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# EFFECT OF RECLAIM ADDITION ON THE MECHANICAL AND TECHNOLOGICAL PROPERTIES OF MOULDING SANDS BASED ON PRO-ECOLOGICAL FURFURYL RESIN

Increasing demands are imposed on foundries to enforce the manufacture of castings characterized by tight dimensional tolerances, high surface finish and total absence of casting defects. To face these challenges, castings are increasingly made in loose self-hardening sands with furfuryl resin, commonly known as furan sands. In the group of self-hardening sands with synthetic resins, loose self-hardening sands with furfuryl resin enjoy the greatest popularity. The sand mixtures based on furan resins are usually subjected to mechanical reclamation. The consumption of binder and hardener and thus the cost of the sand depend on the quality of reclaim, and mainly on the dust removal degree.

The planned tightening of the environmental protection regulations in the EU countries, including limiting the content of free furfuryl alcohol in resins and reducing the emission of furfuryl alcohol, formaldehyde and BTEX compounds at workplaces, necessitated the development of a new generation of eco-friendly furfuryl resins that have recently appeared on the market.

The main aim of this article was to determine the effect of reclaim content on the sand parameters, such as bending strength, tensile strength, bench life, gas-forming tendency and loss on ignition. Tests were carried out with reclaim content in the sand mixture varying from 50 to 90%. The reclaim obtained by dry mechanical reclamation was supplied by one of the domestic foundries.

The results showed that the highest mechanical properties were obtained in sands containing 60% of the reclaim.

*Keywords:* loose self-hardening sands, pro-ecological furfuryl resin, environmental protection, strength tests, gas-forming tendency

## Introduction

The concept of sustainable development was created at the beginning of the 19th century by Hans Carl von Carlowitz. At first, it concerned only prudent management of forest resources but over time was transferred to other sectors of the economy [1]. Sustainable development is a development that meets the basic needs of all people and preserves, protects and restores the health and integrity of the Earth's ecosystem, without jeopardizing the ability to meet the needs of future generations and without exceeding the long-term limits of the capacity of the Earth's ecosystem [2]. Thus, it is the development of all sectors of the economy in a way that does not threaten the natural resources of the environment [3].

The rapidly developing industrial economy not only brings humanity a highly developed material civilization, but also becomes a cause of many environmental problems. The foundry industry consumes large amounts of natural resources, energy and metals, and generates equally large amounts of gases and solid waste, which have a significant impact on the environment. Caring for ecology and introducing more eco-friendly changes can increase production and reduce costs, improve brand recognition, strengthen customer relationships and increase business profitability. Thanks to the implementation of environmental management systems, combined with the use of proper materials, proper waste management and recycling, foundry plants can play an important role in the sustainable use of natural resources [4,5].

Foundries whose activities are largely based on waste processing and reclamation (recycling of used moulding and core sands and re-use of the recovered base sand) are important elements of the concept of sustainable development [6,7].

Following applicable regulations requiring a reduction in the amount of generated waste, used moulding sands are largely subjected to mechanical reclamation. As a result of this process, a reclaim with the required properties is obtained along with the

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waste in the form of dust, which can constitute up to 10 wt% of the total amount of the moulding sand used [8-10].

At present, binders based on furfuryl resins enjoy the greatest popularity in the group of no-bake moulding sands, i.e. sands hardened without heating [11,12]. This is mainly due to the wide range of applicability of the reclamation process, the possibility of making castings with high dimensional accuracy, the ability to make intricate moulds and cores, binding at ambient temperature and low binder content in the sand mixture, all of which make these sands attractive for industrial applications in the production of moulds for various types of castings made from steel, iron and non-ferrous metal alloys [13,14].

In the literature you can find a lot of information about the process of moulding sands with furan resin reclamation. Łucarz, Monish and Krishna [15,16] describe the process of thermal reclamation moulding sand with furan resin, properties of the obtained reclaim and comparable parameters of moulding sand prepared with its participation. In other publications [17-20], the authors focused on determining the physico-chemical and ecological properties of the reclaim obtained by mechanical dry reclamation.

Together with industrial partners, the ŁUKASIEWICZ – Krakow Institute of Technology is implementing a project whose main objective is to develop and produce a domestic pro-ecological furfuryl resin with reduced content of free formaldehyde. In addition to limiting the negative impact on the environment, the use of the resins of a new generation will allow reducing their percentage content in the sand mixture, which will translate into positive economic effects obtained by potential users [21].

## 1. Materials and methods

Two types of furfuryl resins were used in the research, i.e. the resin whose synthesis was part of the project work (designated as Resin 1) and commercial resin (designated as Resin 2).

Table 1 compares the characteristics of the resins tested. Both resins are brown, clear liquids with similar density, viscosity. Resin 1 is characterized by a higher content of furfuryl alcohol with a lower percentage of nitrogen and free formaldehyde content [15].

TABLE 1

Characteristics of the tested resins [15]

| Parameter | Resin 1 | Resin 2 |
|---|---|---|
| **State** | liquid | liquid |
| **Appearance** | clear, brown | clear, brown |
| **Density (20°C), g/cm$^3$** | 1.150 | 1.163 |
| **Viscosity (20°C), mPa·s** | 20 | 26 |
| **Free formaldehyde, %** | 0.035 | 0.13-0.15 |
| **Furfuryl alcohol, %** | 84±1 | 77±1 |
| **Nitrogen, %** | 1.9±0.5 | 3.5±0.5 |

For the preparation of loose self-hardening sands containing 0.8 part by weight of the resin and 0.3 part by weight of hardener, silica sand from Sibelco, classified according to the Polish standard PN-85/H-11001 as medium sand was used. The reclaim was supplied by one of the domestic foundries. Moulding sand subjected to the reclamation process was based on commercial resin (Resin 2).

The basic parameters of both silica sand and reclaim are compared in Table 2. Paratoluene sulphonic acid was used as a hardener.

TABLE 2

Parameters of silica sand and reclaim

| Designation | | Silica sand | Reclaim |
|---|---|---|---|
| **Sieve analysis – recalculated mesh fraction, %** | **Sieve No.** | — | — |
| | **1.60** | — | — |
| | **0.80** | — | 0.04 |
| | **0.63** | 0.20 | 0.13 |
| | **0.40** | 6.40 | 3.39 |
| | **0.315** | 17.45 | 11.40 |
| | **0.20** | 50.65 | 62.03 |
| | **0.16** | 14.10 | 12.56 |
| | **0.10** | 10.20 | 9.13 |
| | **0.071** | 0.85 | 1.14 |
| | **0.056** | 0.10 | 0.10 |
| | **pan** | 0.05 | 0.08 |
| **Binder content, %** | | 0.130 | 0.131 |
| **Homogeneity index, %** | | 82.20 | 86.30 |
| **Average grain size, mm** | | 0.23 | 0.22 |
| **Main fraction** | | 0.200/0.315/0.160 | 0.200/0.160/0.315 |

From the prepared sand mixture, standard oblong specimens with dimensions 22.36×22.36×172 mm were made for the bending test and 8-shaped specimens for the tensile test. The sand mixture was pre-compacted in a LUZ-1 type vibratory compaction device. The vibration time was 20 seconds, the maximum vibration amplitude was 2 mm. Strength measurements were taken on a LRu-2e device by the Polish standard PN/83/H-11073. The lapse of time between completing the specimen compaction process and testing was 1, 2, 4 and 24 hours. Measurements were carried out on a minimum of three specimens for each hardening time and the results presented are a mean of these tests.

Bending and tensile tests were carried out on samples of foundry moulding sands with the addition of Resin 1 and Resin 2, prepared according to the following formula:

Sand mixture 1 – fresh silica sand (100/0%),
Sand mixture 2 – fresh silica sand and reclaim in a 50/50% ratio,
Sand mixture 3 – fresh silica sand and reclaim in a 40/60% ratio,
Sand mixture 4 – fresh silica sand and reclaim in a 30/70% ratio,
Sand mixture 5 – fresh silica sand and reclaim in a 20/80% ratio,
Sand mixture 6 – fresh silica sand and reclaim in a 10/90% ratio.

In the next stage of research, all prepared sand mixtures were subjected to the loss on ignition test and the amount of emitted gases was determined. The loss on ignition test (LOI), 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 900°C for a period of 2 hours (following PN-83/H04119). The amount of emitted gases (gas-forming tendency) was determined by the industrial standard BN-76/4024-05. The measurement was carried out in an electric furnace provided with a temperature control unit in a measuring range of up to 1300°C. The measurement consisted of placing the measuring boat with the sample put inside in a furnace heated to 1000°C. For the measurement of gas-forming tendency, 1 g of dried material was placed in the boat. The volume of emitted gases was read every 5 seconds. The test was interrupted after 10 minutes or earlier if, within 1 minute after the last reading, the volume of gases in the burette did not increase.

## 2. Test results

Figures 1-3 illustrate the results of bending tests performed on loose self-hardening sand mixtures with the addition of reclaim (Sands 2-6). As a reference material, the sand mixture with furfuryl resin based on new sand (Sand 1) was used.

For all the tested times of hardening, in the sand mixtures containing Resin 1 (Fig. 1), the addition of reclaim in an amount of 50% caused a significant increase in the sand bending strength. In the sand mixtures containing Resin 2, the addition of reclaim in an amount of 50 and 60% also increased the sand bending strength (Fig. 2). However, a further increase in the amount of reclaim added to the sand mixture caused a decrease in this strength. The authors of the publications about the effect of the amount reclaim in the sand mould on its properties obtained very similar tests results. The increase of reclaim amount in sand moulds caused a decrease in its strength properties, which was most visible after a hardening time of 24 hours [10,21]. The values of bending strength of sand moulds prepared with commercial Resin 2 are similar to those obtained by other authors. After 24 hours of hardening, the sand mixture with Resin 1 developed under the project was characterized by much higher

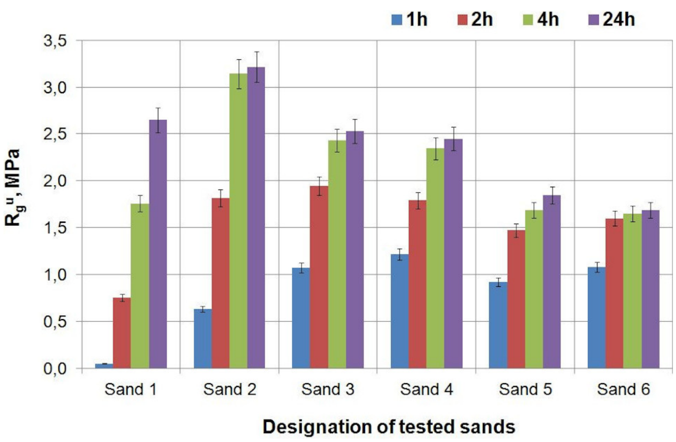


Fig. 1. Effect of hardening time on bending strength of sand mixtures based on Resin 1

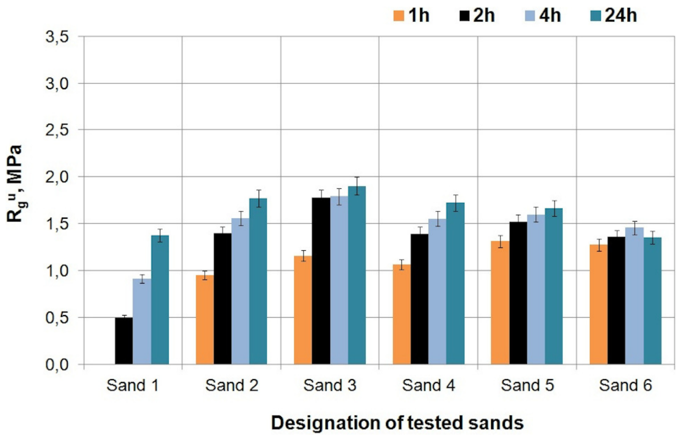


Fig. 2. Effect of hardening time on bending strength of sand mixtures based on Resin 2

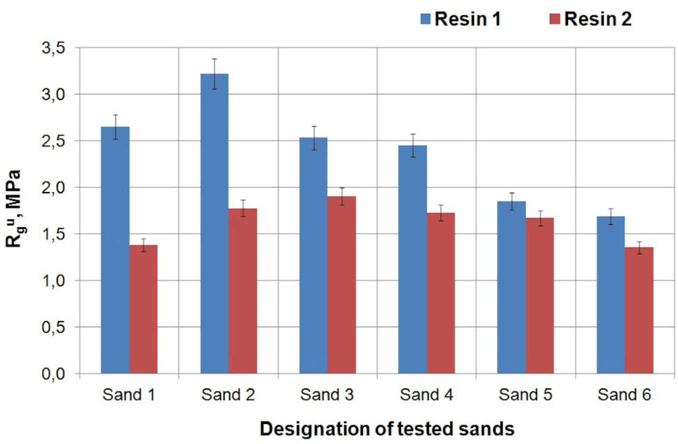


Fig. 3. Comparison of bending strength values obtained for the tested sand mixtures based on Resin 1 and Resin 2 after 24 hours of hardening

strength than the same sand mixture prepared with commercial Resin 2 (Fig. 3). In the case of the sand mixtures based on pure silica sand (Sand 1) and the sand mixtures with reclaim added in a ratio of 50/50% (Sand 2), these values were two times higher. This was probably due to the higher content of furfuryl alcohol in resin, accelerating the hardening process of the resin and increasing its binding capacity.

Another aim of the research was to compare the results of tensile tests carried out on the sand mixtures based on Resin 1 and Resin 2 after 24 hours of hardening (Fig. 4). In the case of tensile strength, the same pattern of changes was obtained as in the case of bending strength, but actual values were two times lower. The highest value of the strength was 1.76 MPa and it was obtained in Sand 2 based on Resin 1.

Table 3 summarizes the results of tests carried out on all prepared sand mixtures to determine the sand mouldability (bench life), loss on ignition (LOI) and the amount of emitted gases.

The presence of reclaim in the sand mixture, and especially its increasing content, significantly reduces the time during which the sand is suitable for moulding, i.e. the bench life. This is due to an increase in the amount of sulfur in the moulding sand derived from the hardener and accumulated on the warp grains.

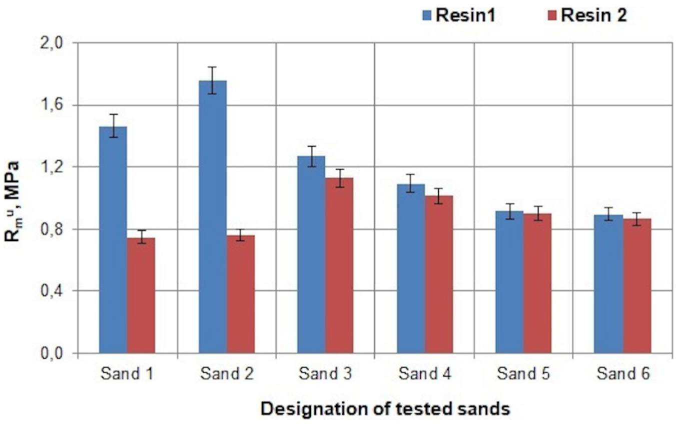


Fig. 4. Comparison of tensile strength values obtained for the tested sand mixtures based on Resin 1 and Resin 2 after 24 hours of hardening

This phenomenon harms both the technological properties of the moulding sand, reduced strength and bench life, but can also affect the surface of castings [22,23]. The shortest lifetime of 14 and 11 minutes, respectively, was mixtures containing 90% of the reclaim. Compared to the sand mixtures based on Resin 2, the sand mixtures based on Resin 1 were characterized by a lower gas-forming tendency determined at 1000°C and lower loss on ignition (by about 20-25%) (Fig. 5) [24]. This is due to the lower formaldehyde content in the resin.

TABLE 3

Studies of the sand bench life, loss on ignition and gas-forming tendency

| Designation | Resin 1 | | | Resin 2 | | |
|---|---|---|---|---|---|---|
| | Bench life, min | LOI, % | Gas emission, $cm^3/g$ | Bench life, min | LOI, % | Gas emission, $cm^3/g$ |
| **Reclaim** | — | 2.206 | 15 | — | 2.206 | 15 |
| **Sand 1** | 67 | 1.449 | 12 | 86 | 1.854 | 14 |
| **Sand 2** | 29 | 2.295 | 13 | 35 | 2.865 | 16 |
| **Sand 3** | 27 | 2.866 | 18 | 28 | 3.452 | 20 |
| **Sand 4** | 23 | 2.995 | 19 | 23 | 3.715 | 22 |
| **Sand 5** | 16 | 3.304 | 20 | 19 | 3.894 | 24 |
| **Sand 6** | 17 | 3.364 | 21 | 11 | 4.018 | 25 |

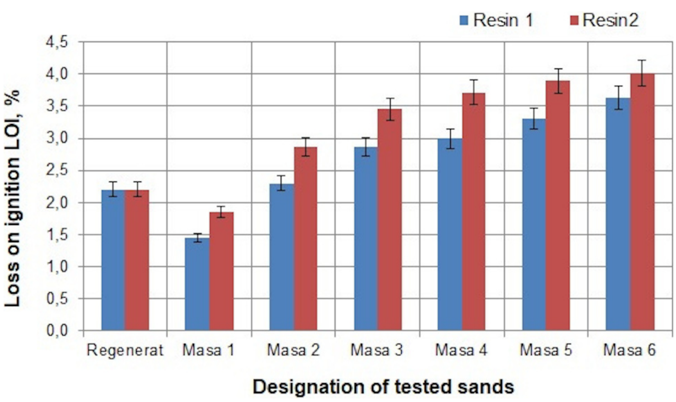


Fig. 5. Comparison of loss on ignition values obtained for the tested sand mixtures based on Resin 1 and Resin 2

## 3. Summary and conclusions

The study aimed to determine the impact of reclaim addition on the sand parameters, such as bending strength, tensile strength, bench life, gas-forming tendency and loss on ignition. Tests were carried out on five sand mixtures containing the reclaim in an amount from 50 to 90%. As a reference material, the sand mixture based on pure silica sand was used. Another aim of the study was to compare the properties of the sand mixtures prepared with two types of furfuryl resins, i.e. Resin 1 subjected to synthesis as part of the project work and commercial resin designated as Resin 2.

The research allowed drawing the following conclusions:

- Within the tested range of hardening times, the sand mixtures composed of the base sand and reclaim added in a ratio of 50/50%, 40/60% and 30/70% (Sands 2, 3 and 4) had the tensile strength $R_m^u$ and bending strength $R_g^u$ comparable to or even higher than the sand mixture based on new silica sand (Sand 1).
- The sand mixtures containing 80 and 90% of the reclaim were characterized by lower strength, mainly due to the accumulation of active hardener in reclaim, radically reducing the sand bench life.
- Compared to the sand mixtures with commercial Resin 2, the sand mixtures with Resin 1, made by synthesis as part of the project work, were characterized by higher strength, a lower amount of emitted gases and lower by 20-25% loss on ignition.
- For the sand mixture based on pure silica sand with Resin 1 (Sand 1) and the sand mixture with reclaim added in a ratio of 50/50% (Sand 2), the obtained values were two times higher. This was due to the higher content of furfuryl alcohol in resin, accelerating the hardening process of this resin and increasing its binding capacity.
- The results of the studies have shown that up to 70% of the reclaim can be used in moulding sand without the risk of deteriorating its properties.

The obtained test results clearly confirm that the synthesis of resins carried out as part of the project enabled the development of a new generation, pro-ecological furfuryl resin dedicated to the foundry industry. Compared to furfuryl resins currently available on the market (Resin 2), the sand mixtures based on Resin 1 are characterized by lower harmfulness, while maintaining high technological parameters. Improving the ecological properties of the Resin 1 includes the process of its synthesis, which allows the use of resin and very high content of formaldehyde.

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