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Investigations of the Quality of the Reclaim of Spent Moulding Sands with Organic Binders

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Abstract

Modern investigation methods and equipment for the quality estimation of the moulding sands matrices with organic binders, in their circulation process, are presented in the paper. These methods, utilising the special equipment combined with the authors investigation methods developed in the Faculty of Foundry Engineering, AGH the University of Science and Technology, allow for the better estimation of the matrix quality. Moulding sands systems with organic binders require an in-depth approach to factors deciding on the matrix technological suitability as well as on their environmental impact. Into modern methods allowing for the better assessment of the matrix quality belongs the grain size analysis of the reclaimed material performed by means of the laser diffraction and also the estimation of the moulding sand gas evolution rate and identification of the emitted gases and their BTEX group gases content, since they are specially hazardous from the point of view of the Occupational Safety and Health.

Key words: Reclamation, Moulding sand, Moulding sand examinations, Gas formation

1. Investigation methods of reclaimed materials and moulding sands

1.1. Traditional methods

Methods of assessing reclaimed materials and moulding sands with these materials obtained from different kinds of spent sands with organic binders, subjected to the mechanical reclamation, are presented in Table 1. Numbering placed in parenthesis means rating of the assumed criteria on a five-point scale (1÷5), where the highest value have criteria of a low numbering. Thus, the criteria marked 1÷3 should be taken into account in the assessment as the binding criteria. Repetition of the same assessment value for various criteria means their equal status.

Thus, the technological criteria of the following importance rating [1] are recommended for the assessment of the materials reclaimed – by the mechanical reclamation of moulding sands with organic binders :

- Ignition loss acc. to PN-83/H-04119,
- Grain composition of the reclaimed matrix in relation to fresh sand (sieve analysis acc. to PN-83/H-11077),
- Flexural strength of moulding sand R_g^u,
- Chemical reaction (pH, Z_K).

In addition, it is recommended to determine:

- Matrix sintering point acc. to PN-81/H-11074,
- Microscopic examinations of matrix grains surface morphology and sand grains shape factor acc. to PN-83'H-11078.

Table 1. Proposed assessment criteria of the reclaim obtained on the grounds of different kinds of spent moulding sands with organic binders [1]

Recommended criteria of reclaim assessments	**Synthetic resins – systems of spent moulding sands intended for the matrix regeneration**			
	Furan monosand system	**Phenolic strongly alkaline hardened by:**		**CB –sands amine processes. Mixed sands system**
		CO_2	**Acids**	
Ignition loss	(1)	(1)	(1)	(2)
Flexural strength of moulding sands	(2)	(2)	(2)	(1)
Sieve analysis	(3)	(3)	(3)	(2)
Chemical reaction (pH)	(3)	(4)	(4)	(4)
Acid demand (Z_K)	(4)	(4)	(4)	(3)
Surface morphology, sand grains shape factor acc. to PN-83/H-11078	(5)	(5)	(5)	(5)

1.2. Supplementing investigation methods

A specificity of moulding sands with resins, resulting from the organic character of a binder and its chemical composition, which can influence castings quality requires, apart from standard tests, an application of advanced assessment methods of the reclaimed sand grains.

A negative influence on the surface of the casting of the high ignition loss value of the reclaimed matrix manifested by its too high gas evolution rate, is known and described in the references [2÷6], in a similar way as the accumulation of sulphur and nitrogen in the reclaimed matrix being the reason of changes in surface layers of castings [7-10].

Listed below investigations of moulding sands with organic binders with reclaimed matrices belong to the group of important, however still treated as marginal, examinations. These investigations concern assessments of:

- Gas evolution rate of moulding sands with the matrix after the recycling process,
- Carcinogenic aromatic hydrocarbons from the BTEX group (benzene, toluene, ethylbenzene, xylene) content in gases generated during thermal decomposition of moulding sands with organic resins,
- Determination of sulphur and nitrogen content in moulding sands,
- Castings surface quality, including surface defects and porosity.

2. Experimental part

2.1. Moulding sands characteristics

Investigations concerning the mentioned above problems were performed for the moulding sand with the Kaltharz U404 resin, hardened by the 100T3 hardener. The matrix constituted high-silica sand or the reclaim after various degrees of treatment characterised by the ignition loss value. 4 variants of the sand composition differing only in the matrix grade were prepared with the recommended – by the producer - binder content. These moulding sands marked by symbols: MT1-1÷MT1-4, were of the following composition:

- matrix (high-silica sand or reclaim) 98.5%,
- Kaltharz U404 resin 1.0 %
- 100T3 hardener 0.5%

The moulding sand matrices were as follows:

- high-silica sand – moulding sand: MT1-1,
- reclaim 1 (after one cycle of the matrix circulation) – moulding sand: MT1-2,
- reclaim 2 (after two cycles of the matrix circulation) – moulding sand: MT1-3,
- reclaim 3 (after three cycles of the matrix circulation) – moulding sand: MT1-4.

The rotor test AT-2 apparatus was applied as the system for the mechanical reclamation. Two kilograms of spent moulding sand was subjected to the reclamation treatment for 15 minutes at the rotor system rotational speed being 560 rpm. These reclamation parameters were determined within previous investigations of the author [3].

The matrix grain size characteristics of the prepared moulding sand variants is presented in Table 2. The grain size analysis was carried out by means of the Analisette 22 NanoTec apparatus, according to the procedure presented in paper [3].

Table 2. Grain size analysis and ignition loss of the moulding sands and matrices used for the preparation of test sands: MT1-1÷MT1-4 [3]

Moulding sand	Characteristics of the moulding sands		Characteristics of the matrix			
	matrix	Loss of ignition $SP_{(mz)}$ %	Granulometric analysis (Analysette 22 NanoTec)			Loss of ignition
			d_a	d_g	S_t	$SP_{(P)}$ $SP_{(R)}$
		%	mm	mm	mm	%
MT1-1	Quartz sand	1,47	0.287	0.235	1173	0.02
MT1-2	Reclaim 1	2.89	0.304	0.241	1713	1.44
MT1-3	Reclaim 2	3.86	0.305	0.243	1777	2.41
MT1-3	Reclaim 3	4.26	0.312	0.252	1812	2.81

It can be noticed, that the ignition loss of the moulding sand with the high-silica matrix after three circulation cycles is nearly three times larger (2.9) than of the moulding sand prepared on the fresh sand matrix. Despite the reclamation process, preceding the sand preparation, the matrix itself shows a significant increase of the ignition loss as the number of circulation cycles increases.

This indicates that a spent binder, not removed during the reclamation treatment, is accumulating on grains. The observed effect constituted the justification of undertaking investigations of the moulding sands gas evolution rate. The prepared moulding sands, to a certain degree, represent other - applied in foundry practice - moulding sands with organic binders, in which the reclaimed matrix constitutes either a total or a partial substitute of the high-silica foundry sand.

2.2. Investigations of the gas evolution rate of the moulding sands with a reclaim

During the production process of castings an intensive thermal decomposition of organic components of moulding sands occurs, causing the emission of large amounts of gases. These gases are hazardous for the casting quality as well as for the work safety in the foundry plant. Dangerous factors are:

- possibility of gases migrating into the casting and worsening its surface quality,
- harmful conditions at pouring stands being a result of the chemical composition of gases, mainly polycyclic aromatic hydrocarbons or components of the BTEX group.

Investigations of the gas evolution rate were performed according to the original method developed in the Faculty of Foundry Engineering, AGH [11].

Investigations of the amount and kinetics of gases generated in the process of pouring shaped elements were performed for all moulding sands variants (MT1-1÷MT1-3), which characteristics can be found in Table 2. The obtained emissivity pathways as a time function are shown in Fig. 1.

It can be noticed that the most intensive gas evolution occurs directly after pouring the mould with liquid metal. The evolution kinetics presented in Fig.2 allows to state that – under the investigated conditions – the most intensive evolution occurs in the first 90 seconds after metal pouring. Two peaks of the highest evolution kinetics can be exposed. The first peak is seen directly after pouring shaped elements with liquid metal and the second one approximately 80 seconds later.

The analysis of pathways indicates also that both volume and kinetics of evolving gases depend essentially on ignition losses of the tested moulding sand. The presentation of gas volumes generated by moulding sands versus ignition losses is shown in Fig.3. An application of a moulding sand of a higher ignition loss causes a directly proportional increase of the gas evolution. A similar conclusion can be drawn from the analysis of the maximum values in the curves of the kinetics of the gases emission from the tested samples, also presented in this figure.

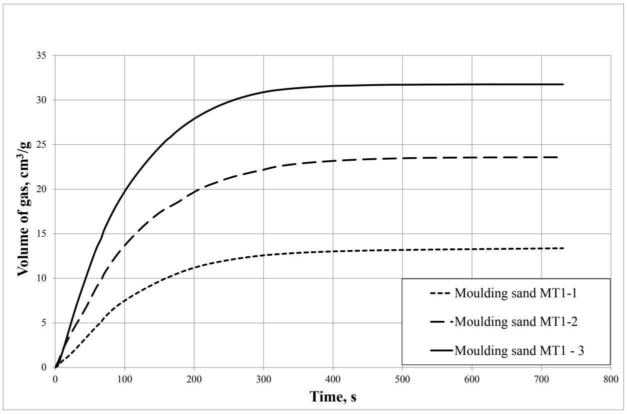

Fig. 1. Volume of gases emitted by the investigated moulding sands in the process of pouring them with liquid metal. Pouring temperature: 1350^{0}C [11]

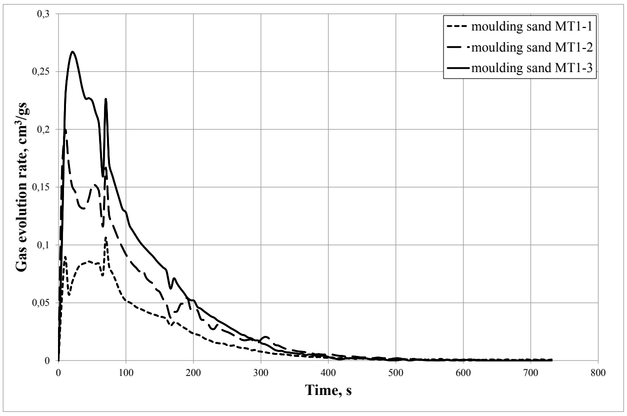

Fig. 2. Kinetics of gases emitted by the investigated moulding sands in the process of pouring them with liquid metal. Pouring temperature: 1350^{0}C [11]

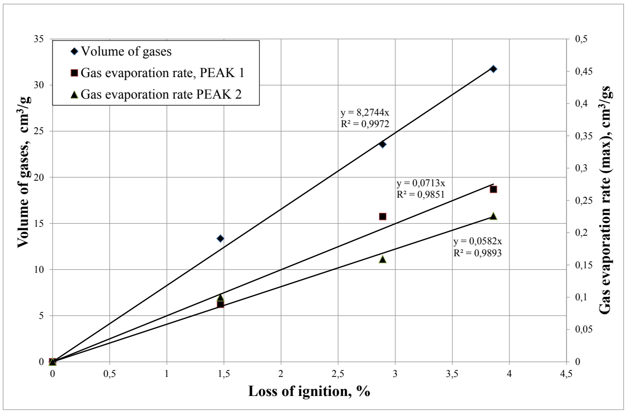

Fig. 3. Volume and kinetics of gases generated as the result of pouring shaped samples made of the investigated moulding sands versus the ignition loss of these sands

3.2.1. Investigations of the BTEX content in gases emitted from moulds

Gases emitted from a mould after pouring it with liquid metal contain specially hazardous components such as aromatic hydrocarbons: benzene, toluene, ethylbenzene and xylene, known as the BTEX group. However, the allowable standards concerning the emission of these gases are not yet drawn up for foundry practice, nevertheless there is a general striving for their limitation in the produced binding materials [11].

Within the performed investigations the BTEX components content emitted from two moulding sands with the Kaltharz U404 resin was determined. Moulding sands MT1-1÷MT1-3 (Table 1) were examined and the results are presented in Fig.4.

On the bases of the obtained results, it can be stated that the amount of emitted gases from the BTEX group is larger for moulding sands containing matrices of higher ignition losses. The character of changes is similar to the one found for the general emission of gases, which allows to estimate - in approximation - the BTEX content on the basis of knowing the moulding sand ignition loss. It would be favourable for practical aims to include in the catalogues of binding materials the data concerning gas evolution rates and emission of gases from the BTEX group.

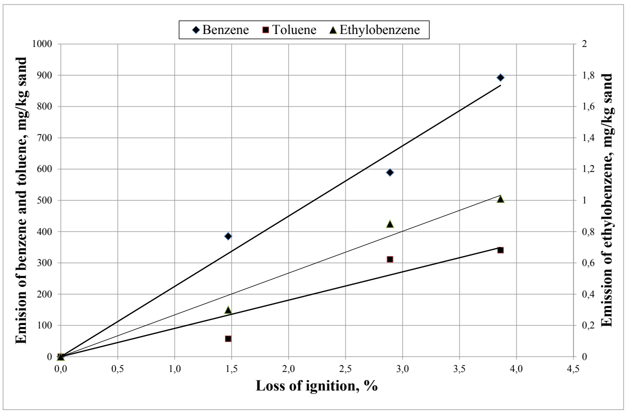

Fig. 4. Measurement results of the BTEX gases emission from the tested moulding sands MT1-1 ÷MT1-3 with Kaltharz U404 resin (1mass %) and 100T3 hardener (0.5 mass %) [11]

3.3. Investigations of sulphur and nitrogen content in moulding sands

Within the quality investigations of the reclaimed matrix the measurements of sulphur and nitrogen content in 4 moulding sands listed in Table 2, were performed in the Carbochemistry Laboratory of the Institute of Chemical Carbon Treatment in Zabrze.

The obtained results presented graphically in Figure 5 confirm the effect of accumulating the sulphur and nitrogen content in moulding sands which underwent multiple reclamation treatments. The results presented graphically in Figure 5 confirm the accumulation effect of the sulphur and nitrogen content. The increase of sulphur and nitrogen content in moulding sands analysed versus their ignition losses is nearly linear. Thus, a determination of the limiting thresholds and allowable content of elements being dangerous for the coatings surface microstructure - justifies the more detailed investigations [3].

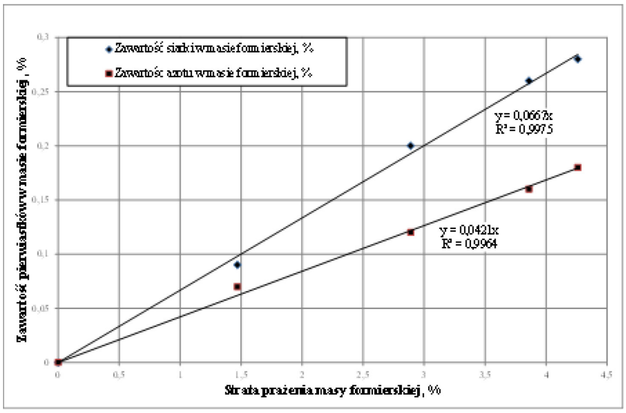

Fig. 5. Measurement results of sulphur (S) and nitrogen (N) content in investigated moulding sands with the Kaltharz U404 resin (1 mass%) and 100T3 hardener (0.5 mass%); ignition losses as in Table 2 [3]

3.4. Surface quality of the test castings

3.4.1. Visual assessment

Moulding sands MT1-1 ÷ MT1-4 were used to produce wedge shaped moulds according to the ASTM A 536-84 standard. Thermal weighting of moulding sand expressed by a ratio of the casting weight to the mould weight was: $m_{odl} : m_{masy} = 1{:}1.6$ at the casting weight being equal 1.7 kg. The average apparent density of the compacted moulding sand was app. 1600 kg/m^3.

After pouring the moulds with liquid spheroidal cast iron of the PN-EN-GJS-500-7 grade, at a pouring temperature of 1400^{0}C, cooling and casting knocking out, their surfaces quality was analysed. Macroscopic photos of the wedge casting surface cast in moulds of self-hardening moulding sands with organic resin of various ignition losses are presented in Figure 6.

It can be noticed that the best (visually assessed) surface quality has the casting cast in the mould made of the moulding sand MT1-1, prepared on the matrix of the pure high-silica sand. The successive castings have worsening surfaces and are developing blowholes as ignition losses (characterising indirectly the gas evolution rate) of the applied moulding sands increase (see Fig. 1).

3.4.2. Estimation of geometrical parameters of casting surfaces

Investigations of geometrical parameters of casting surfaces were performed by means of the TalyScan 150 apparatus of the Taylor Hobson Company with the software: TalyMap Expert v.2.0.19. The measured section was 6 mm. Measurement accuracy - 10 µm. Tests were carried out in the Laboratory WBMiL of the

Department of Production Techniques and Automatisation of the Rzeszów Technical University.

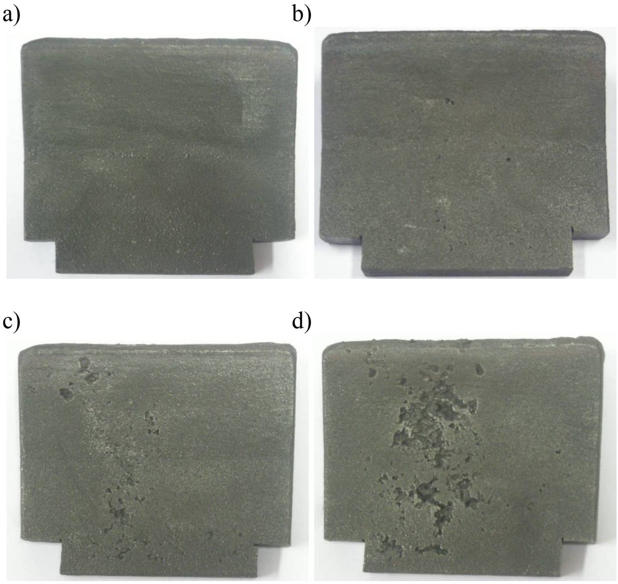

Fig. 6. Surface of wedge castings acc. to the ASTM A 536-84 standard cast from cast iron in moulds made of moulding sands of various ignition losses: a) sand MT1-1; $IL_{(mz)}$= 1.47%, b) sand MT1-2; $IL_{(mz)}$=2.89%, c) sand MT1-3; $IL_{(mz)}$=3.86%, d) sand MT1-4; $IL_{(mz)}$= 4.26% [3]

Height parameters were taken into account in investigations. They are marked: S_q, S_t, S_z and S_a in the testing procedure and defined as follows:

S_q - mean square value of the tested surface deviation from the averaged surface,

S_t – distance between the elevation and cavity lines on the surface,

S_z – arithmetic mean of absolute heights of five highest elevations and five deepest cavities of the fracture surface.

The performed measurements enabled presentation of three dimensional pictures (3D) of the tested surfaces (Figures 7a-7d) of the samples cut from the wedge casting, cast from spheroidal cast iron in moulds of chemically hardened moulding sands of various ignition losses.

The cumulative list of the determined height parameters for castings made in moulds prepared from the investigated moulding sands presented in Figure 8, allows to state that the geometrical parameters of the casting surfaces are significantly worsening as sands of an increasing ignition loss are applied. This unfavourable effect can be explained, among others, by changes of the matrix geometrical parameters, which result from the analysis of the average diameters values of high-silica sand grains and reclaims (see Table 2). In the case of the matrix reclaimed in the recycling process the grains diameter increases together with its ignition loss, which is related to the accumulation of the spent binder layer on high-silica grains.

Another reason of such worsening of the surface quality is a higher gas evolution rate of the moulding sand. This causes local influencing of the casting surface by the binder thermal decomposition products, which can be seen in Figures 7 and 8.

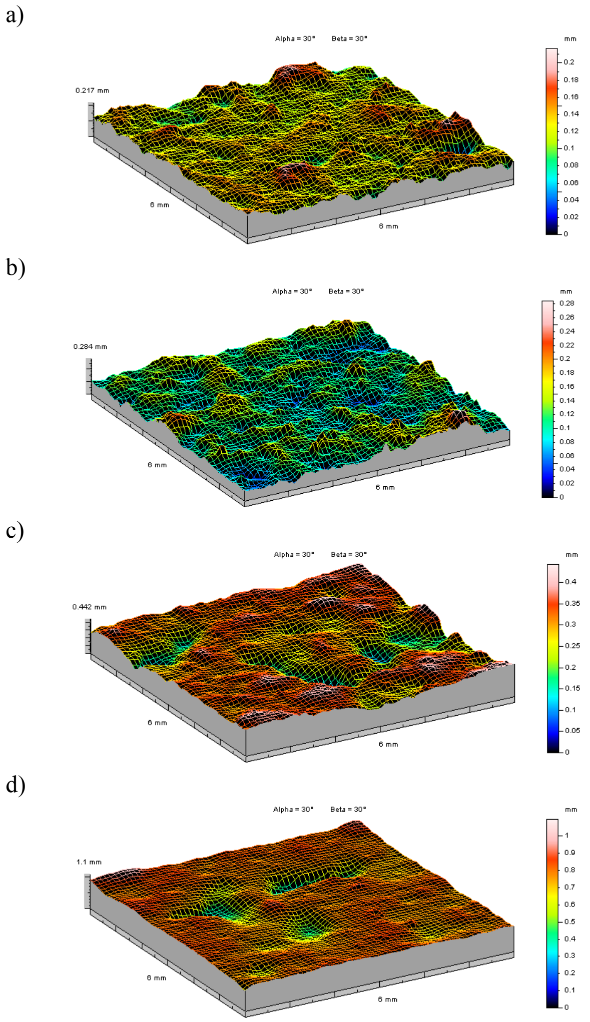

Fig. 7. Three dimensional pictures (3D) of the surface of the castings, cast in moulds made of: a) MT1-1, b) MT1-2, c) MT1-3, d) MT1-4

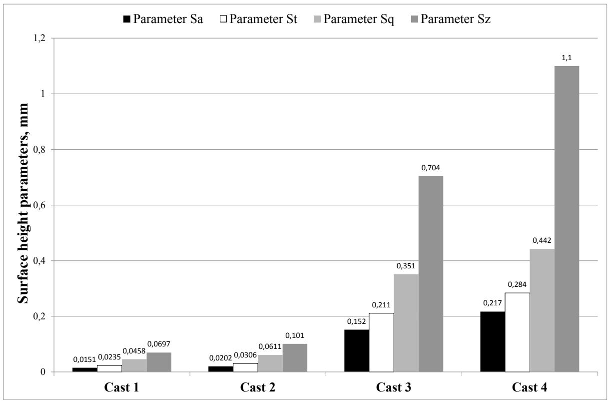

Fig. 8. The cumulative list of the height parameters: Sa, S_q, S_t, S_z obtained for the wedge casting acc. to the ASTM A 536-84 standard made in moulds produced from the investigated moulding sands [3]

4. Conclusions

An application of the reclaimed – in the recycling process – high-silica matrix as a fresh sand substitute requires the development of the matrix assessment method, which will take into consideration the unfavourable influence of the moulding sand, prepared on this matrix, on the castings quality. The presented results justify the usefulness of a periodical testing of the matrix, after the recycling process, since substances being potentially hazardous for the casting quality can be accumulated in it. The unsatisfactory reclamation of certain moulding sands with resins requires the application of special coatings preventing a degradation of the nodular graphite structure in casting outer layers, caused by sulphur compounds accumulating in the matrix. Tests performed on simple wedge castings allowed to asses the moulding sand influence on the microstructure and surface state of the castings.

The presented techniques of assessing moulding sands on matrices, which underwent recycling processes in multicyclic pathways, introduce new elements into the matrix qualification as a substitute of high-silica sands. Broadening of conventional methods of the matrix quality assessment is especially useful, when obtaining the moulding sands of optimal – from the point of view of utilising the reclaim and the casting quality - technological parameters at simultaneous fulfilment conditions related to the environment protection, is aimed.

Taking into consideration the fact that the accessibility of the presented techniques is limited and that they are more complicated and time-consuming in comparison with traditional testing methods applied in foundry plants, postulating the development of the generally accessible catalogue listing moulding sands of organic type used in practice, seems fully justified. Information in this catalogue should include the data concerning gas evolution rate of binders, composition of gases – together with the BTEX group gases – and the presence of elements constituting a potential hazard for the microstructure, properties and quality of the casting surface.

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