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The Effect of Reclaim Primary Quality on Moulding Sand Parameters and Quality of Ductile Iron Casting Surface Layer

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Abstract

The aim of the research was to determine the effect of the primary quality of reclaim from dry mechanical reclamation on the strength properties and service life of moulding sands based on this reclaim. Another aim was to establish the effect of the quality of reclaim, sulphur content - in particular, on the surface quality and thickness of the deformed surface layer in ductile iron castings. The research has revealed differences in the strength parameters and service life (mouldability) of sands based on the tested reclaims, depending on the type of the furfuryl resin used, including resins whose synthesis was done as part of the Żywfur project. Examinations of the structure of the surface layer of test castings poured in moulds made of loose self-hardening sands containing the addition of reclaim have confirmed the occurrence of degenerated spheroidal graphite in this part of the casting. It should be noted here that when massive castings with a long solidification time are made, the graphite degeneration effect can be more visible and the layer with the changed structure can increase in thickness. The research has clearly shown that it is necessary to control the parameters of the reclaim, including sulphur content which is transferred from the hardener and accumulates on the grains. This phenomenon has a negative impact not only on the sand strength and technological properties but also on the surface layer of castings.

Keywords: Foundry industry, Furfuryl resin, Reclaim, Self-hardening moulding sand, Surface quality

1. Introduction

A significant part of medium-size and massive iron and steel castings are produced in moulds based on loose self-hardening sands with furfuryl resin. The wide application of furan resin sands is due to the advantages they offer, which include the possibility of obtaining castings with high dimensional accuracy, the possibility of making intricate moulds and cores, binding at ambient temperature (no-bake systems), and low content of the binder in the sand mixture [1-4]. In most cases, loose self-hardening moulding sands with furfuryl resin are based on reclaiming obtained by dry mechanical reclamation of the waste sand [5-9]. In the reclaim obtained by mechanical reclamation, apart from the loss of ignition and binder content, the level of sulphur content, which has its source in the hardener and accumulates on the sand grains, is also controlled [1, 10]. Sulphur accumulation in the reclaimed material is a very unfavourable phenomenon. It has a negative impact on the technological properties of moulding sand (reduced strength and service life) and can result in sulphur diffusion from the sand to the surface layer of casting. In the case of ductile iron, this phenomenon contributes to the degeneration of spheroidal graphite in the casting surface layer [10-12]. Additionally, it may increase the emissions of sulphur dioxide during the pouring of moulds, which affects both working conditions and the environment.

The following factors control the thickness of the deformed surface layer in ductile iron castings: high content of sulphur hardener, which distorts the shape of graphite particles, high pouring temperature, which increases the thickness of the layer, heavy and massive design of the casting, which makes it more prone to this effect, and high content of reclaim in moulding sand, which increases the thickness of the layer. Increasing the addition of a spheroidizer allows the thickness of the deformed layer to be reduced but not totally eliminated [13-16].

Together with industrial partners, the Łukasiewicz - Krakow Institute of Technology is implementing a project aimed at the development and manufacture of a domestic pro-ecological furfuryl resin. The resin after synthesis is characterized by a low content of free furfuryl alcohol and formaldehyde. Apart from the reduced negative impact on the environment, the resin of a new generation can be added to moulding sands in lower amounts, thus contributing to a more effective process of mechanical reclamation of the waste sand [2].

The aim of the research presented in this article is to show that the pro-ecological furfuryl resins used in no-bake systems allow producing the casting skin with a reduced thickness of the sulphur-affected zone and can be widely used in ductile iron casting. The research results may answer the question of whether it is possible to replace the currently used no-bake technology with furfuryl resins without the need to replace the entire reclaimed sand in the production process.

2. Materials and Methods

In the first stage of the research, four types of reclaimed no-bake moulding sands with furfuryl resins were obtained (Table 1). All the reclaimed sand mixtures were based on silica sand. Reclaim 1 was "own" reclaim from moulding sands with resins synthesized under the Żywfur project after primary dry mechanical reclamation. Reclaims nos. 2, 3 and 4 came from domestic iron foundries using commercial furfuryl no-bake technologies.

The used moulding sand (called Reclaim 1) was in the form of small lumps after pouring of moulds and knocking out of iron castings. The reclaimed materials delivered by foundries, designated by numbers 2, 3 and 4, were also in the form of small lumps, easy to crush.

All reclaims have undergone the primary dry reclamation process, consisting in crushing the moulds, separating metal impurities and dedusting [17]. The reclaimed product was not subjected to the process of proper mechanical reclamation in foundries to preserve for this research the cyclically used moulding sands in their original unchanged condition.

To check the current condition of the reclaims, several basic tests were made, including the determination of binder content, total loss on ignition (LOI) and sulphur content. The LOI test, involving heating of the previously dried sand sample, was carried out in a high-temperature chamber furnace, model FCF 4/160M made by Czylok, at a temperature of 900ºC for a period of 2 hours (in accordance with the PN-83/H04119 standard). The sample was next cooled down and weighed on an OHAUS EX324M laboratory balance with an accuracy of 0.0001 g. The sulphur content in the reclaims was determined on a CS-600 (LECO) carbon and sulphur analyzer. The basic properties of the reclaims are summarized in Table 1.

Table 1.
Parameters of reclaims

Parameter	Reclaim 1	Reclaim 2	Reclaim 3	Reclaim 4
Main fraction	0.20/ 0.16/0.315	0.315/ 0.20/0.40	0.315/ 0.20/0.40	0.40/ 0.315/0.20
Average grain size, mm	0.23	0.27	0.28	0.32
Clay binder content, %	0.28	0.77	0.32	0.38
Total LOI, %	1.21	3.05	3.52	5.39
Content of S, %	0.037	0.137	0.184	0.220

The content of binder, total loss on ignition (LOI) and sulphur content increase with the increasing numbers by which the reclaims are designated. Therefore Reclaim 1 is characterized by the most advantageous parameters due to the lowest value of LOI and sulphur content. Sulphur present in the loose self-hardening moulding sands with furfuryl resins comes from the hardener, which is a mixture of sulphonic acid and sulphuric acid, sometimes with the addition of phosphoric acid. Sulphur from the hardener tends to pass to the sand grains and accumulates on their surface, even when a proper mechanical reclamation process is carried out. Compared to other reclaims, Reclaim 4 contains the sand with the highest degree of use after the repeated cycles of its operation in a foundry shop (now considered to be a waste material).

Moulding sands based on reclaimed materials, designed for tests carried out in this research, were prepared using four furfuryl resins, i.e. two resins synthesized as part of the Żywfur project, designated as Resin 1 and Resin 2, and two commercial resins with similar furfuryl alcohol content widely available on the market, designated as Resin 3 and Resin 4 (Fig.1). All furfuryl resins were brown, clear liquids of similar density and viscosity. Resins 1 and 2, synthesized under the Żywfur project, had a low content of free formaldehyde, i.e. at the level of 0.09 and 0.12%, respectively, compared to commercial resins in which the content of formaldehyde exceeded the value of 0.13%. Resins 1 and 3 as well as 2 and 4 were characterized by a similar content of furfuryl alcohol, amounting to approximately 75% and 65%, respectively.

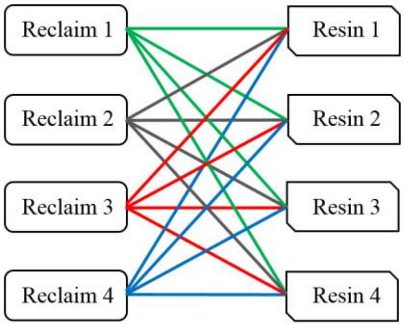

Fig. 1. Schematic plan of moulding sand preparation

According to the schematic plan shown in Figure 1, moulding sands were made in an LMR-2 laboratory ribbon mixer. For the preparation of loose self-hardening moulding sands containing 1.0 part by weight of resin and 0.35 part by weight of hardener, four types of reclaims were used. The base sand was mixed with the hardeners for 90s, and then the resin was introduced and the whole was mixed for another 90s.

Moulding sands were used to make standard oblong specimens with dimensions of 22.36 x 22.36 x 172 mm for the test of bending strength. The sand was pre-compacted in an LUZ-1 device for the vibratory compaction of samples. The vibration time was 20 seconds, the maximum vibration amplitude was 2 mm. The strength of the specimens was measured with an LRu-2e apparatus in accordance with the Polish standard PN/83/H-11073. The specimens were tested in 1, 2, 4 and 24 hours after the end of the compaction process. For each hardening time, the measurements were made on a minimum of three samples and the results presented are an average of the results obtained in these tests.

In the second stage of the research, melts were carried out to determine the effect of the reclaim quality on the quality of the outer surface of iron castings and the impact of sulphur contained in reclaim on the degradation of the particles of spheroidal graphite. Moulds were prepared from sands based on the reclaim with Resin 1. A scanning electron microscope, model TM-3000, made by HITACHI and dedicated graphic and analytical software were used to reconstruct the surface of the castings. Measurements of the thickness of the layer of the degenerated spheroidal graphite in castings were carried out with a Zeiss light microscope provided with an AxioObserver Zm10 program.

3. Results

Mouldability

The increasing content of reclaim in moulding sand significantly shortens the sand service life, otherwise known as the sand mouldability. This is due to the increasing content of sulphur in moulding sand derived from the hardener and accumulating on the sand grains. This phenomenon has a negative impact on the technological properties of the sand mixture reducing its strength and service life. Additionally, it can also affect the surface layer of castings [7, 18-19].

Table 2 shows the results of the sand mouldability (service life) test carried out on the reclaim-based moulding sands.

Table. 2.
Results of the mouldability test

Sand life:	Reclaim 1 [min]	Reclaim 2 [min]	Reclaim 3 [min]	Reclaim 4 [min]
Resin 1	25	18	13	9
Resin 2	26	18	14	9
Resin 3	23	16	12	8
Resin 4	12	12	10	6

Sulphur content in the reclaim also affected the service life of moulding sands. The moulding sands based on Reclaim 1, containing about 0.04% of sulphur, had a lifetime of 22 ÷ 26 minutes, while those based on Reclaim 4, with the highest sulphur content of 0.22% had a much shorter service life, i.e. at the level of 6 ÷ 9 minutes.

Strength tests

The research was focused on the determination of the strength parameters of loose self-hardening moulding sands as a function of the hardening time. The kinetics of changes in the technological parameters was plotted on the example of the bending strength of moulding sand samples made with the four tested types of resins and reclaims (Fig. 1).

Figure 2 shows the test results obtained after 24 hours of hardening. These are the maximum values measured in 1, 2 and 4 hours after the end of the compaction process. It is assumed that the strength of the moulding sands based in 100% on the reclaim should be minimum 1.4 MPa.

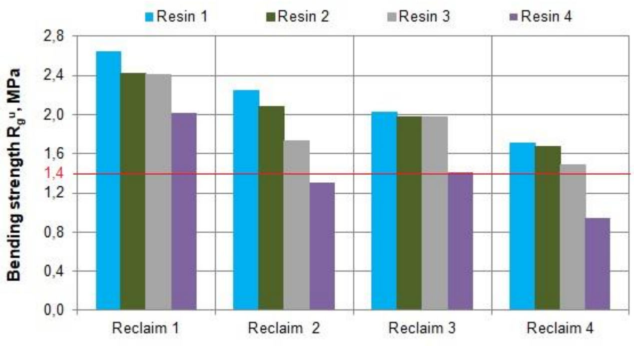

Fig. 2. The effect of the type of reclaim on the sand bending strength determined after 24 hours of hardening

From the graphs in Figure 2 it follows that after 24 hours of hardening, in the entire group of moulding sands based on reclaims and in the entire group of the tested reclaims, the sand mixtures prepared with Resin 1 and Resin 2, synthesized under the Żywfur project, had the highest strength parameters. In the case of Reclaim 3, the sand mixtures with Resins 1, 2 and 3 offered similar strength values (about 2.0 MPa). Comparing the results obtained for the resins synthesized under the project with commercial resins characterized by similar furfuryl alcohol content, it can be concluded that for all the tested reclaims, the sands mixtures prepared with the resins synthesized under the project were characterized by a much higher bending strength determined after 24 hours of hardening.

Casting surface quality

The methodology of surface roughness measurements has been described in the literature [2, 20]. Moulds for the assessment of external casting surface quality were made from the moulding sands based on the reclaims with Resin 1. Moulds were poured with ductile iron at a temperature of 1410°C. After pouring, the castings were sandblasted and surface roughness was measured.

Figure 3 shows, as an example, the segmental roughness measurement for Reclaim 1 along with its 2D transverse profile (OE = 239,63 µm).

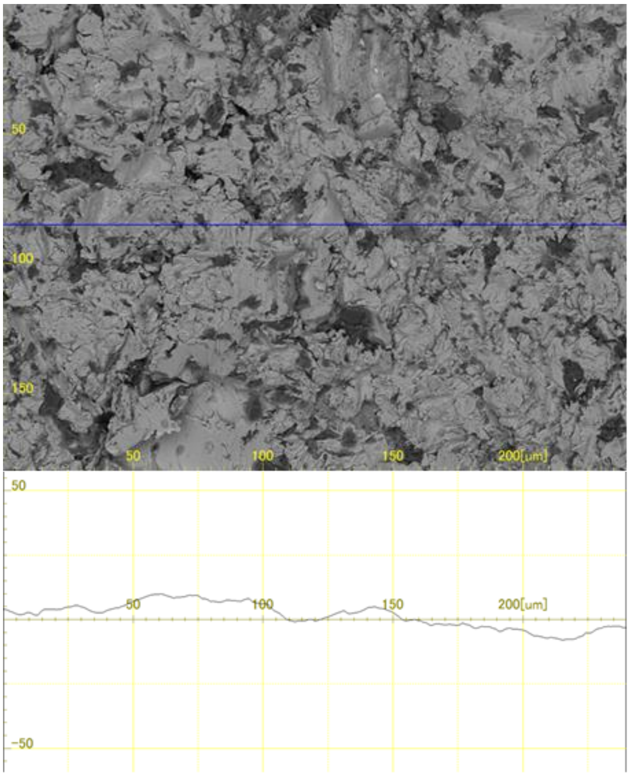

Fig. 3. Moulding sand based on Reclaim 1: a) the examined casting surface, b) transverse profile of the surface

Table 3 summarizes the results of measurements of the surface roughness parameters.

Table 3.
Test results for selected roughness parameters

Parameter	Reclaim 1	Reclaim 2	Reclaim 3	Reclaim 4
SRa, µm	3.44	2.71	4.26	3.69
SRq, µm	4.23	3.45	5.24	4.62
SRz, µm	21.87	21.10	24.91	30.73
SRp, µm	10.24	8.71	16.32	10.73
SRv, µm	11.64	12.39	14.00	14.058
SRIr, µm	107.10	106.05	105.53	106.16
SRSm, µm	60.82	59.36	97.20	67.14

where: SRa - arithmetic mean of absolute values; SRq - root mean square of values, SRz - ten highest peaks and lowest valleys over the entire sampling length, SRp - maximum peak height, SRv - maximum valley depth, SRIr - profile length coefficient, SRSm - mean width of the roughness profile elements;

On the elongated elementary measuring section 10xOE with SR, a tendency towards the deterioration of the surface roughness parameters was noticed along with the deteriorating quality of reclaims and sulphur content increasing in their composition.

The SRz roughness parameter, reflecting the value of the ten highest and lowest peaks along the entire sampling length, increases with the sulphur content increasing in reclaim. A similar relationship was observed for the depth of the valley SRv.

Microstructural assessment of the surface layer in ductile iron castings

To determine the effect that sulphur content in moulding sand has on the thickness of the layer with degenerated spheroidal graphite in castings, microscopic examinations were performed. Figures 4-7 show photographs of the microstructure of castings made in moulding sands based on the reclaims with different sulphur content. The photographs were taken during examinations carried out with a Zeiss light microscope at a magnification of 200x.

The microstructure of samples cast in moulding sands based on the reclaimed materials consisted of two different areas. The structure of the casting centre was composed of spheroidal graphite and a ferritic-pearlitic matrix, while flake graphite appeared in the structure of the casting surface. The layer with the changed structure had different thickness, which increased with the increasing sulphur content in reclaims (1-4). In the case of the casting made in the moulding sand based on Reclaim 1 (Fig. 4) with the sulphur content of 0.037%, the thickness of the layer was in the range of 40 to 100 µm. For Reclaim 2 (Fig. 5), containing 0.137% of sulphur, the thickness of the deformed layer was in the range of 100 ÷ 200 µm. For moulding sands based on Reclaims 3 (Fig. 6) and 4 (Fig. 7), containing 0.184 and 0.220% of sulphur, respectively, the thickness of the layer increased and was from 400 to 600 µm. The authors of publications on the effect of sulphur content in moulding sand on the degradation of graphite precipitates in ductile iron castings obtained very similar research results [10, 11].

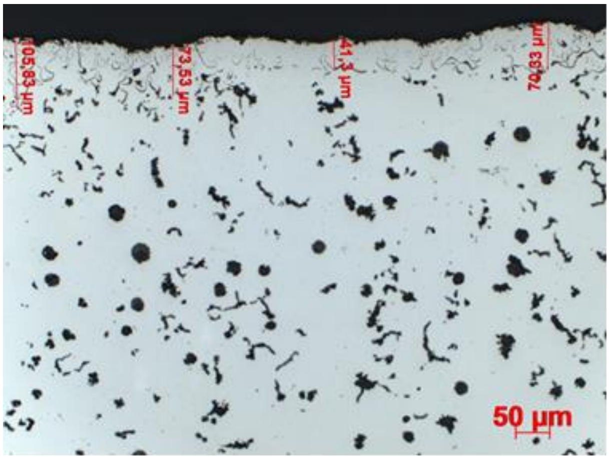

Fig. 4. Microstructure of casting made in moulding sand based on Reclaim 1 with sulphur content of 0.037%. Non-etched state

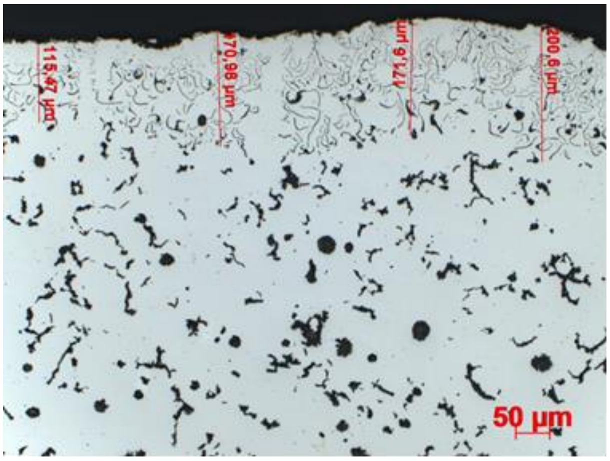

Fig. 5. Microstructure of casting made in moulding sand based on Reclaim 2 with sulphur content of 0.137%. Non-etched state

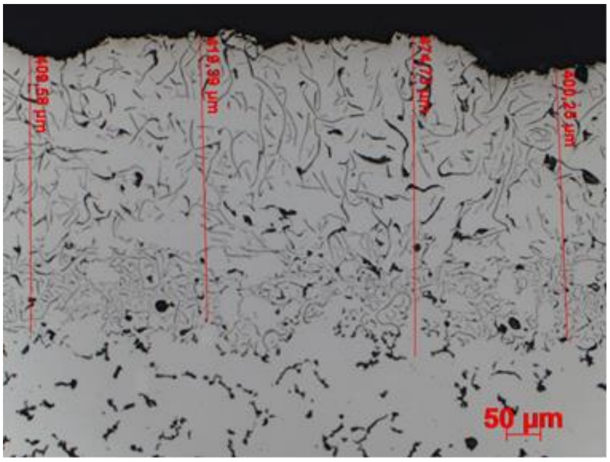

Fig. 6. Microstructure of casting made in moulding sand based on Reclaim 3 with sulphur content of 0.184%. Non-etched state

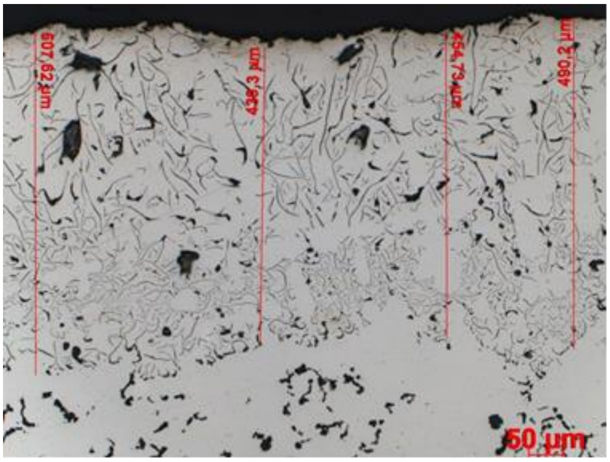

Fig. 7. Microstructure of casting made in moulding sand based on Reclaim 4 with sulphur content of 0.220%. Non-etched state

4. Conclusions

The conducted research allowed for the following conclusions:

- the higher is the sulphur content in the reclaimed material, the shorter is the sand life and the lower is the sand strength determined after 24 hours of hardening;
- the increasing sulphur content in the reclaimed material, and thus in the moulding sand, results in a tendency of the surface roughness parameters to deteriorate;
- due to the diffusion of sulphur from the moulding material to the surface of ductile iron castings, degenerated spheroidal graphite appears in the surface layer (skin) of the casting;
- the higher is the sulphur content in the reclaimed material, and thus in the moulding sand, the thicker and more uneven is the layer of the changed structure;
- the layered structure was observed in all castings; the skin (surface layer) included flake graphite in a ferritic matrix, while the remaining (central) part of castings was composed of spheroidal graphite embedded in a ferritic-pearlitic matrix.

Examinations of the structure of the surface layer of test castings poured in moulds made from the loose self-hardening moulding sands based on reclaims have confirmed the presence of degenerated spheroidal graphite caused by sulphur diffusion from the moulding sand to the casting surface.

Moulding sands prepared with resins synthesized under the Żywfur project (Resin 1 and Resin 2), using all tested reclaims as a base material, are characterized by the technological parameters superior to the sands made with furfuryl resins with similar furfuryl alcohol content available on the market (Resin 3 and Resin 4).

The results of the research open the possibility for successive implementations of Resin 1 and Resin 2 to replace the currently used no-bake technology with furfuryl resins without the need to replace the entire reclaim in the foundry production process.

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