers [13, 24, 26-28]. Ways of the reclamation treatment enabling application of the reclaimed material containing binders for the preparation of core sands characterised by very high technological requirements are presented in several papers [20-21, 29].

The main emphasis of numerous Polish publications [9, 18, 22-23, 25-26, 30-35] was placed on the proper selection of kinds and parameters of the reclamation of spent used sands originated from the most often applied technologies. Research was carried out on experimental test-stands for the mechanical, mechanical-cryogenic and thermal reclamation in different versions of the process.

In foundries producing ferrous alloys castings most often occurs the necessity of reclamation of moulding sands originated from different technologies, which is unfavourable from the point of view of the reclaimed material quality. Mixture of spent used sands of various chemical character and ways of binding, often not compatible, require a complicated reclamation treatment for obtaining the needed purity of the material. A practise indicates that in many cases – regardless of high costs incurred – the reclaimed sand grains can be used as a substitute of fresh sands in the limited range only.

The optimal solution is an introduction of new ways of moulding sands management in foundries allowing to substitute the mixture of spent used sands by the system of quasi uniform sands, obtained by separating streams of individual sands and their proper grouping to achieve the compatibility of three elements of the technological process: spent used sands – reclaimed sand grains – fresh sands. This compatibility should concern the features, which influence the reclaimed material quality in the most significant way, e.g. pH, Zₖ.

5. Assessment methods of the reclaimed material quality

An assessment of the reclamation effects is a complex problem due to a large number of reclamation methods. A development of a single, universal assessment method of the reclaimed material quality and - indirectly - technological effectiveness of the device, seems not possible and not justified.

Methods listed in Table 1 can be used for an assessment of the reclamation effects of sand grains – destined for making cores.
Depending on the requirements for the reclaimed materials only the most important methods can be used.

Table 1.
The proposed assessment criteria of the reclaimed material obtained from various types of used sands with inorganic binders [9, 27, 36]

<table>
<thead>
<tr>
<th>Recommended assessment method</th>
<th>Type of a binding material in used sands intended for matrix regeneration</th>
<th>Water glass hardened by:</th>
<th>Cement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moulding sand strength</td>
<td>Bentonite</td>
<td>CO₂</td>
<td></td>
</tr>
<tr>
<td>PN-83/H-11073, permeability</td>
<td>(1)</td>
<td>(2)</td>
<td>(2)</td>
</tr>
<tr>
<td>PN-80/H-11072, Sand friability</td>
<td>(1)</td>
<td>(2)</td>
<td>(2)</td>
</tr>
<tr>
<td>BN-77/4024-02.</td>
<td>(1)</td>
<td>(2)</td>
<td>(2)</td>
</tr>
<tr>
<td>Binder content acc. to</td>
<td>(2)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>PN-73/H-11076</td>
<td>(2)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>Montmorillonite content</td>
<td>(3)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>(binder activity) acc. to</td>
<td>(3)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>BN-77/4024-16</td>
<td>(3)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>Ignition loss acc. to</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>PN-83/H-04119</td>
<td>(3)</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>Sieve analysis acc. to</td>
<td>(3)</td>
<td>(3)</td>
<td>(2)</td>
</tr>
<tr>
<td>PN-83/H-11077</td>
<td>(3)</td>
<td>(3)</td>
<td>(2)</td>
</tr>
<tr>
<td>N₂O content</td>
<td>(-)</td>
<td>(1)</td>
<td>(1)</td>
</tr>
<tr>
<td>Surface morphology, the grain</td>
<td>(4)</td>
<td>(5)</td>
<td>(5)</td>
</tr>
<tr>
<td>shape coefficient acc. to</td>
<td>(4)</td>
<td>(5)</td>
<td>(5)</td>
</tr>
<tr>
<td>PN-83/H-11078</td>
<td>(4)</td>
<td>(5)</td>
<td>(5)</td>
</tr>
<tr>
<td>Chemical analysis acc. to</td>
<td>(5)</td>
<td>(4)</td>
<td>(4)</td>
</tr>
<tr>
<td>BN-70/4024-15</td>
<td>(5)</td>
<td>(4)</td>
<td>(4)</td>
</tr>
<tr>
<td>Chemical reaction (pH, Zk)</td>
<td>(5)</td>
<td>(5)</td>
<td>(5)</td>
</tr>
</tbody>
</table>

6. Non conventional systems and devices for the reclamation treatment

Innovative solution of the thermal reclaimer is presented by device in which surface heating of sand is being done in an infrared range up to the temperature of 2200°C.

Grains of spentused sands are surrounded by infrared lamps immersed in fluidised bed for a very short time in order not to cause caking of quartz grains but only burning of the resin envelope. The very fact that overheating sand grains is not necessary decreases the energy consumption of the process and makes cooling of the reclaimed sand easier.

Another novelty is an application of a steam-pressure reclamation of sand grains from highly oölitised moulding sands containing bentonite and additions of spentused core sands with synthetic resins. Used sands introduced into the reclaimer are moisturised to 3 - 4%. Inside the working part of the reclaimer, at the temperature of 850 to 900°C, a violent water vapourisation accompanied by explosive increase of steam volume occurs. In result of the violent steam expansion the coatings of spentused and partially oölitised binding agent are ruptured from sand grain surfaces.

Successful tests of introducing new physical phenomena into intensification of the reclamation process of spentused classic sands (containing bentonite) as well as chemically bonded sands are presented in Tordoff’s paper [37] and in some domestic papers [7, 14, 38]. SpentUsed sands are submitted to a low temperature, which changes features of binding agent coatings. The binding agent hardens and the mechanical influence becomes more effective in removing its particles from the sand grains base.

7. Identification methods and an environmental impact assessment of used sands

The development of analytical investigation methods gave rise to research linking problems related to assessment the impact of spentused foundry sands on the natural environment. Papers [6, 26, 29-40] present procedures applied to spentused sands in the USA. SpentUsed sands are classified there according to strictly specified standards concerning toxicity of stored wastes and leaching of hazardous substances [40] (mainly heavy metals). According to the binding standards of EPA (Environmental Protection Agency) spentused sands are classified for storage on dumping grounds, characterised by different protection degrees and isolation of stored materials from the surroundings. Similar, very rigorous, standards are in force in Germany. Concentrations of hazardous chemical substances, which might be leaching from particular dumping grounds, decide on the class of those grounds and on the related to it storage costs of waste materials.

The task of systematising regulations and standards concerning the management of wastes and spentused foundry products - being in force in Poland - was undertaken in paper [39]. Regulations being in force in Poland were compared to the ones in the European Union countries.

8. Moulding and core sands of an increased reclaimability and a decreased harmfulness for environment

Development directions of moulding and core sands containing inorganic binding agents, in respect of meeting the environment protection requirements are discussed in papers [26, 39]. It was stated, that further work on this topic should be pointed towards improving known inorganic binders (on sodium silicate or phosphate basis) or towards developing completely new binders, not hitherto applied in the foundry engineering.

Part of the research concentrates [41, 42] on searching for new additives to improve parameters of sands containing waterglass, which are relatively cheap and ecologically neutral ways of producing moulding sands. Perspective investigations should
concern the improvement of their knocking out properties and reclaimability.

9. Economic aspects of the reclamion process of spentused sands

Special attention was focused on economic aspects of the reclamion process in several papers [9, 13, 15, 23, 39]. Indices of process effectiveness, which take into consideration the kind of sand under the reclamion, were worked out and examples of reclamating systems were given. The papers [15, 16, 22] deal with the possibility of organising reclamion centres, rendering services for foundries, which have no possibility of reclaiming used sands in their own plants. Optimal reclaiming parameters of such centres are given, as well as indices allowing to calculate the profitability of building such a plant in the given location.

10. Conclusions

Further significant progress in the reclamion is related to several factors, which should be considered. The most important are:

– basic research, supportive to searching for the sands, which would be the reclamion friendly and neutral for the natural environment,

– striving to achieve the compatibility of mould and core technologies substantiated by the possibility of the common reclamion of spentused sands in the system of mixed sands and allowing to utilise the specialist reclaimers of much simpler construction instead of very costly universal ones,

– application of the proper material management in the range of moulding and core sands leading to diminishing the number of sands being used in the foundry,

– optimisation of the existing reclamion methods by introduction of improvements and new solutions to the process, especially by adapting reclaimers to the binding mechanism characteristic for the given binding agent, in order to increase quality and yield of the reclaimed material.

Acknowledgements

The project is co-financed by the European Regional Development Fund within the framework of the Polish Innovative Operational Programme, no WND-POIG.01.03.01-12-007/09

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