Microstructure and properties of test castings of cast iron made in moulding sands with the BioCo2 binder

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Abstract

In this paper the results of investigations on using new BioCo2 polymer binders in a form of thermodynamically stable polymer compositions are presented, together with the indication for its possible application as moulding sand binding agents. Moulding sands bound with the BioCo2 binder hardened by microwaves or under an influence of a temperature are characterized by a compression strength ($\mu_c R$) of an order of 2 MPa and a bending strength ($\mu_g R$) of an order of 1 MPa, after 1 hour of sample maturing (storing).

In addition, binders in moulding sands are reversible (renewable) in this part, which was not completely overheated and the spent sand is easily knocked out, thus enabling recycling of spent sands. Experimental tests performed in the casting house confirmed the laboratory investigations concerning the use of these binders for moulding sands, and the castings met the qualitative and strength requirements for the selected cast iron grade.

Keywords: Biopolymers, Polymer binders, Moulding sands, Spheroidal cast iron, Microstructure

1. Introduction

Organic polymer binders are, among others, applied in the foundry technology as binding agents for moulding and core sands. Polymer binders contain in their composition only synthetic or natural polymers dissolved in the properly selected solvent [1-5].

The last investigations carried out in the Laboratory of Environment Protection of the Faculty of Foundry Engineering (AGH) concern the development and the application in the foundry industry the new generation of polymer binders: BioCo in a form of a polymer composition with the fraction of biopolymers, for which the proper cross-linking and hardening methods were already selected [6]. The BioCo binding agents, based on biopolymers, are characterized by good qualities in respect of the technology (right qualities of moulding sands), ecology (solubility in water, intoxicity, biodegradability and renewability of spent binders) as well as in respect of economy (relatively low price of binders) [7]. The reclaimability of spent sands with the given binder is often decisive in a practical, industrial application of such binder. Within this scope of research a broad spectrum of investigations is undertaken to assure the
high reclaimability level of the spent moulding sands, which were prepared with these newly designed binders [8, 9].

The spheroidal cast iron, due to its properties, belongs to a group of potential materials for obtaining light castings of good mechanical and functional qualities, which production costs are relatively low [10, 11]. Obtaining such castings requires an application of moulding sands of a high strength and rigidity. On account of that the chemically bound moulding sands are generally used in the production of the spheroidal cast iron high quality castings.

An attempt to prepare the spheroidal cast iron castings, which would meet the quality and strength requirements for this cast iron grade, with the application of casting moulds made of moulding sands bound by the new BioCo2 binder, was undertaken.

2. Methods of investigations

The new generation polymer binding agent: BioCo2 in a form of a water solution of the two-component polymer composition (Fig.1), formed by mixing a synthetic polymer (polyacrylic acid of the BASF Company) and a natural polymer (dextrin of the Fluka Company) in the weight ratio 1:1, was used in tests.

In addition, high-silica sand (1K of a fraction 100 – 200 μm) and another binder: urea-furfuryl resin Kaltharz 404U (1.3 weight %) with a hardener from a group of paratoluenesulphonic acids 100 T3 (0.5 weight %) were used.

The preparation of a moulding sand was as follows: at first a high-silica sand was introduced into the paddle mixer (Ms -017A) then the BioCo2 polymer binder was added in amount of 3 weight % and the whole was mixed for 3 minutes. The moulding sand with the resin and hardener was prepared in an analogous manner as with the BioCo2 binder, adding in 3 minute intervals: sand, resin and hardener. From such moulding sands the casting moulds reconstructing Y type ingots (12.7 mm acc. ASTM A305), were made.

The experimental melt was done in the induction furnace. The furnace charge consisted of the following materials: Sorelmetal, technically pure silica, Fe-Mn and steel scrap. After metal heating to a temperature of 1490°C, the bath was hold for 2 minutes and after that the spheroidization and modification operations were performed by a bell method. For the spheroidisation the foundry alloy Fe-Si-Mg (6% Mg) was used, while the modification was done with using the Foundrysil modifier in an amount of 0.5 weight %. The pouring temperature was app. 1400°C. The cast iron of the following chemical composition was obtained: C – 3.71%; Si – 2.69%; Mn – 0.44%; P – 0.05%; S – 0.010%; Cr – 0.04%; Mg – 0.042%; Cu – 0.02%.

Casting moulds made with the application of the BioCo2 polymer binder are presented in Figure 2.

The general view of the casting moulds after the process of pouring with liquid metal and after metal obtains the temperature of surroundings are given in Figure 2b. The thin layer of the burned moulding sand, located on the contact surface: metal-mould, is clearly seen. This is a positive effect, since the thermal destruction of the moulding sand, occurring due to the liquid metal influence is beneficial from the point of view of the matrix reusing, which is possible after certain reclamation operations.

![Fig. 2. General view of the casting moulds made with the BioCo2 polymer binder: a) before pouring, b) after pouring](image)

Samples cut from lower parts of type Y ingots of a mass 2.5kg were subjected to metallographic and strength investigations. Metallographic examinations were performed by means of the optical microscope Leica MEF-4M. Microstructures were estimated at magnifications of 25 and 100x. Strength testings were carried out by means of the Zwick/Roell Z050 device equipped with the Macro extensometer. The examination rate was 0.008 s⁻¹. Shapes and dimensions of samples for strength tests (in accordance with PN-62/H-04310) are shown in Figure 3.

![Fig. 3. Sample for strength testing: d₁ = 8 mm, D = 10 mm, m = 30 mm, L₉ = 40 mm, L₇ = 48 mm, L₈ = 115 mm](image)

3. Moulding sands with the BioCo2 binder

Moulding sands with the BioCo2 binder fraction hardened by dehydration as the result of physical factors (temperature, microwaves) are characterized by a compression strength ($R_c$) of an order of 2 MPa, and by a bending strength ($R_b$) of an order of 1 MPa after 1 hour of the sample maturing (storage). The weight ratio of the binder and high-silica matrix applied in the moulding sands is 3 to 100 [6, 7]. In addition, binders in the moulding sands are reversible (renewable in a sense of the possibility of
performing the rebounding of these sands) in this part, which was not completely overheated and the spent sand was easily knocked out, thus enabling recycling of spent sands. Due to the fact, that binders contain only atoms of carbon, oxygen and hydrogen and are water soluble, they are characterized by a minimum emission of gases during the moulding sands formation, casting mould making as well as during pouring with liquid metal. The emitted gases are safe for the environment and people since they do not contain the harmful volatile organic compounds (VOC) and polycyclic aromatic hydrocarbons (PAH).

Photographs of the morphology of the moulding sand with the polymer composition prepared with high-silica sand and hardened by a microwave radiation are presented, as an example, in Figure 4. Heterogeneous sand grains adherent to each other can be seen. In between these grains a thin binder layer can be noticed and also binder bridges, which are bonding grains, are visible.

![Fig. 4. Morphology of the moulding sand with the BioCo2 binder](image)

### 4. Casting microstructure

The microstructure of the spheroidal cast iron at the boundary casting-mould is presented in Figure 5.

![Fig. 5. Microstructure of castings: a, c) Made in moulds with the application of the new generation polymer binders: BioCo2, b, d) Made in moulds with the application of the urea-furfuryl resin (Kaltharz 404U). Polished sections not etched.](image)

Polished sections not etched.

The application of the new generation BioCo2 polymer binder enables making the casting moulds, which can be used for obtaining the spheroidal cast iron. Metallographic examinations (Fig. 5) indicate uniformly located graphite nodules in the whole cross-section of the casting. No faults, which would be related to the moulding sand influence on the casting surface and microstructure, are observed in these castings. Castings are without such defects as: pinholes, deformations of casting surface, gaseous porosities or graphite deformations in the near surface layer. When comparing the moulding sands with the BioCo2 polymer binders and the moulding sands hardened by the urea-furfuryl resin (Kaltharz 404U) no essential differences in amounts and sizes of graphite nodules were found. However, the difference is seen at the casting - mould boundary, where - in case of using the Kaltharz 404U resin - the deformed graphite zone occurs. This zone encompasses the flake and vermicular graphite. A thickness of the degenerated graphite zone depends mainly on despheroidizing elements (especially sulphur) content in the moulding sand and on the magnesium to sulphur ratio in the cast iron. The graphite degeneration occurs due to the magnesium (spheroidizing element) concentration decrease in the near surface layer of the cast iron. This decrease is caused by the magnesium reaction with sulphur or oxygen which are diffusing from the moulding sand into metal. The higher concentration of these elements in the moulding sand, the higher thickness of the degenerated graphite layer. It should be mentioned, that the flake graphite presence significantly changes the cast iron properties (first of all, it lowers strength and deprives of ductility) in the near surface layer, which can be the reason of the casting rejection.

The sulphur diffusion from the moulding sand into metal causes also the pearlite formation in the near surface layer, which was observed when the moulding sand with the Kaltharz 404U resin was applied (Fig. 6 b, d).

![Fig. 6. Microstructure of castings: a, c) Made in moulds with the application of the new generation polymer binders: BioCo2, b, d) Made in moulds with the application of the urea-furfuryl resin (Kaltharz 404U). Polished sections etched with nital.](image)

The increased pearlite layer in the casting at the metal - mould boundary with the sulphur content increase in the moulding sand, occurs due to the pearlite-forming sulphur character. The application of the new generation polymer binders, BioCo2, provides the uniform matrix in the entire casting cross-section. Microstructure diversification, manifesting itself by the pearlite
and ferrite layers occurrence in the near surface casting layer, were seen in case of the casting made in the mould with the application of the Kaltharz 404U resin. The casting moulds made with the application of the new generation of polymer binders, BioCo2, assure the uniformity of the microstructure and - to this end - also the properties (mechanical, functional, corrosive) in the whole cross-sections of castings.

5. Mechanical properties

The static tensile test allowed to determine strength properties of the spheroidal cast iron obtained in the mould made with the application of the new generation polymer binders, BioCo2. The following strength parameters were determined:

- $m_E$ – modulus of elasticity;
- $R_{p0.2}$ – yield strength;
- $R_m$ – tensile strength;
- $A_g$ – uniform elongation;
- $A_{gt}$ – total elongation at the highest tensile force;
- $R_B$ – breaking stress;
- $A_t$ – total elongation at destruction.

The pathway of the stress as the deformation function for the casting obtained in the mould made with the application of the new generation polymer binders, BioCo2, is presented in Figure 7 as an example.

![Figure 7](image_url)

Fig. 7. Stress as a function of the deformation for the casting obtained in the mould made with the application of the new generation polymer binders, BioCo2

The results of strength properties of castings obtained in the moulds made with the application of the new generation of polymer binders, BioCo2, confirm that the spheroidal cast iron in EN-GJS-500-7 grade was obtained.

6. Summary

The new generation polymer binders, BioCo, on the biopolymers basis, characterized by several desirable physical, chemical technological and ecological properties can constitute a serious alternative for the typical organic and inorganic binding agents for moulding and core sands, being applied in the foundry industry.

The preliminary investigations indicated that the application of the BioCo2 binder in moulding sands warrants obtaining the casting moulds, which can be used for making castings from the spheroidal cast iron and that these castings will meet the requirements both qualitative and strength for the selected cast iron grade.

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References