

Assessment Method of Overheating Degree of a Spent Moulding Sand with Organic Binder, After the Casting Process

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Abstract

A proper management of sand grains of moulding sands requires knowing basic properties of the spent matrix after casting knocking out. This information is essential from the point of view of the proper performing the matrix recycling process and preparing moulding sands with reclaimed materials. The most important parameter informing on the matrix quality – in case of moulding sands with organic binders after casting knocking out – is their ignition loss. The methodology of estimating ignition loss of spent moulding sands with organic binder – after casting knocking out - developed in AGH, is presented in the paper. This method applies the simulation MAGMA software, allowing to determine this moulding sand parameter already at the stage of the production preparation.

Keywords: Moulding sand, Thermal degradation, Organic binder, Simulation calculations

1. Introduction

In case of casting moulds made of moulding sands with organic binders, high temperatures cause self-acting overheating of the part of sand in the vicinity of a mould, which allows to determine local and average ignition losses after the process of making the moulds. The effect of 'self-reclamation' of a part of moulding sand encompasses the zone in which the moulding sand was heated above a temperature causing the thermal degradation of a binder. The binder contained in the moulding sand loses its binding and strength properties, becomes totally or partially overheated and its knock out properties as well as ability for recycling in mechanical systems increases. This effect has various ranges for various temperatures, mass ratios of casting/moulding sand, casting mass and shape, kind of matrix and organic binder and time during which the casting is in the mould. Knowing the range of this effect for the given binder, at quasi stable other

parameters of the process, is very important for the proper realisation of the matrix recycling, especially when the assessment of the forecasted purification degree of grain is done indirectly, on the basis of measuring the amount of dusts generated during the process [1].

2. Thermal degradation degree of spent moulding sand

The way of determining the relative degree of the thermal degradation of a moulding sand $D_{m(T)}$ heated to the given temperature and thus the change of its ignition loss, at quasi stable other parameters of the technological process, can be determined from the equation:

$$D_{m(T)} = \left(1 - \frac{SP_{(T)}}{SP_{(mi)}}\right) \cdot 100\% \quad (1)$$

where:

$D_{m(T)}$ – relative degree of the thermal degradation of a moulding sand at a temperature T , %

$SP_{(T)}$ – ignition loss of a moulding sand heated at the determined temperature; %,

$SP_{(mi)}$ – ignition loss of a moulding sand in a wet state; %.

It can be assumed that thermal resistance of a moulding sand $O_{m(T)}$ can be expressed by the equation:

$$O_{m(T)} = \left(\frac{SP_{(T)}}{SP_{(mi)}}\right) \cdot 100\% \quad (2)$$

where:

$O_{m(T)}$ – thermal resistance of a moulding sand at a temperature T , %

Information concerning the actual thermal degradation degree $D_{m(T)}$ of the investigated moulding sands subjected to heating at the determined temperatures, can be used for the ignition loss forecasting of a moulding sand after making the casting, under the given conditions of the realised process. The empirically determined moulding sand destruction degree (at the determined temperature ranges) and the moulding sand volume, which was overheated to a temperature causing either complete or partial thermal degradation of a binding material is required for the $D_{m(T)}$ determination.

The degradation degree of the whole moulding sand forming the casting mould, after making in it the casting, can be determined from the following dependence:

$$D_{mf} = \sum_{T=T_{cd}}^{T_d} \frac{V_{(T)}}{V_{(C)}} \cdot D_{m(T)} = \sum_{T=T_{cd}}^{T_d} \frac{V_{(T)}}{V_{(C)}} \cdot \left(1 - \frac{SP_{(T)}}{SP_{(mi)}}\right) \cdot 100\% \quad (3)$$

where:

D_{mf} – thermal degradation of a moulding sand in a casting mould, %

T_{cd} – temperature of a complete binder destruction, $^{\circ}\text{C}$,

$V_{(T)}$ – volume of a mass heated to a temperature T , cm^3 , m^3 ,

$V_{(C)}$ – total volume of a moulding sand, cm^3 , m^3 ,

$D_{m(T)}$ – as in Eq. (1).

Temperatures T , characteristic for a binder, usually analysed every 100°C , are taken into account in the equation. Values of $D_{m(T)}$ for these temperatures and moulding sand volumes overheated to their values are determined and then related to the total mould volume. Values of $D_{m(T)}$ were determined within the temperature range 23°C - 800°C , applying the temperature interval of 100°C .

Knowing the total thermal degradation degree of a moulding sand D_{mf} : it is possible to calculate the ignition loss of spent moulding sand:

$$SP_{(mz)} = SP_{(mi)} (1 - 0,01 \cdot D_{mf}); \% \quad (4)$$

$SP_{(mz)}$ – spent moulding sand ignition loss, %

3. Laboratory investigations of the thermal degradation of moulding sand samples with the Kaltharz U404 furfuryl resin

In order to confirm the rightness of the given above reasoning the verifying investigations were performed. The first stage consisted of testing the thermal degradation of moulding sand samples with the Kaltharz U404 furfuryl resin, hardened by PTS 100T3 acid, added in an amount of 50 mass % in relation to resin.

Three kinds of moulding sands were applied. These sands were prepared on the matrix being after various cycle numbers, characterised by various initial ignition losses before subjecting them to 1 hour heating in the silite furnace heated to the required temperature. The initial ignition losses were: 1.56%, 2.28% and 3.82% for the successive kinds of moulding sands, while the heating temperature of samples was: 100, 200, 300, 500, 600, 700 and 800°C . The average value of the relative thermal degradation degree $D_{m(T)}$ of moulding sand samples with the Kaltharz U404 resin and 100T3 hardener as a function of the heating temperature is presented in Figure 1.

It can be noticed that within the temperature range from 23°C to 200°C an increase of the average value of the relative thermal degradation degree of self-hardening moulding sand with resin on matrices of a relatively wide range of ignition losses (1.56-3.82%) does not exceed 6%. Successive thresholds of temperature cause a significant degradation increase, being approximately 60% when the moulding sand was heated at 400°C and approximately 90% at a temperature of 600°C . The highest destruction intensity occurs within the range 300- 400°C , and then 400- 500°C and equals 19% and 33.15% - respectively, of the growth of the $D_{m(T)}$ degree obtained at 100°C of a temperature increase, $D_{m(T)}/100^{\circ}\text{C}$.

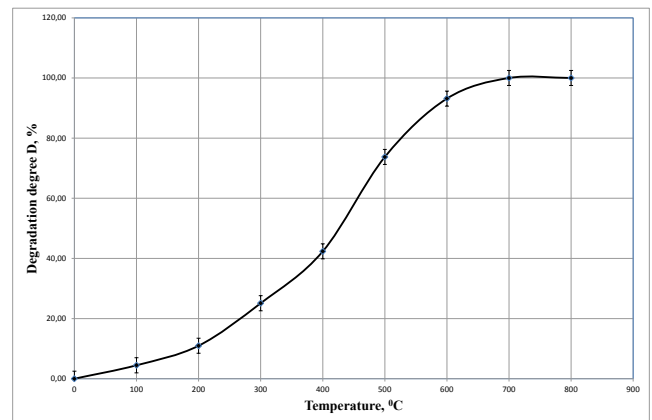


Fig. 1. Average thermal degradation degree of moulding sand samples with binding resin Kaltharz U404, hardened with PTS 100T3 acid, as a function of a temperature

4. Investigations of the thermal degradation of self-hardening moulding sand in the process of making the model casting

Regardless of laboratory experiments the investigations of the thermal degradation of organic moulding sand during the process of wedge casting preparation, according to ASTM A 536-84 standard, were performed.

Verifying investigations consisted of making 4 wedges from the self-hardening moulding sand organic type (Kaltharz U404 resin, 100T3 hardener), which matrices differed in ignition loss values, assuming the following: mass 1 – 1.47%, mass 2 – 2.89%, mass 3 – 3.86%, mass 4 – 4.26%. The thermal load of a moulding sand expressed as a ratio of the casting mass to the moulding sand mass was: $m_{odl} : m_{masy} = 1:1.6$, at the casting mass equal 1.7 kg. Average apparent density of the compacted moulding sand – approximately 1600 kg/m³. After pouring moulds with liquid spheroidal cast iron of PN-EN-GJS-500-7 grade of a temperature of 1400°C, the temperature measurements were performed in the mould during casting cooling. 6 thermocouples type K (NiCr-NiAl), of the measuring range of the cable temperature sensor up to 1200°C, were installed in the mould. They were placed in the middle of the height of the flat, wider mould wall, which die pocket in the moulding sand, counted from the external casting surface was respectively: 5, 10, 15, 20, 25 and 30 mm. The seventh thermocouple (PtRh-Pt) was placed in the pocket in the middle of the opposite mould wall. The moulding sand temperature in the mould was recorded during a continuous 3-hour measurement. The view of the moulds, on the measuring stand for testing the thermal degradation of the moulding sand with the Kaltharz U404 resin, is presented in Figure 2.

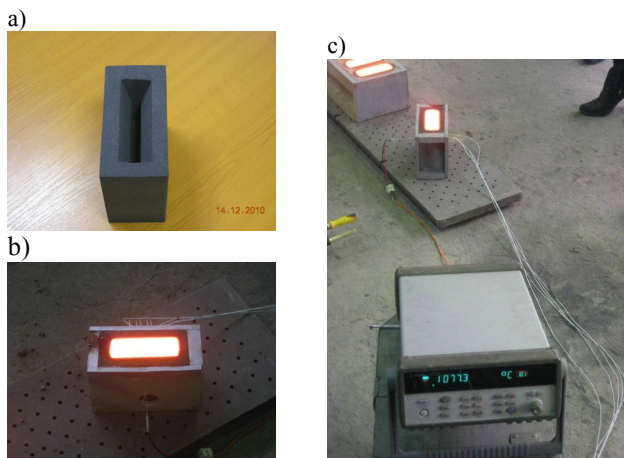


Fig. 2. View of the moulds prepared for the wedge casting, acc. to ASTM A 536-84 standard, on the stand for testing the thermal degradation of the moulding sand with the Kaltharz U404 resin. a) Mould before being poured with liquid metal, b) Mould after being poured with liquid metal, c) Measuring of temperatures in the mould

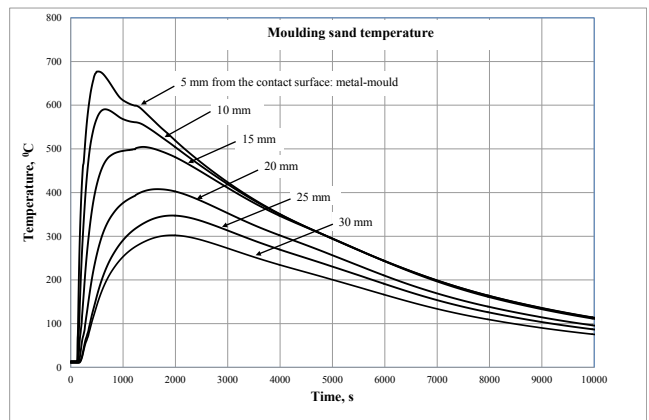


Fig. 3. Temperatures recorded in the model mould of the wedge casting, acc. to ASTM A 536-84 standard, made of the moulding sand with the Kaltharz U404 resin, poured with spheroidal cast iron of the PN-EN-GJS-500-7 grade. Pouring temperature 1400°C. Casting mass 1.7 kg, heat load of the mould: $m_{odl} : m_{masy} = 1:1.6$

The recorded temperatures in the model mould of the wedge casting (acc. to ASTM A 536-84) made with the KaltharzU404 resin are presented in Figure 3.

On account of the temperature scale assumed in the graph, the metal temperature is not shown in the figure, since its highest value recorded in the mould was 1395°C.

5. Determination of the destruction degree of the spent moulding sand – with using the MAGMA package

The use of simulation software in the foundry industry is very wide [2-5]. These programs can also be used to predict the degree of destruction of moulding sand in the mould.

To be able to compare the obtained experimental results the numerical simulation of the temperature distribution in the mould was performed with the application of the MAGMA software, introducing virtually the same data and process conditions, which actually were in the experiment.

As the result of simulations the temperature maps were obtained (the example is presented in Figure 4) and the predicted temperature distribution in the same places of the mould, in which thermocouples in experimental tests were placed. Simultaneously the forecasted temperature distribution in the mould generated in the MAGMA software is shown in Figure 5.

In spite of a doubtless similarity of the experimental and simulation results, the detailed comparative analysis of temperature changes shown certain discrepancies, which imply procedures aimed to the optimal solution of the problem.

Dependencies determined by means of numerical calculations indicate higher – in relation to the experiment - intensities of increasing both a stability time, and a temperature decrease for all mass layers. The thickness of each of them is determined by the distance in between the end points of the previous and next

thermocouple placed at the proper depth. In the given situation the process enthalpy, at a constant value of a mass and specific heat, is mainly determined by the temperature difference and time of its influencing. This induces to correct each time the simulation results on the grounds of data – collected in the data-base – concerning, first of all, thermo-physical properties of the determined organic moulding sands and conditions applicable to the particular casting as well as to the whole casting process.

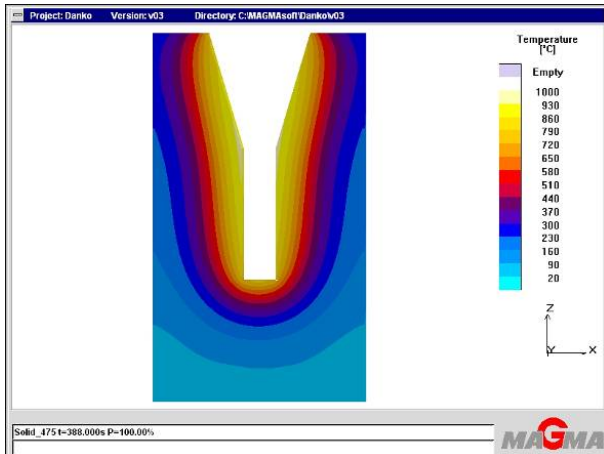


Fig. 4. Temperature map obtained - in the MAGMA software – in the virtual model mould of the wedge casting (acc. to the ASTM A 536-84 standard) made of the moulding sand with the Kaltharz U404 resin. Casting of spheroidal cast iron of the PN-EN-GJS-500-7 grade, temperature of pouring: 1400°C. Other conditions taken into account in numerical calculations assumed as in the experiment

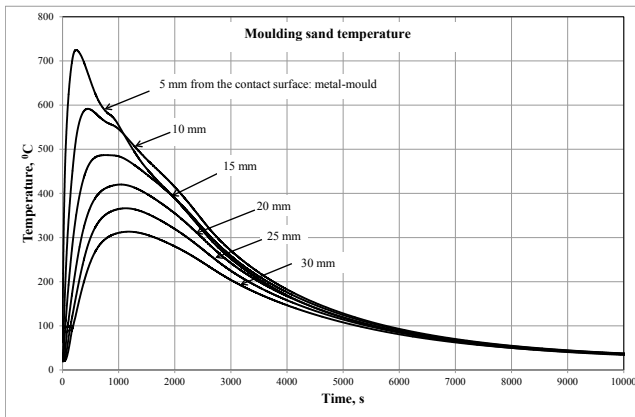


Fig. 5. Forecasted (as the simulation results in the MAGMA software) temperature distributions in the virtual model mould of the wedge casting (acc. to the ASTM A 536-84 standard) made of the moulding sand with the Kaltharz U404 resin. Casting material: spheroidal cast iron of the PN-EN-GJS-500-7 grade, temperature of pouring: 1400°C. Casting mass: 1.7 kg, thermal load of the mould: modl : mmasy = 1:1.6

6. Investigations of the thermal degradation of self-hardening moulding sands during making the model casting

Maximum temperature values to which the moulding sand is heated at the determined distance from the cast wedge surface (determined by the temperature measuring point) were established on the grounds of the measured and calculated by the MAGMA software temperature courses. The obtained data are drawn up in Figure 6. The dependence used for determining the moulding sand volume in the model mould, in percentage terms in relation to the total volume, which corresponds to the given thickness growing from the casting surface and calculated in this way, is given.

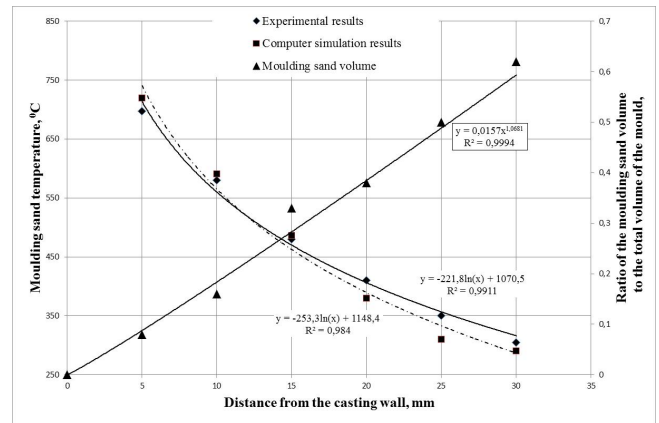


Fig. 6. Maximum moulding sand temperature in the model mould for the wedge casting, acc. to the ASTM A 536-84 standard, as a function of the distance from the casting surface and the ratio of the moulding sand volume to the total volume of the mould in the temperature measurement place.

The results of experimental data, on which bases the graphs in Figure 6 were presented, can be approximated by logarithmic dependence allowing to calculate a temperature T in the determined place at the model mould thickness, marked by 'x', starting from the casting surface. This dependence is as follows:

$$T = 1070 - 221 \cdot \ln(x); [^{\circ}\text{C}] \quad (5)$$

where:

x – distance of the measuring point from the casting surface.

Rearrangement of equation (6) allows to calculate the distance between the measurement point and casting surface x , representing the thickness of the moulding sand layer, at a temperature T . This is suitable for the determination of the thermal degradation relative degree of the moulding sand, $D_{m(T)}$ in accordance with the data given in Figure 1.

$$x = e^{\frac{1070-T}{221}}; [\text{mm}] \quad (6)$$

Taking into account geometrical dimensions, it is possible to determine the volume taken by the moulding sand within the space from the casting surface to the distance x , in relation to the total mould volume, V_C . The equation – in relation to the analysed model mould of the wedge casting – is of the form:

$$V_{(x)} = 0,0157 \cdot x^{1,068}; [l] \quad (7)$$

The total mould volume $V_{(calc)}$ and volume $V_{(x)}$, taken by the moulding sand in the space from the casting surface to the distance x , can be presented as a quotient:

$$V_{(x\%) } = \frac{V_{(x)}}{V_{(c)}} \cdot 100\% \quad (8)$$

It should be considered that $V_{(x)}$ represents the moulding sand volume overheated to the given temperature and over it. Therefore the determination of the amount of the moulding sand heated up to the given temperature range, precisely by the lower and upper temperatures and giving quotient V_T/V_C .

The calculated data and the thermal degradation of the moulding sand characteristics allow to determine the total moulding sand degradation and the amount of binder, which should be still removed from grain surfaces during the recycling process.

The calculation results - taking into consideration that in the analysed model mould the maximal distance of the moulding sand from the casting equals 70 mm - are given in Table 1.

Table 1.
Percent fraction of the moulding mass volume heated up to the determined temperature range

Temperature	$V_{(x)}$	Temperature range	$\frac{V_T}{V_C}$	Degradation degree $D_{m(T)}$ [%]	Local degradation degree D_{mf} [%]
Over 800°C	0.0578	800°C + 900°C	0.0578	100.0	5.78
Over 700°C	0.939	700°C + 800°C	0.0359	95.56	3.43
Over 600°C	0.1522	600°C + 700°C	0.0583	89.04	5.19
Over 500°C	0.2467	500°C + 600°C	0.0945	75.60	7.13
Over 400°C	0.4000	400°C + 500°C	0.1532	57.66	8.82
Over 300°C	0.6486	300°C + 400°C	0.2485	24.51	6.09
Over 200°C	1.0000	200°C + 300°C	0.3518	5.51	1.93
Over 100°C	1.0000	100°C + 200°C	0	0	0.00
<100°C	1.0000	< 100°C	0	0	0.00
Total degradation degree of the moulding sand forming the form D (equation (5))					38.38

Values of the forecasted ignition losses of the moulding sand after the casting process, taking into account the total degree of the thermal degradation of sand D, are listed in Table 2. These values are compared with the average values of ignition losses, determined experimentally for samples of the investigated spent moulding sands with the Kaltharz U404 resin.

Table 2.
Values of forecasted ignition losses of the moulding sand with the Kaltharz U404 resin after the process of the casting making and the ignition loss values obtained in experiments.

Mass marking	Initial ignition loss of the moulding sand %	Forecasted ignition loss SP _(mz) %	Verified ignition loss %	Relative error of forecastin g %
Mass 1	1.47	0.91	0.93	2.15
Mass 2	2.89	1.78	1.76	-1.14
Mass 3	3.86	2.38	2.45	2.86
Mass 4	4.26	2.63	2.72	3.31

7. Conclusions

The performed investigations, the part of which is related to the experiment carried out on the model mould for the casting wedge (acc. to ASTM A 536-84 standard), made of self-hardening organic moulding sand with the KaltharzU404 resin, indicate that – in the recycling process of its matrix - there is a possibility of forecasting the temperature distribution and average ignition losses of spent moulding sands after casting knocking out. The forecasting is done due to the simulation calculations of temperature fields in the mould by means of the MAGMA software.

Achieving a highly reliable forecast requires the knowledge of input data concerning several categories.

Kind and properties of the casting mould material, including:

- Grain size characteristic of the matrix as well as the determined amount and strength of the binder, in order to establish the reference level for the quality assessment of the currently realised recycling process and its optimisation (expected tensile strength, grain composition of the main fraction, addition of fresh sand).
- Properties of self-hardening organic moulding sand, from the point of view of its thermal degradation in a wide temperature range, thermal and physical data of the moulding sand, it is: thermal conductivity, specific heat and density.

A. Grade and properties of the casting material, including:

- Casting material and its mass.

B. Technological parameters of the casting process, including:

- Temperature of mould pouring and time of casting being in the mould,
- Ratio: casting mass : mould mass,
- Virtual notation of the casting and mould geometry.

When drawing conclusions it should be remembered, that obtaining a reliable forecast of a temperature distribution and ignition losses of spent moulding sand originated from large moulds intended for complex castings of diversified wall thickness, is much more difficult than the one illustrated for the model mould for the casting wedge. The prognosis of the temperature distribution and ignition loss can be burdened with

a larger error due to uneven thermal loads of the mould. In such cases, the data concerning more accurate investigations of thermal degradations of various kinds of organic moulding sands – specially considering their thermal loads - should be gathered.

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