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## INVESTIGATION OF THE RESULTS OF COMBINED RECLAMATION ON THE PARTICULAR STAGES OF GRAIN MATRIX RECOVERY

In this article, there were presented the results of research on combined mechanical and thermal regeneration of waste moulding sand with furfuryl resin originated from one of national foundries manufacturing aluminium alloys castings. Attempts of mechanical reclamation were led on the REGMAS reclaimer enabling to realize preliminary and primary reclamation with use of two modes of mechanical interactions on waste moulding sand. In the first attempt the reclaimer worked without any additional regenerating elements, and as the second solution, the reclaimer operated with additional crushing and abrasive elements to increase the result of primary reclamation. Thermal reclamation was led in the prototypic thermal reclaimer, enabling to fully control the process of grain matrix recovery. As a result of completed investigations the small efficiency of mechanical reclamation was determined. However, use of combined regeneration allowed for obtaining grain matrix of high purity. Thermal regeneration was conducted in prototypic thermal reclaimer. Evaluation of reclaim (reclaimed material) quality was carried out in the way of ignition losses and grain-size analysis, surface morphology and also by executing of strength testing of moulding sand prepared on obtained grain matrix for the particular reclamation operations.

*Keywords:* waste moulding (foundry) sand, mechanical reclamation, thermal reclamation, roasting losses, grain-size analysis.

### 1. Introduction

The combined mechanical-thermal regeneration is well known method of the recovery of waste foundry masses, in particular the mixed ones, in which moulding sand composes of moulding sand with bentonite, however core sand consists of different kind of sands bonded chemically. However it seems that such a regeneration process can also find an application in case of the regeneration of waste moulding sand with organic binder, in which castings are made of non-ferrous metals alloys. Relatively low temperature of casting such type of alloys is not ensuring sufficient overheating of moulding sand in the form that has positive influence on reclamation of waste moulding sand obtained after the process of castings knocking out. Waste moulding sand is brought into regeneration. It is characterized by the large content of binder not-burned in the mould, what at multi-cycle circulation of matrix influences the accumulation of waste binding material on matrix grains after the mechanical regeneration process. It can also cause defects in castings manufactured in moulding sands made from such obtained reclaimer [1-7].

Therefore it seems logical it is worth considering the application of the method of combined reclamation, in the foundries in which more advanced castings are made, particularly for the aircraft or automotive industries. Entire waste moulding sand made in the foundry was submitted to the process of mechanical regeneration during which the agglomerated sand was crushed in individual matrix grains. Thereafter, during the process of the thermal regeneration in

the fluidized bed a destruction (burn-out) of binder layer from the grain surface is carried out.

### 2. Experimental stands and investigation methods

The subject of investigation was waste moulding sand (MZ), obtained in one of national foundries producing aluminium alloys castings.

Mechanical reclamation was performed in the REGMAS vibrating reclaimer [8], using following parameters of work modes of the device: mode 1 (without additional crushing-abrasive elements) – RM1, mode 2 (additional crushing-abrasive elements) - RM2.

After mechanical reclamation process, obtained reclaimers were submitted to thermal reclamation [9, 10], obtaining matrix (RMT1) from determined material (RM1), and determined reclaimer (RMT2) from material (RM2). In the investigations, the work parameters of thermal reclaimer were: regeneration temperature of 550°C, and regeneration time of 20 min.

#### 2.1. Vibrating reclaimer

The universal REGMAS vibrating reclaimer [8], functionally integrated with cascade flow classifier, is intended for mechanical regeneration of almost every dry waste moulding sand. It should be installed in regeneration sockets

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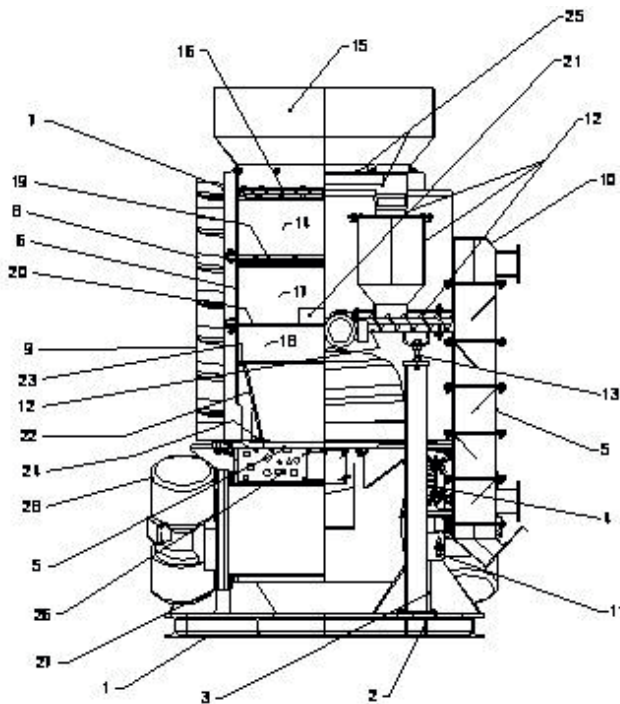


Fig. 1. Diagram of the prototypic REGMAS vibrating reclaimer: a) diagram: 1 – base frame, 2 – frame ledge, 3 – vertical brackets of oscillating supports, 4 – oscillating supports, 5 – device supporting structure plate, 6 – inner reclaimer column, 7 – cylindrical body, 8 – outer transport channel, 9 – channel (runner) cover, 10 – pneumatic cascade classifier, 11 – classifier support, 12 – auger feeder, 13 – feeder support, 14 – upper column segment, 15 – waste foundry sand container, 16 – grating for mould packages crushing 17 – central column segment, 18 – bottom column segment, 19 – upper flat sieve, 20 – central flat sieve, 21 – revision hole, 22 – bottom cone sieve, 23 – elastic sealing, 24 – fixing ring, 25 – covered channel, 26 – moulding sand buffer chamber, 27 – connection pipes with flanges, 28 – rotodynamic motors, b) view of reclaimer stand [8]

in small and medium size foundries. The structural diagram of the prototypic REGMAS regenerator is presented in Figure 1.

## 2.2. Thermal reclaimer

Thermal reclamation was realized in the experimental thermal reclaimer [6, 7], of which the diagram and view are presented in Figure 2.

The device fully is automated. In the area of being active of burners in the corps thermocouples are installed. In the area of burners activity there are thermocouples mounted in the body. They are situated so that they are in a bed of reclaimed moulding sand.

Thermocouples are connected to temperature controllers which enable adjusting the regeneration process to the required temperature. The signal from the controllers is transmitted to ignition machines of the burners. Depending on the set temperature control units, for every burner, start the ignition system and control formation of flame, what is very significant in terms of the safe functioning of the device supplied by natural gas. As the completion of the process is in progress, the ignition machine is controlling the work of solenoid valves installed in the systems providing burners with air and gas. The device is equipped also with the independent module enabling to set the bed fluidization in different ways.

The thermal reclaimer is also equipped with data recorders in which main parameters of the regenerator functioning are registered: temperature in chamber, air temperature for fluidization, pressures, quantity of media used (electric energy, natural gas). Thanks to the automatic data logging of the course of the process, it is possible to verify which variant of the functioning of regenerator in comparison with the quality assessment of acquired reclaimer, is the most effective. The systems of control, supervision, data logging are presented in Figure 2b.

## 2.3. Investigation methods

Acquired reclaimers, as a result of completed mechanical and combined regeneration processes were examined in terms of grain-size analysis, evaluated before (bk) and after the process of pneumatic classification (pk). The grain-size analysis of dusts collected in the cascade classifier was also performed. Reclaimer received after the mechanical regeneration and samples taken of the material during the thermal regeneration were examined for ignition losses, which are the most essential evaluation criterion of acquired reclaimer. Bending strength tests of foundry sand from acquired reclaimers were also executed and for the comparison of foundry sand from fresh components.

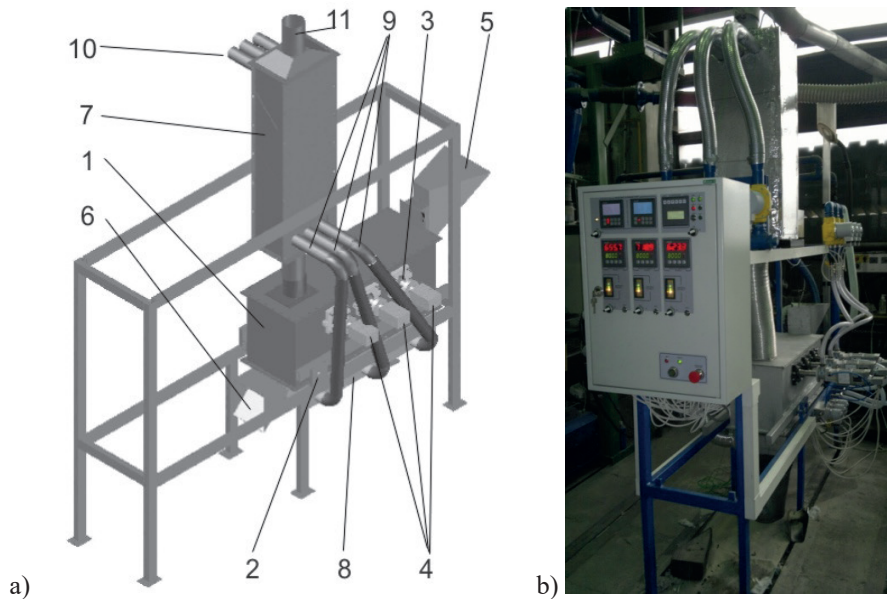


Fig. 2. Experimental thermal reclaimer: a) diagram: 1 – reclaimer chamber, 2 – support bearing for chamber inclination, 3 – articulated burner socket, 4 – burners, 5 – waste moulding sand chute, 6 – reclaim discharge, 7 – recuperator, 8 – fluidizing chamber divided into sections, 9 – pipes supplying heated air to fluidization, 10 – fluidization air inlet, 11 – fumes outlet, b) view of reclaimer stand [9, 10]

Microscopic images of matrix grains surface obtained after reclamation treatments were also performed.

Grain-size analysis of received reclaimers and blown-away dusts were carried out in the “analysette 22” NanoTec laser analyzer for loose materials, from FRITZSCH company, in wet method. The device works using the phenomenon of the optical Fourier transformation [11].

Samples of grain matrix after the mechanical regeneration and after the determined times of the thermal regeneration they subjected to ignition operations in the silt furnace. The results presented in the article are an average from two samples of reclaimer which was heated in the furnace for 2 hours, in temperature of 950°C ensuring burning all organic products [9].

The tests of the moulding sand strength was conducted for the following matrices:

- fresh sand (MS) – 100 mass parts
- grain matrix obtained from smashed sand (MZ), without pneumatic classification – 100 mass parts
- reclaimer (RMT1) – 100 mass parts
- reclaimer (RMT2) – 100 mass parts

- In all cases, the same quantities of components were added:

- binder, furan resin (rosin) – 0.80 mass parts
- hardener – 40% in relation to resin

First, hardener was added to every matrix and mixed for 1 minute, next resin was added and mixed for 2 minutes. In the LUZ-2e device for thickening samples, shapes were performed from the prepared foundry sand. The tests of flexural strength were carried out in the LRU-2e device. The presented results are an average of three measurements.

Examination of the grains surface of received reclaimers was conducted by the Nikon microscope with the microscopic camera coupled with the software for image analysis.

### 3. Analysis of investigation results

During the research on mechanical regeneration, the materials were collected for grain-size analysis, in order to determine the effect of additional crushing and abrasive

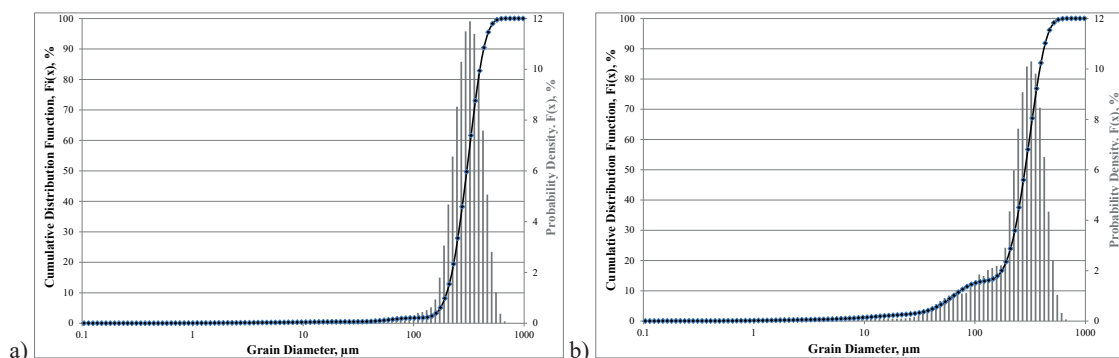


Fig. 3. Grain-size analysis of reclaimer, before final classification process, received in REGMAS regenerator: without using additional crushing and abrasive elements (a) and with using them (b)

components on the efficiency of mechanical interactions towards grain matrix coated with cured resin binder. The earlier observations of authors shows that organic binder in waste moulding sand with small burn-out degree is very slightly removed from grains surface.

In Figure 3, the grain-size analysis results for grain matrix taken from transport channel (without pneumatic classification) were presented. However, in Figure 4 the laser analysis results for reclaimer after final pneumatic classification were presented.

Grain-size analysis of dusts collected in cyclone during mechanical reclamation process with and without crushing-abrasive elements was depicted in Figure 5.

Selected parameters of grain-size analysis of materials investigated are presented in Table 1.

Comparing received results it is possible to state that applying of crushing and abrasive elements causes the bigger comminution of agglomerated waste moulding sand, if grain diameters are compared which are smaller after applying

crushing and abrasive elements. Applying of pneumatic classification proves more effective removal of consumed binder from grain matrix, if additional components interacting with reclaimed moulding sand are used in REGMAS regenerator. This more efficient cleaning is also confirmed by grain size analysis of dusts collected after individual mechanical treatments. Dust picked up after applying crushing and abrasive elements is finer what also shows more effective influence on reclaimed waste moulding sand. However it should be stressed that no negative influence was defined on the same grain matrix which was not subjected to meaningful comminution, in this case.

The results of ignition losses of material samples taken in discharge (after: 1, 2, 4, 6, 8, 10, 15 and 20 minutes) from the thermal regenerator (Fig. 2) were presented in Figure 6. Temperature of regeneration of 550°C at which the treatment was carried out, was selected based on the other examinations concerning effective realization of the thermal regeneration process. Sampling during the process

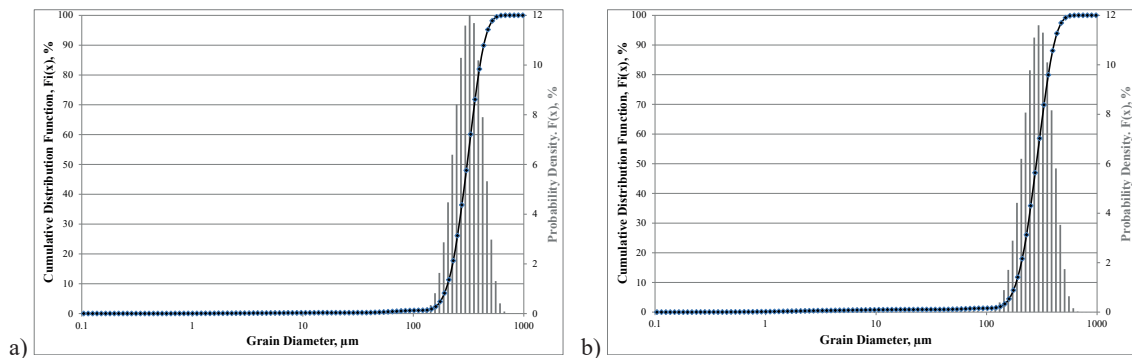


Fig. 4. Grain-size analysis of reclaimer after final classification process, obtained in REGMAS regenerator: without using additional crushing and abrasive elements (a) and with using them (b)

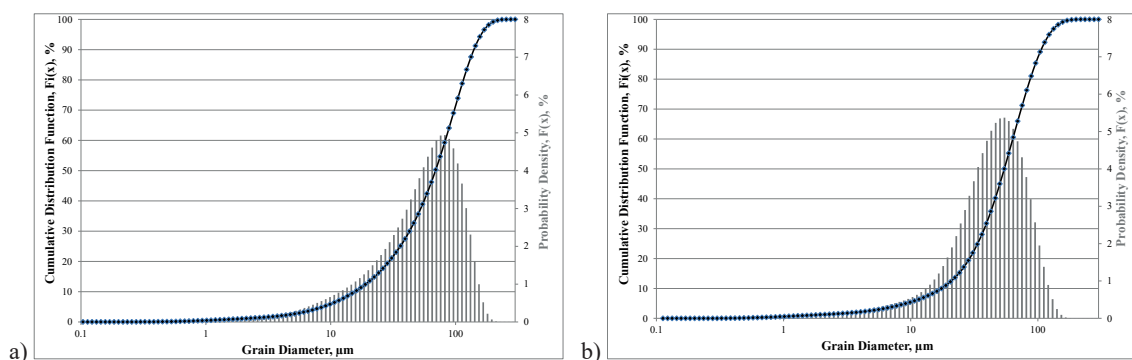


Fig. 5. Grain-size analysis of dusts collected during mechanical reclamation in cascade classifier in REGMAS regenerator: without using additional crushing and abrasive elements (a) and with using them (b)

Grain-size characteristics obtained during testing materials

TABLE 1

Specific parameter	RM1 (dust)	RM2 (dust)	RM1 (bk)	RM2 (bk)	RM1 (pk)	RM2 (pk)
$d_{50}$ , $\mu\text{m}$	77,35	73,26	322,05	279,25	361,25	301,95
$d_1$ , $\mu\text{m}$	56,92	50,18	301,48	239,43	327,15	279,35
$S_t$ , $\text{cm}^2/\text{g}$	2432	2822	221,07	301,12	265,15	289,47
$d_d$ , $\mu\text{m}$	104,34	69,42	331,25	316,27	331,26	302,27
$d_M$ , $\mu\text{m}$	243,2	282,2	221,07	301,12	265,15	289,47

was to define the time necessary to purify grain matrix of waste organic binder. Comparing the results presented in Figure 6 it is possible to state that in case of applied organic binder the time of the regeneration depends on its quantity in sand. Foundry sand prepared from fresh components with small quantity of binder is regenerating very quickly in the given temperature. However the time of regeneration of the materials (time needed for burning defined quantity of organic material) acquired after the mechanical regeneration is definitely longer. It results from bigger quantity of binder on the grain surface. Significant accumulation of cured binder occurred on the grain matrix which was exploited many times (waste moulding sand was only mechanically reclaimed). Since the temperature of alloy casted is too small for considerable burning of binding material in every following cycle its quantity is increased on the grain surface. Simultaneously the mechanical reclamation applied in the foundry didn't remove organic binder in a significant way. It is confirmed by examinations of roasting losses of waste moulding sand (MZ) which amounts to 7%, what is presented in Figure 7.

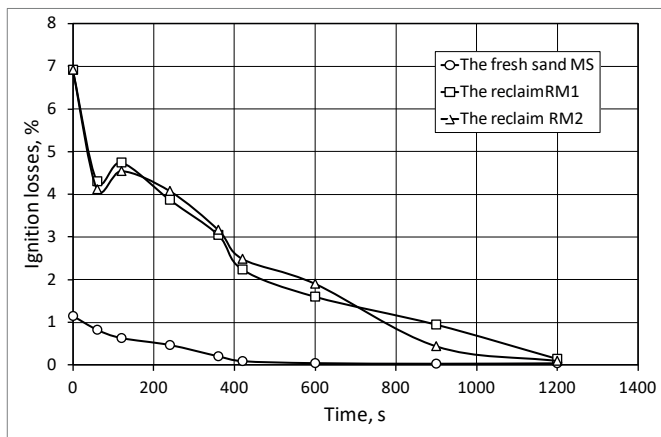


Fig. 6. Ignition losses of tested materials depending on thermal reclamation time

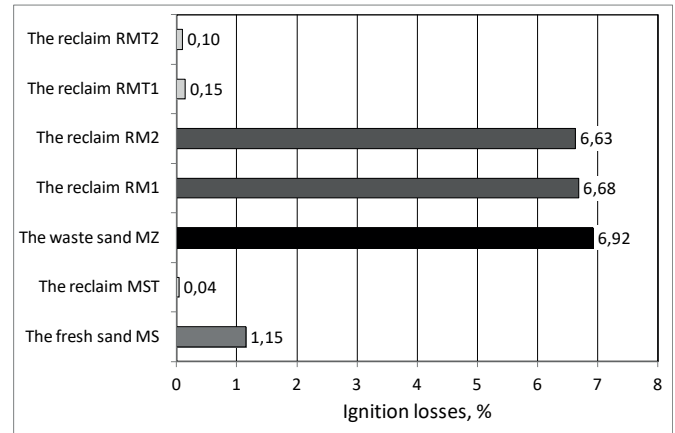


Fig. 7. Ignition losses of tested materials

The conducted mechanical regeneration of tested moulding sand in the REGMAS regenerator also turned out to be not very effective causing, as observed from roasting losses in Figure 7, removal of only 0.29% of consumed binder in a system with additional crushing and abrasive components (RM2) and of 0.24% without additional components intensifying the purification process (RM1). The grain-size analysis described above also confirmed slight, but however additional influence of crushing and abrasive components on the result of mechanical regeneration. The large contents of organic binder in moulding sand creates conditions for the increased emission of gases (gas generation of moulding sand increases) what can contribute to forming defects in castings. Therefore the best solution for the moulding sands is applying of thermal reclamation what is confirmed by examinations described in Figure 7. For 20 minutes time in thermal regeneration of waste moulding sand (MZ) crushed mechanically (RM1) and (RM2) losses of roasting were below 0.15%. In the situation when there is less binder, as observed for roasting losses for moulding sand prepared from fresh components, the process can be shorter and more effective. It is also confirmed by examinations of the morphology of the reclaimers surface (Fig. 8 - 10).

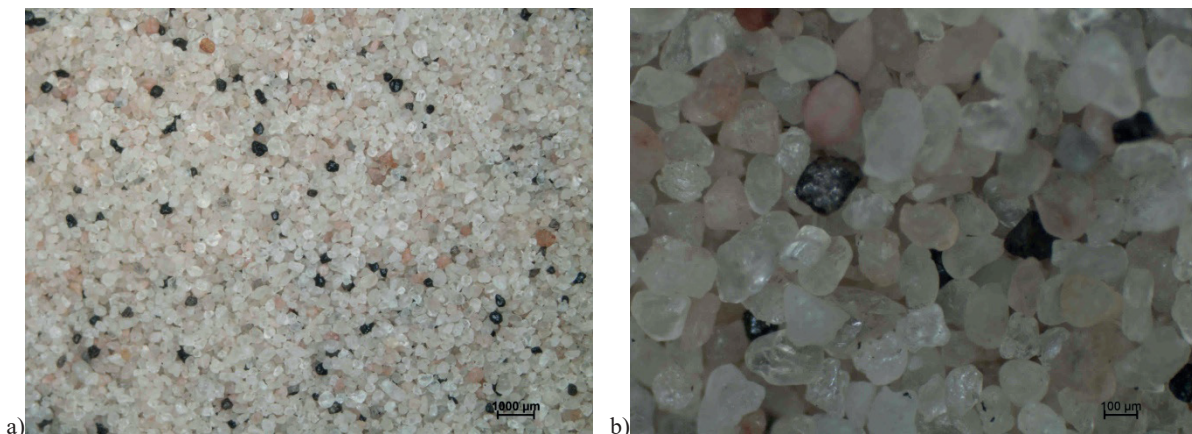


Fig. 8. Microscopic images of grain matrix after thermal reclamation of foundry sand performed from fresh components: a) 10x magnitude, b) 50x magnitude

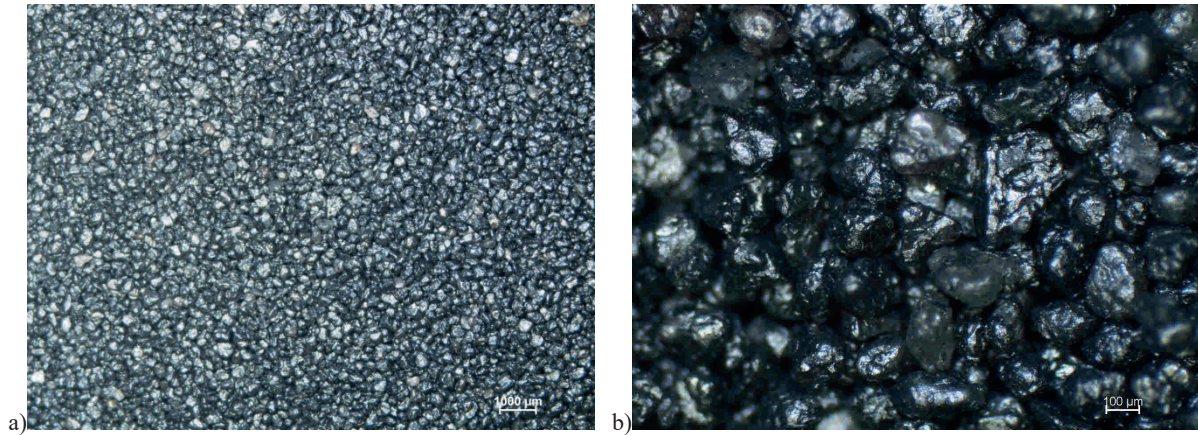


Fig. 9. Microscopic images of grain matrix after mechanical reclamation and pneumatic classification of waste foundry sand received in the REGMAS reclaimer with additional crushing and abrasive components (RM2): a) 10x magn. b) 50x magn.

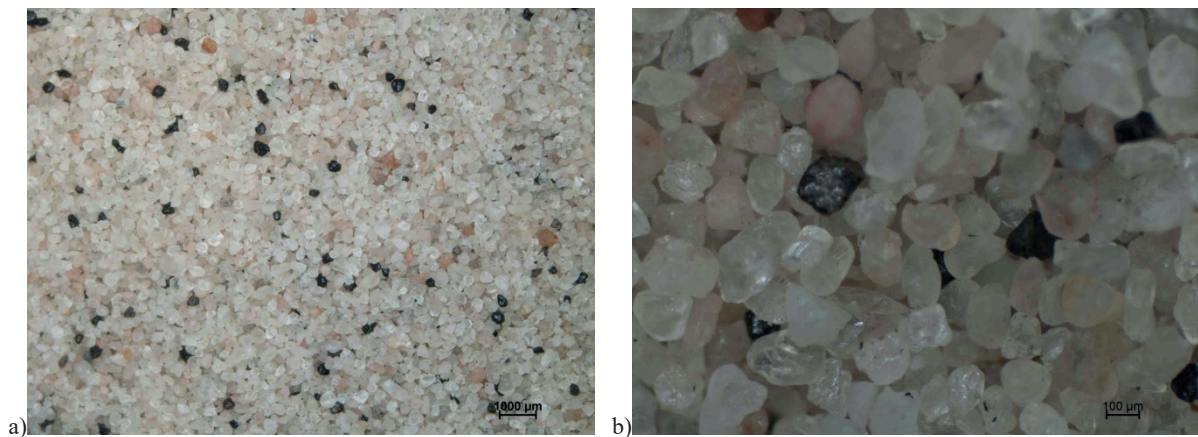


Fig. 10. Microscopic image of grain matrix (RMT2) after thermal reclamation of reclaimed material (RM2): 10 x magn, b) 50x magn.

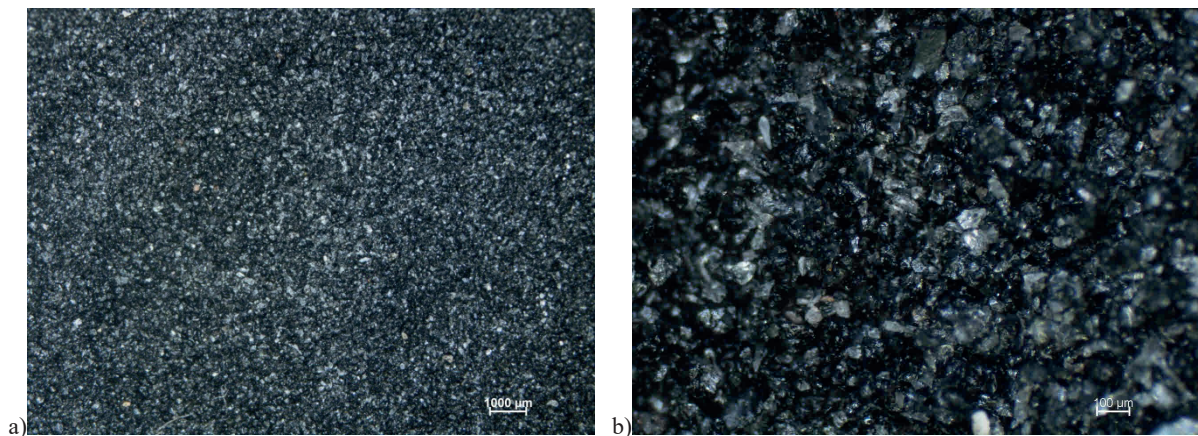


Fig. 11. Microscopic image of dusts collected during pneumatic classification after mechanical reclamation in the REGMAS reclaimer with additional crushing and abrasive components: a) 10x magn., b) 50x magn.

In Figure 11, the microscopic image of dusts created during the mechanical regeneration is presented, where it is possible to notice the fragments of binder mechanically separated, but also small fractions of grain matrix crushed out while mechanical interaction of additional crushing and abrasive components.

Strength of moulding sand prepared from reclaim is also valid evaluation criterion of performed regenerative treatments. The results of discussed evaluation criterion

were presented in Figure 12. If it is possible to notice that after thermal regeneration the bending strength was a bit worse than for fresh sand and grain matrix obtained mechanical crushing of waste foundry sand. However it is sufficient for realization of any operations with the mould without damaging it. Smaller gas generation from moulding sand prepared from reclaim acquired after the thermal process constitutes more essential criterion than its strength [1, 4].

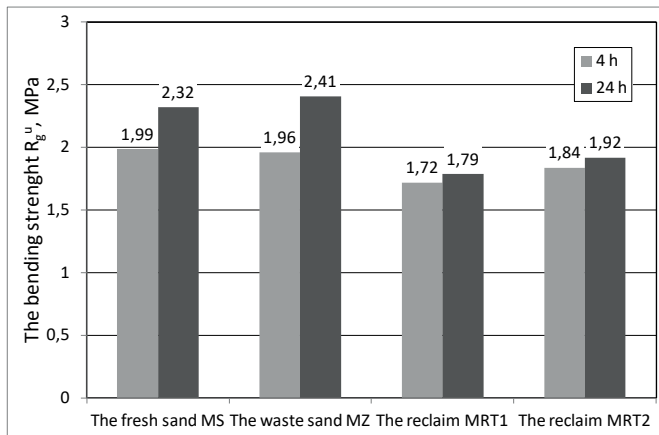


Fig. 12. Bending strength of moulding sand shapes prepared from fresh sand and reclaims

#### 4. Conclusions

As a result of completion of testing, it was noted that there is a positive effect of implementing additional crushing and abrasive components on the result of conducting reclamation process mechanical, as for comminution of foundry sand. For the forcing power applied in investigations, no significant damaging of grain matrix was stated. However applying exclusively mechanical reclamation to the waste molding sand with organic binder (even when quantity of binder in foundry sand is large) is not very effective what is confirmed by ignition losses performed for received reclaims. Individual observations of the mechanical regeneration process of foundry and core sands with chemically cured resin binder are indicating that during mechanical interactions these binders demonstrate certain flexibility what makes it more difficult to remove them from grains surface. Either with use of crushing or abrasive operations. Visible little losses of binder in the waste foundry sand are probably connected to the crushing of bridges linking grains and to crushing small fragments of cured binder out from them.

The use of thermal reclamation in case of waste foundry sand with organic binder is definitely a better solution. However the limit of an application of this method is

connected to the costs. Seeking optimal structural solutions of thermal regenerators and selection of operation parameters can create conditions to reduce costs of implementing process. The quality (purity and small gas generation associated with it) obtained by thermal method of grain matrix (reclaimed material) is definitely better in the case of using it in the manufacture of responsible castings for the aircraft and automotive industries.

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