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Destruction of Moulding Sands with Chemical Binders Caused by the Thermal Radiation of Liquid Metal

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Abstract

The obtained results of heating of sand moulds with binders by means of a thermal radiation of liquid metal are presented in this study. Standard samples for measuring R_g made of the tested moulding sands were suspended at the lower part of the cover which was covering the crucible with liquid metal (cast iron), placed in the induction furnace. The authors own methodology was applied in investigations. The progressing of the samples surface layers heating process was determined as the heating time function. Samples of a few kinds of moulding sands with chemical binders were tested. Samples without protective coatings as well as samples with such coatings were tested. The influence of the thermal radiation on bending resistance of samples after their cooling was estimated. The influence of several parameters such as: time of heating, distance from the metal surface, metal temperature, application of coatings, were tested. A very fast loss of strength of moulding sands with organic binders was found, especially in cases when the distance between metal and sample surfaces was small and equaled to 10÷15 mm. Then, already after app. 15 seconds of the radiation (at T_{met}=1400°C), the resistance decreases by nearly 70%. Generally, moulding sands with organic binders are losing their strength very fast, while moulding sands with water glass at first increase their strength and later slightly lose. The deposition of protective coatings increases the strength of the mould surface layers, however does not allow to retain this strength after the metal thermal radiation.

Keywords: Sand moulds, Thermal destruction, Radiation, Heating of moulds, Loss of strength

1. Introduction

Moulds pouring with liquid metal leads to a continuous heating of their surface layers. This heating is of two characters: in places where liquid metal contacts with the mould surface heating is of convection character (exchange by means of a contact), while in places situated above the metal surface (its upper part) heating occurs mainly by the radiation. The heating process, in the current investigations, is analysed in relation with the possibility of formation surface defects such as scabs [1, 2, 3, 4,], veins [5], swells [6, 7], or shifting caused by mould or core deformations. This last strength assessment is known as hot - distortion test [8, 9].

Moulding sands with resins - organic binders, are characterised by relatively low thermal resistances. Derivative tests indicate that these sands undergo destruction already at temperatures slightly above 200°C. A time factor is important in the thermal destruction process. It results from the author's studies [11] that moulding sands with organic binders have the lowest thermal conductivity, which should be related to the burning process of binders themselves and to the generation of an additional heat.

The moulding sand resistance to the metal thermal influence is essential for the allowable mould filling time. This time should be shorter that the time after which a disintegration of moulding sands in the surface layer of the mould cavity starts. Not meeting this condition leads either to washing out of lower mould layers or to spontaneous crumbling of sand grains from upper surfaces of the mould. Both effects cause sand holes, slug inclusions, burn-on or scabs.

Investigations of influences of the liquid metal radiation on the surface layer of moulds made of a few moulding sands with chemical binders, were performed. The thermal influence on the final strength of the moulding sand was determined. A very low strength of moulding sands with organic binders and the thermal influence of liquid metals was confirmed. Times after which individual moulding sands are losing their cohesion were determined. In addition, the role of the distance between the metal surface and the mould surface as well as the metal temperature was determined.

2. Own investigations

Heating of the sand mould surface being at a certain distance from the liquid metal surface (e.g. cast iron) is a complex process of heat exchange. In this process the most important is the radiation, but the exchange of the heat by means of convection is also important. According to the Stefan – Boltzman law the energy emitted (E_0) by a body is proportional to the 4-th order of its absolute temperature (θ):

$$E_0 = C\left(\frac{\Theta}{100}\right)^4 \quad (1)$$

The surface heating rate depends, first of all, on the radiating body temperature, distance between the radiating and heated surfaces and on the heat absorption coefficient. The mould heating degree increases as the radiation time prolongs.

2.1. Conceptual approach to the investigations

Investigations of the heat influence on moulding sands with chemical binders were carried out utilising liquid cast iron in the induction furnace crucible as the heat source. The concept of performing tests is given in Figure 1. Standard samples of moulding sands applied in the bending test were suspended under the insulated cover, which was placed on the upper surface of the crucible, in which liquid metal was kept. An intensity and scale of heating can be controlled by selecting the liquid metal temperature, distance between sample surface and the upper surface of liquid metal (distance „x" in Fig. 1) and by changing time of holding samples above metal. After heating the samples were cooled to an ambient temperature, and then their bending strength was determined. This strength was referred to the strength of initial samples which were not heated.

2.2. Results of investigations

Investigations, which results are presented hereby, concern moulding sands: with furan resin, with two kinds of alkyd resins and with water glass (normal and modified, called Besil). Individual binders were applied in amounts recommended by producers (furan resin - 1.0%, alkyd resins - 1.3%, water glass - 3.5%). The moulding sand with furan resin was prepared with the reclaim as the matrix. The remaining sands were prepared with the matrix of fresh sand of similar average grain sizes. From these moulding sands the samples for bending tests were prepared (22.36x22.36x120mm). After 24 hours of hardening the samples were subjected to tests.

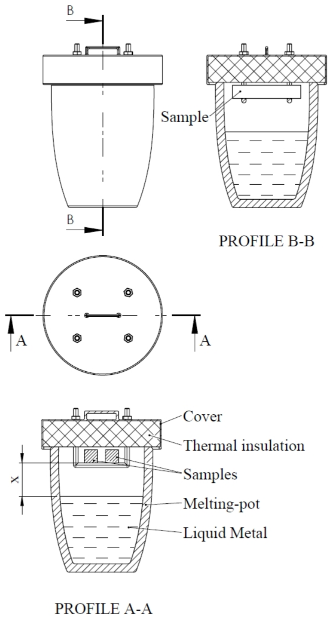

Fig.1. Concept of heating moulding sand samples by means of the metal thermal radiation

2.2.1. Investigations of the samples heating

The course of the mould surface heating by liquid metal by means of the radiation is relatively poorly known. The series of measurements were performed to determine the course of samples heating when these samples were placed above the metal surface (as shown in Fig.1). Heating of the sample surface layer subjected to the thermal radiation from the liquid cast iron surface was investigated.

Two thermocouples were placed in each sample (as shown in Fig.2). One thermocouple was placed in such a way as to have the measuring junction adjacent to the heated surface, while the second one in such a way as to have the measuring point at the depth of 2.0 mm from this surface. Investigations concerned samples without protective coatings as well as with coatings deposited on surfaces subjected to heating.

The obtained results of heating the samples with furan resin are shown in Figure 3. Protective coatings were deposited on tested samples. Liquid metal (cast iron) in a crucible was of a temperature of 1400°C, a distance between metal and sample surfaces was within limits: 10 – 15 mm. The highest heating rate of the moulding sand surface layer occurs in a few first seconds (up to 10 s). Later on this heating is much slower and samples after 30 s are heated to temperatures: 650 ÷ 800°C. In the same time layers at the depth of 2.0 mm are heated to temperatures: 200 ÷ 300°C. Layers being in between 0.0 ÷ 2.0 mm are heated to intermediate temperatures. Depositing of protective coatings changes the heating pathways to a small degree only. Coatings on a zirconium matrix (PCM and ALKO) seem to 'promote' heating, while graphite coatings (PCG4) seem to 'protect' surfaces against intensive heating.

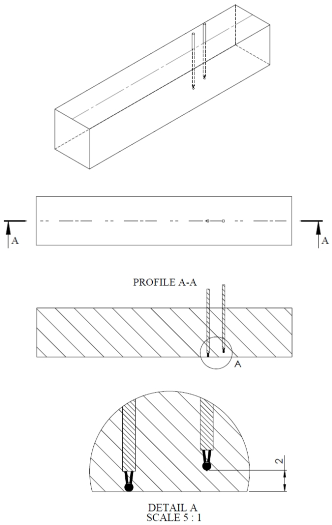

Fig. 2. Thermocouples placement in samples subjected to a thermal radiation

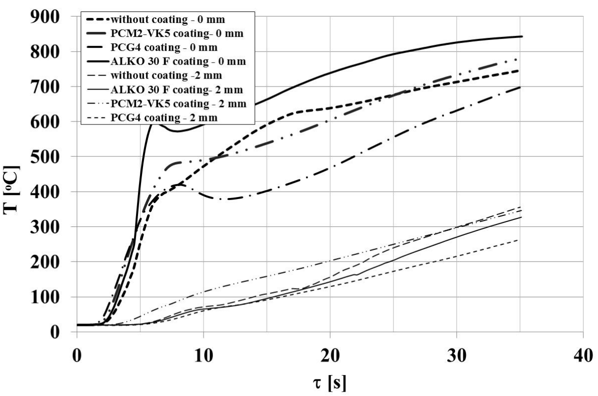

Fig. 3. Pathways of heating samples placed above the liquid cast iron surface. Upper lines - surface layers of the sample, lower lines – layers at the depth of 2.0 mm, [10]

2.2.2. Influence of the heating time on resistance R_g

The heating time influence (up to 60 s) on the resistance R_g of the moulding sand, determined after this sand cooling, was estimated. Investigations concern the moulding sand prepared on the reclaim matrix (moulding sand with furan resin) and the remaining moulding sands prepared on the fresh sand matrices.

The strength tests results are presented in a system of relative values R_g in Fig.4. Samples were bent in such a way as to have the tensile stress in the zone of the burned moulding sand. Comparisons of pathways of strength changes allow to draw the given below conclusions.

- Moulding sands with furan resin lose their resistance R_g in the fastest way and to the highest degree.
- Moulding sands with water glass, in the initial heating period increase their strength (effect of 'drying up'), while later on slightly decrease.
- Moulding sands with the Besil binder, which is the modified - by organic compounds - version of water glass, lose their strength much faster than moulding sands with 'pure' water glass.
- Moulding sands with alkyd resins are characterised by significantly higher thermal resistances to the influence of the radiation, than furan moulding sands.

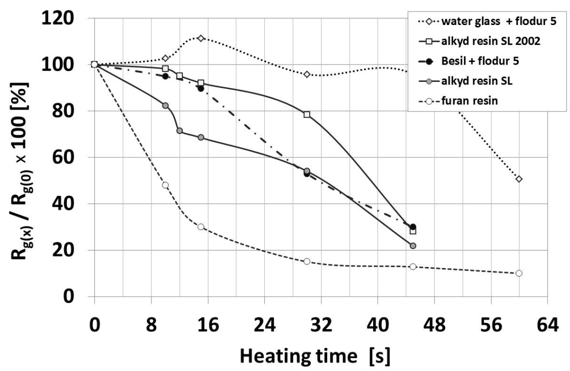

Fig. 4. Resistance R_g changes caused by the liquid cast iron radiation; $T_{met.}$ = 1400°C, distance between the sample and the metal surface: x ≈ 10 mm

When a moulding sand is heated the grain bonds formed by a binder are destructed in its successive layers. Binders destruction (burning) at the radiation influence occurs under conditions of an 'unlimited' oxygen access. In a different way and much slower are progressing destruction processes when the moulding sand was heated by liquid metal by means of its direct contact with the mould, (e.g. in lower parts of the mould cavity). The binder destruction is of the 'oxygen-free' character and thus it is the pyrolysis process.

Heating of samples leads to separation of moulding sand layers and their falling out from the surface. The measuring of loses of the lower layers of samples with furan resin hold above the liquid metal surface for 10, 15, 30 and 60s were carried out. The results are given in Figure 5. It can be noticed that the highest destruction rate is observed in the first period of heating. Moulding sand mass losses are whit surfaces of the sample in average above 0.30mm/s. Later on the moulding sand destruction rate decreases to app. 0.15 mm/s.

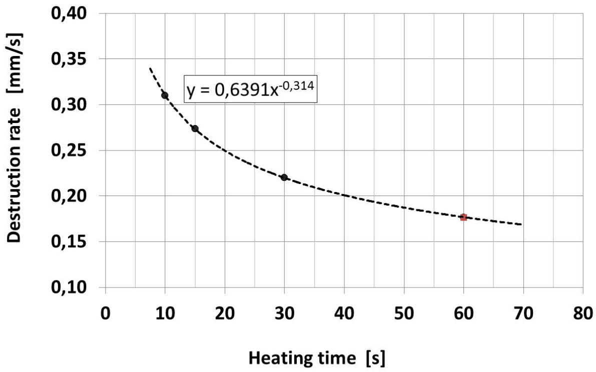

Fig. 5. Influence of the heating time on the destruction rate of the furan moulding sand layer - reclaimed. $T_{met.}$ = 1400°C; Distance between the sample and the metal surface: x ≈ 10 mm [10]

2.2.3. Function of protective coatings

Protective coatings are deposited to improve strength of surface layers of moulds and cores and to decrease the liquid metal tendency to penetrate into the mould depth. Coatings are deposited, in practice, on all moulds and cores made of moulding sands with chemical binders. Using the described methodology, tests of the radiation resistance of moulding sand samples - on which surfaces coatings (of three kinds) were deposited - were performed. In a similar fashion as before, the strength of the moulding sand samples was determined after cooling the samples previously heated by the radiation.

The resistance tests confirmed that the protective coating deposition strengthens surface layers of the mould (samples) increases their bending strength in the after drying state. The strengthening effect is shown in Figure 6, where the bending test resistance increased from 1.80 MPa to above 3.50 MPa.

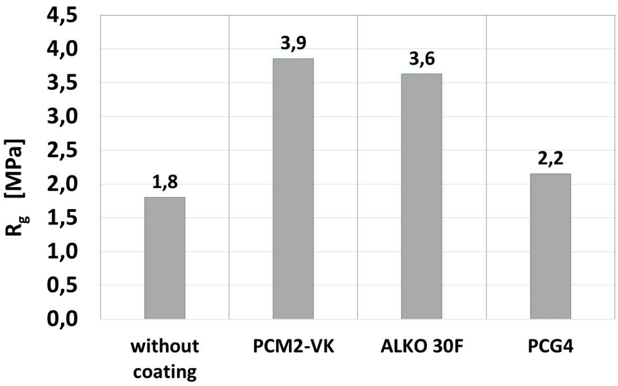

Fig. 6. Influence of protective coatings on the bending strength of moulding sands with furan resin, prepared on the reclaim matrix [10]

Unfortunately, a thermal radiation causes the surface destruction even when this surface is covered by a protective coating. Strength of samples subjected to heating for 30 seconds is presented in Figure 7. A strength loss in samples with coatings is larger than in samples without coatings. E.g. the sample with the PCM2-VK coating - in a cold state after drying - had the resistance R_g > 3.80MPa, while after heating for 30 s its resistance decreased to R_g ~ 0.60 MPa. The remaining coatings subjected to heating by the liquid cast iron surface behave in a similar fashion. This indicates that the moulds protection by coatings deposited on moulding sands with the reclaim matrix and furan resin binder is efficient for a very short time only.

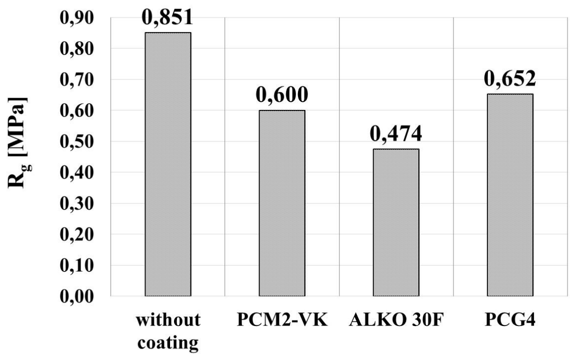

Fig. 7. Bending strength of samples of moulding sands with furan resin after their heating by radiation for 30 s, distance between the metal and sample surfaces: x =10 mm [10]

2.2.4. Influence of a distance: metal surface – sample surface

The intensity of the heat flux, emitted from the radiating surface, according to the Lambert's law decreases proportionally to the distance square. This is caused by the fact that the radiation energy is scattered uniformly in all directions forming spherical images. Surfaces of successive spherical spheres are increasing proportionally to the distance square, thus decreasing the heat flux intensity.

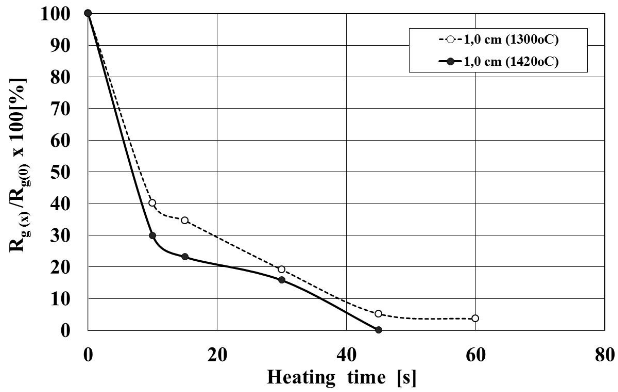

Fig. 8. Heating time and the distance from the metal surface influence on the resistance R_g of moulding sand with furan resin, T_{met} = 1420°C

Investigations of the influence of the distance between surfaces were performed for the moulding sand with furan resin. The tested samples were placed at the distance of 10, 25 and 40 mm from the metal surface. The obtained results are shown in Figure 8. Increasing the distance leads to decreasing the intensity of the radiation heat flux reaching the sample surface and to decreasing its heating degree. Due to that, loses of moulding sand strength are slower. Even a small increase of the distance from the surface metal e.g. by 2.5 cm causes a significant decrease of the moulding furan sand destruction degree, (Fig. 8).

2.2.5. Influence of the metal temperature

Sand moulds in the production of iron casting are the most often poured with metals of a temperature from a range: 1300 – 1400^{o}C. Investigations were performed of the temperature changes (within this range) influence on the destruction rate of the furan moulding sand subjected to the radiation. The results obtained when the metal surface distance from the sample surface was shortened to 1.0 cm, are given in Figure 9. The metal temperature increased by slightly above 100^{o}C accelerates the destruction process, however this influence is not significant.

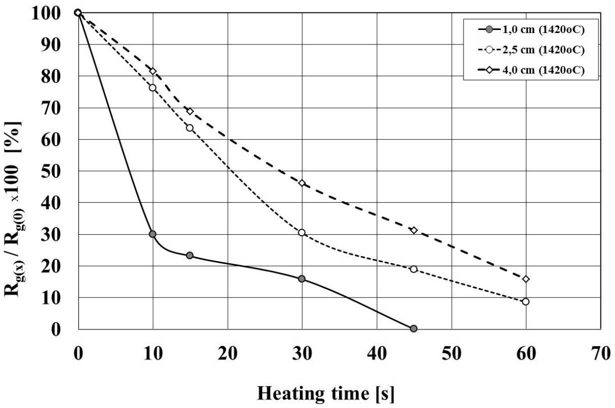

Fig. 9. Influence of the heating time and the liquid metal temperature on the resistance R_g of moulding sand with furan resin

3. Conclusions

Moulding sands with chemical binders are the most often used for moulds at production of medium and large sizes iron and steel castings. The filling time of such moulds takes usually more than 60 seconds, sometimes even 2.0 ÷ 3.0 minutes. Moulding sand layers adjusted to the mould cavity are heated by liquid metal by means of: conduction, convection and radiation. The upper and partially side walls of the mould cavity are mainly heated by the radiation.

Investigations indicated that the process of strength losing by moulding sands with furan resin is very fast, the fastest from the group of the tested moulding sands. A dozen or so seconds of the radiation is enough for losing 2/3 of the initial strength. Moulding sands with the reclaim were tested, however it can be expected that moulding sands with fresh matrices will behave in a similar way. A binder but not a matrix undergoes the thermal destruction. Protective coatings deposited on surfaces subjected to thermal stresses only poorly protect them from losing strength.

Destruction of successive moulding sand layers after moving closer the metal surface (to app. 10 mm) proceeds very fast, with a rate: 15 - 0.30 mm/s. A small thermal resistance of moulding sands with furan resins can make difficult obtaining castings without surface defects especially in cases when upper surfaces of the mould cavity are large and developed. In such cases a mechanically mixed moulding sand, which already lost contact with the moulds due to binders destruction, can appear in surface layers of castings.

Moulding sands with alkyd resin are characterised by a better resistance to the metal radiation, while moulding sands with inorganic binder (water glass) by the best. As it was shown in tests, the distance between metal and mould surfaces is very important. E.g. furan moulding sand loses 70% of its resistance after 10 s (when x =10 mm), after 45 s (when x = 25 mm) and after 58 s (when x= 40 mm).

The liquid metal temperature is generally very important in the moulding sand destruction process, however changes within the practical range (1300÷1400^{o}C) do not cause significant changes.

The presented hereby study constitutes a contribution to wider investigations on the resistance of surface layers of moulds to thermal shocks caused by the radiation heat of liquid metals filling the mould cavity.

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