

Recycling of Waste Moulding Sands with New Binders

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Abstract

This paper presents the results of research which is part of studies carried out under the project POIG.01.01.02-00-015/09 "Advanced Materials and Technologies", one of the aims of which is to introduce new, environment-friendly, inorganic binders to the production of castings from non-ferrous metals. The paper presents the results of research on the management of waste moulding sands prepared according to the new technology, including their multiple reclamation and management of post-reclamation waste. Studies of multiple reclamation are a continuation of the preliminary research described earlier. The programme of the studies described in this paper also included validation of the results under industrial conditions.

Keywords: Innovative foundry materials and technologies, Modified inorganic binders, Reclamability, Management of post-reclamation waste

1. Introduction

According to the law on waste management [1, 2], the following actions should be taken:

- prevent the formation of waste or reduce the amount of waste and its adverse environmental impact at the stage of product manufacture, and during and after its use,
- provide reclamation process consistent with the principles of environmental protection, if unable to prevent the occurrence of the waste,
- ensure consistent with the principles of environmental protection disposal of the waste, the occurrence of which could neither be prevented, nor mitigated by reclamation.

The waste disposal to a landfill should be considered as a last resort.

Often the waste material which is treated as a waste in one manufacturing process can be utilised in another process as a valuable raw material. That is why more and more often the term "by-product" is used instead of the term "waste".

The economic use of waste is the most effective method of elimination of the resulting hazards [3, 4, 5].

It is the fact well-known that the waste disposed from foundries, that could potentially affect the environment, in most cases consists of the used moulding and core sands and dust [3]. Its share in the total amount of waste generated by the non-ferrous metal casting industry represents more than 85%.

In the case of self-hardening sands, which include the sands with new binders, reclamation is a fundamental and effective way of managing the waste on-site in a foundry shop in accordance with environmental guidelines [5] according to which the waste, if possible, should be treated in the place of its origin.

2. Aim of the studies

With the ever increasing demands on environmental protection, of increasing importance are becoming these

technologies which, while ensuring the required technological parameters, can provide the least possible harmful effect on the environment. Therefore, the aim of the executed structural project is to introduce to the production of foundry moulds and cores new ecological binders [6,7,8] for casting of non-ferrous metal alloys, along with a method for the disposal of these binders.

The use of new modified inorganic binders is expected to ensure good knocking out properties in sands prepared with these binders, while maintaining an appropriate level of strength properties. Good knocking out properties of sands are directly related with the reclaimability of the waste, which is a "must" of the effective waste management.

Therefore, within the project, tests and studies were carried out on the used moulding and core sands prepared according to the new technology to determine the degree of possible recovery of the useful moulding material (the reclaimed sand) and the extent of its reuse in the production process with trials on the management of post-reclamation waste outside the foundry shop.

The latter applies, first of all, to the dust generated during the reclamation process. Its management is a task extremely difficult and challenging for the foundry industry.

3. Multiple reclamation

Moulds prepared with the new inorganic binders modified with hydrated sodium silicate [9,10] and hardened with ethylene glycol diacetate (2.5 parts by weight of binder and 10% of hardener respective of the binder weight) were used for casting of Al-Si alloy (AlSi9 alloy) and copper alloy (CuZn59 alloy). The waste mould material after knocking out of castings was subjected to the process of reclamation. Based on the results of laboratory tests described in earlier publications[9,10,11,12] and the estimated degree of the reclaim reuse, it was established that the content of the reclaim in new moulding sand will be up to 70%, due to a marked shortening of the moulding sand bench life.

From the point of view of the sand reclaimability and reusability, it is very important to know its behaviour in the long-term use of reclaim, both in terms of the strength properties and, in the case of self-hardening sands, the time of binding. Therefore, the stage of the research described here was based on tests conducted on the multiple reclamation of sands with new inorganic binder "B" to verify the effectiveness of the reclamation after a longer lapse of time, which will occur under the real conditions of a foundry shop.

Studies were carried out according to the following scheme:

* 1st cycle *

- making sand mixture based on new sand and technological testing of the mixture
- making moulds and cores from the mixture based on new sand
- pouring of moulds and knocking out of castings (AlSi9 alloy)
- reclamation of waste sand and physico-chemical testing of the reclaim

* 2nd to 10th cycle *

- making sand mixtures with the reclaim and technological testing of the mixture
- making moulds and cores with the reclaim
- pouring of moulds and knocking out of castings
- reclamation of waste sand and physico-chemical testing of the reclaim

The sand reclamation process was carried out on a laboratory reclamation stand.

The resulting products of the treatment and reclamation of used moulding sands were subjected to laboratory assessment. The process of mechanical reclamation regains from 92 to nearly 94% of the useful material, which is the reclaimed sand.

On the reclaim and new sand serving as a reference, physico-chemical tests were carried out and the results were plotted in the form of graphs (fig. 1, 2). Tests were made after each reclamation cycle.

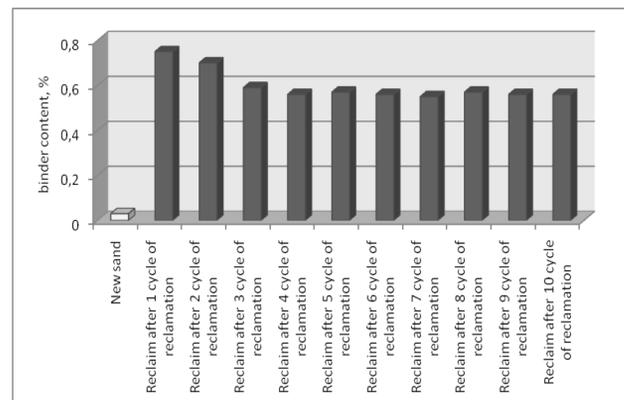


Fig. 1. Binder content in the product of multiple reclamation of self-hardening sands

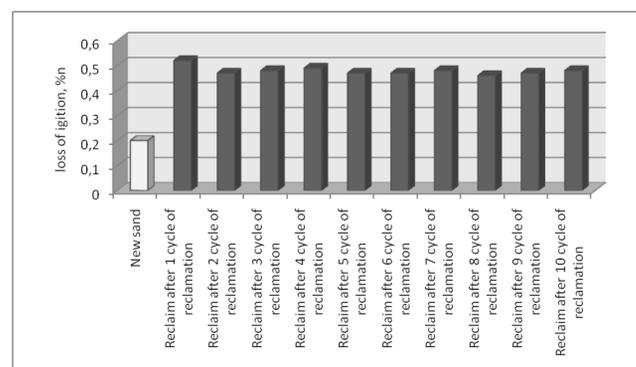


Fig. 2. Loss on ignition in materials from the multiple reclamation of self-hardening sands

The mixtures based on new sand as well as those having in their composition an addition of reclaim were subjected to technological tests, including compressive strength, bending strength (fig.4), permeability and bench life (fig.3).

Sand mixtures for technological tests were prepared according to the formulas given below:

1 st cycle	new sand binder "B" hardener	100,0 parts by weight 2,5 parts by weight 0,25 parts by weight
2 nd – 10 th cycle	new sand reclaim binder "B" hardener	30,0 parts by weight 70 parts by weight 2,5 parts by weight 0,25 parts by weight

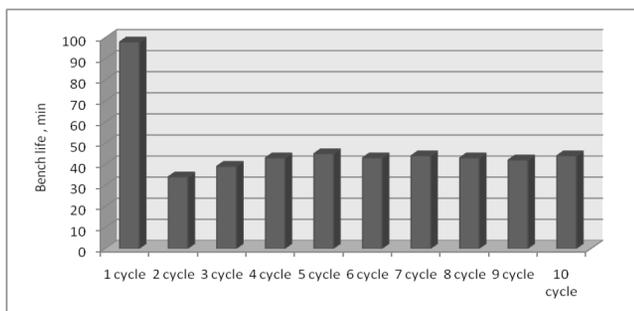


Fig. 3. Bench life of sands with reclaim from multiple reclamation

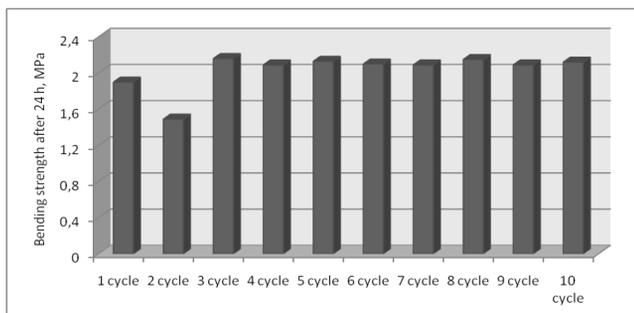


Fig. 4. Bending strength of sands with reclaim from multiple reclamation

Moulding mixtures prepared with modified inorganic binders and with the reclaim from the first cycle of multiple reclamation were characterised by slightly lower bending strength than the mixtures based on new sand (fig.4), but after subsequent cycles, the quality of the sands improved and stabilised.

An important observation, useful in application work carried out for the industry, is that the bench life of the moulding sand is maintained at a constant level (the only exception is cycle 2), which allows making moulds without the loss of binding properties.

4. Studies and trials on the management of post-reclamation waste

Studies on the management of waste included, in addition to the reclamation, also checking the possibility of the reuse of reclaim outside the foundry, knowing that reclamation cannot totally eliminate the problem of waste, but as regards some portion of this waste tends to change its nature only. This

mainly concerns the dust generated in the process of reclamation. Its management is the task very difficult and challenging for the foundry industry.

Therefore, attempts have been made to develop methods for the safe management of this waste outside the foundry. Proper methodology has been developed and studies have been conducted, including both pre-treatment of the waste, as well as technical and technological studies of its further use, e.g. in the cement industry and for the manufacture of construction utilities.

4.1. Chemical studies of reclaim as a substitute for fine aggregate

For the assessment of reclaim, as a substitute for fine aggregate, in addition to granulometric studies confirming the applicability of this material, also chemical studies were carried out. Table 1 shows the results of chemical analysis of reclaim.

Table 1.
The results of chemical analysis of reclaim

Measurement	Reclaim [%]
Chlorides according to PN-EN 1744-1:1998	2.06
Acid resistance	1.34
Sulphates dissolved in acid according to PN-EN 1744-1:1998	0.087
Total sulphur the method of combustion in an oxygen stream	0.017
Sulphides dissolved in acid	0.11
Light impurities according to PN-EN 1744-1:1998	-
Loss on ignition	0.47

4.2. Testing of post-reclamation dust in accordance with the requirements developed for silica dust

Mineral additives according to PN-EN 206-1, i.e. components of fine particle size, are used to improve the properties of concrete and to obtain special properties, this also including the properties of pozzolanic additives (such as fly ash, silica dust). Table 2 shows the results of testing post-reclamation dust as a substitute for silica dust.

Table 2.
The results of testing post-reclamation dust as a substitute for silica dust added as a mineral component to concrete – the requirements according to EN 13263-1

Measurement	Permissible content in silica dust	Post-reclamation dust (silica)
SiO ₂	≥ 85.0 wt%	93.32
Elemental silicon	≤ 0.4 wt%	43.62
Free CaO	≤ 1.0 wt%	0.28
Sulphur as SO ₃	≤ 2.0 wt%	0.057
Na ₂ O	Value declared	0.30
Chlorides	≤ 0.30 wt%	9.90
Acid-resistance		3.55
Loss on ignition	≤ 4.0%	1.09

Comparing the properties of used moulding sands with standard requirements it can be concluded that the properties of the examined reclaim meet the requirements of relevant standards as regards the chemical behaviour and therefore this reclaim can be used in the construction industry as a substitute for natural sand and as a grain modifier in the sand aggregate used for the manufacture of concrete.

Due to the content of chlorides, the post-reclamation dust cannot be used as a substitute for silica dust, but like the reclaim, it can be used in the manufacture of building ceramics as a leaning material. Chemical analysis has shown that there are no grounds to prevent the post-reclamation dust from being used in the manufacture of building ceramics.

4.3. Making and testing of ceramic samples

Using clay, sand, reclaim and post-reclaim dust, cylindrical 50x50 samples were made. Their compositions are given below:

1. 80% clay, 20% sand (M1)
2. 80% clay, 20% reclaim (M2)
3. 80% clay, 15% sand, 5% reclaim (M3)
4. 80% clay, 10% sand, 10% reclaim (M4)
5. 80% clay, 5% sand, 15% reclaim (M5)
6. 80% clay, 20% post-reclaim dust (M 6)

The content of moisture in the mixture was 6 wt%. The mixture was prepared in an RN20/VL2 MULTISERW laboratory mixer, purchased under the project. When the mixture of the requested composition was ready, cylindrical samples were made on a laboratory press under a pressure of 3 MPa. The samples were cured for 5 days at room temperature, then dried for 24 hours at 95°C in a KC1000 laboratory oven. After drying, the samples were placed in a resistance furnace and baked at 1000°C for 24 hours. The increase of temperature was 100 degrees per hour.

Studies of the ceramic samples included:

- a) Determination of soakability N_m , %
- b) Determination of capillary absorption H , g/cm²
- c) Determination of bulk density γ , g/cm³
- d) Determination of compressive strength

The compression test was carried out in accordance with PN EN ISO 8895:2007, using an EU-20 testing machine made by VEB Werkstoffprüfmaschinen Leipzig, Germany, with a maximum range of 200.0 kN. The range of 0 to 100 kN was applied. The increase in stress rate during the compression test was 1.59 MPa/s.

- e) Determination of frost resistance M

$$M = 0,044 R + 3,47 \gamma + 0,18 N_m - 0,65 H_{24} - 0,06 \quad (1)$$

If the test result is positive ($M > 0$) - the sample is frost-resistant.

If the test result is negative ($M \leq 0$) - the sample is frost-sensitive.

Table 3 shows the results of studies of the ceramic samples.

Table 3.

The results of ceramic sample testing

Sample	N_m , %	γ , g/cm ³	H_{24} , g/cm ²	R_c , MPa	M
M1	17,7	1,8	1,6	19,3	9,2
M2	20,3	1,7	1,7	17,7	9,2
M3	21,2	1,7	1,8	21,0	9,4
M4	17,6	1,8	1,6	23,2	9,4
M5	19,4	1,8	1,7	25,9	9,6
M6	20,6	1,7	1,8	21,7	9,4

Studies have shown that samples prepared with both the reclaimed sand and post-reclamation dust are resistant to frost, and their resistance is corresponding to the resistance of samples made with the new sand as a typical leaning material.

Preliminary laboratory tests to replace new sand with the reclaimed sand or post-reclamation dust in a ceramic mixture used for the manufacture of bricks allowed obtaining a product of properties similar to the values demanded by the standard.

4.4. Making and testing of concrete samples

The composition of the concrete mix was determined experimentally. From a mixture of cement, sand, reclaim, aggregate and water, cylindrical samples of $\Phi 50 \times 50$ were made. Their composition was as follows: 1 kg sand + reclaim, 0.4 kg cement, 1.3 kg aggregate, 0.3 kg of water.

All samples were prepared using the equipment for testing of self-hardening liquid sands.

The aggregate was silica gravel in a fraction of 1 - 4 mm.

Cement 32,5R (EN 197-1 CEM II/B-V 32,5R) was used.

Silica sand of the main fraction 020/0,315/0,40 was taken from the Szczakowa mine.

The concrete mix was prepared in an RN20/VL2 MULTISERW laboratory mixer. Then, standard cylindrical moulds were filled with this mixture. Samples in moulds were compacted with a vibrating device for sample compaction, model LUZ.

Strength of the concrete samples was tested in accordance with guidelines given in respective standard. Tests were conducted after 14 and 28 days elapsing since the day when the samples were prepared (fig.5).

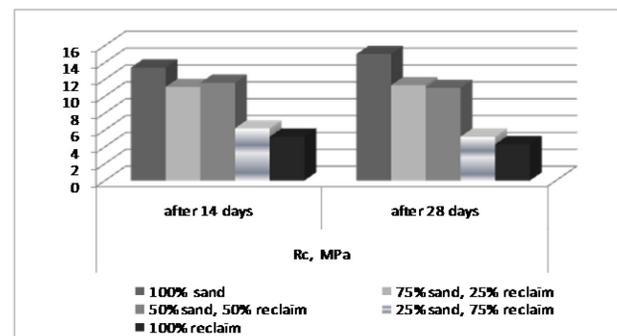


Fig. 5. The results of compression test carried out on samples of concrete with the variable content of reclaim

The preliminary laboratory tests to replace with reclaim the new sand in a concrete mix used for the manufacture of various items have proved that the product obtained had the properties similar to the properties demanded by the standard when the content of reclaim was up to 50%.

5. Industrial trials of making the concrete mix

From each batch of the obtained reclaim used for foundry moulds, certain amount was saved and used for further testing. The volumes of the material saved from the successive reclamation cycles were used in trials on the reclaim management outside the foundry. Separately, the dust from various reclamation cycles was collected.

As a result of the investigations, for the industrial trials on the management of the waste, a "Rys" Company in Marszowice owned by Krzysztof Rudzki - manufacturer of concrete products – was selected.

The composition of the concrete mix was as follows:

- Fine aggregate: Pit sand 0-2 mm 250 kg + 250 kg reclaim
- Coarse aggregate: Gravel (grit) 600kg
- Cement 32.5 R-170 kg
- Make-up water

A photograph below (fig.6) shows the ready drain pan made of concrete with the reclaimed sand.



Fig.6. Ready concrete products (drain pan) made of concrete with the reclaimed sand before and after aging

The concrete samples made in the industrial trials were subjected at the Foundry Research Institute to basic studies, including:

- Determination of the concrete density:

The density of concrete is determined in accordance with PN-EN 12390-7. The standard specifies that for ordinary concrete, its density should be higher than 2000 kg/m³, and lower than 2600 kg/m³. For material discussed in this study, the density of concrete measured in cubic samples was 2250 kg/m³.

- Determination of compressive strength

After 28 days elapsing since the day when the samples were prepared, also blocks with dimensions of 150x150x150 mm were subjected to the test carried out in accordance with the standard guidelines for testing of concrete products given in PN-EN 12390-1. The results of the test are given in the table 4 below.

The test was carried out on a Josef Freundl 25.200 testing machine, with a maximum range of 2000.0 kN.

Table 4.

The results of compression test for samples of dimensions 150x150x150 mm

Sample	Sample active surface [cm ²]	Maximum force [kN]	Compressive strength [MPa]
1	225	450,0	20,0
2	225	500,0	22,2
3	225	550,0	24,4

The obtained values of the compressive strength of samples made in accordance with PN-EN 12390-1 allow classifying the tested concrete as belonging to the class C16/20 (according to PN-EN 206-1:2004).

6. Trials on the management of post-reclamation dust

Since dust has occurred in much smaller amounts (up to 5%), the available amount of this material was not sufficient to check the dust applicability in the manufacture of ceramic products, while the presence of chlorides practically eliminated the possibility to use it as a substitute for silica powder. Therefore some attempts were made to change the dust consistency by granulation and briquetting.

6.1. Test manufacture of briquettes with the addition of post-reclamation dust

At the "Carbon" Research and Production Enterprise in Chorzów, tests were carried out to check the feasibility of using post-reclamation waste in the form of dust in the manufacture of briquettes.

The briquetting mixture was composed of the following dry products: dust - 85%, cement 32.5 - 15%. After adding some water, the dry components were mixed in a wing mixer. From the mixed composition, briquettes were made in a carousel-type briquetting machine (fig.7).



Fig. 7. Ready briquettes containing post-reclamation dust bonded with cement binder

Due to the high silica content, the briquettes are an excellent slag-forming material.

6.2. Trials on the granulation of post-reclamation dust

One of the simplest methods to change the physico-chemical properties of materials designed for storage and / or commercial use is through their granulation with suitable binders and/or additions. Thus obtained granular material may serve as a substitute for natural aggregates.

Therefore, another attempt to manage the post-reclamation dust was carried out at PEDMO Tychy. Tests consisted in making a granulate based on the dust addition. Granulation was done by vigorous stirring in an Eirich type RO-2 mixer with the rotor rotating speed of 2000 to 2100 rev / min.

The composition of the mixture used in the manufacture of the granulate was as follows: post-reclamation dust - 81.4%, cement 52.5 - 14.4%, hydrated lime- 4.2%. The addition of water necessary to obtain the granules was 18.9%.

The resulting granules were dried at 105°C. A photograph below (fig.8) shows the ready granulate after drying and storage.



Fig.8. A sample of the granulated post-reclamation dust

The obtained granular material may be serve as a substitute for natural aggregates

7. Summary

Through the use of multiple reclamation it is possible to manage and re-use up to 70% of the material reclaimed from the manufacture of foundry moulds.

The remaining material can be successfully used in the construction industry (building ceramics and concrete products), as confirmed by tests performed in the industry.

The post-reclamation dust rich in silica is applicable in the production of building ceramics, and in the form of pellets or briquettes can be used as a component of the coarse aggregate (granulate),

or as a slag-forming material, or as one of the raw materials in the manufacture of mineral wool (in the form of briquettes to prevent blowing it out from the furnace).

The results obtained in accordance with the relevant building standards provide basis for the development of full recycling of the waste moulding sands made with the new types of binders.

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