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ARCHIVES
of
FOUNDRY ENGINEERING

DOI: 10.1515/afe-2017-0012

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

DE GRUYTER OPEN

ISSN (2299-2944)
Volume 17
Issue 1/2017

67 – 72

Innovative Laboratory Procedure to Estimate Thermophysical Parameters of Iso-exo Sleeves

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Received 10.07.2016; accepted in revised form 31.10.2016

Abstract

The paper is focused on properties testing of materials used in form of iso-exo sleeves for risers in ferrous alloys foundry. They are grainy-fibrous materials, containing components which initiate and upkeep exothermic reaction. Thermo-physical parameters characterizing such sleeves are necessary also to fill in reliable databases for computer simulation of processes in the casting-mould layout. Studies with use of a liquid alloy, especially regarding different sleeves bring valuable results, but are also relatively expensive and require longer test preparation time. A simplified method of study in laboratory conditions was proposed, in a furnace heated to a temperature above ignition temperature of sleeve material (initiation of exothermic reaction). This method allows to determine the basic parameters of each new sleeve supplied to foundries and assures relatively quick evaluation of sleeve quality, by comparison with previous sleeve supplies or with sleeves brought by new providers.

Keywords: Risering, Thermo-physical parameters, Simulation

1. Introduction

Application of insulating, insulating-exothermic and exothermic sleeves is widespread in foundry. The process engineers have catalogue comparisons of sleeves by various producers at their disposal. In these tables, producers present various materials, shapes and dimensions of sleeves. They are accompanied with FEM values (factor extension modulus, FEM is always above 1 – FEM>1) as indexes globally evaluating effectiveness of a sleeve. Based on the FEM value, prolongation of a riser solidification time can be approximated relatively to a riser in a moulding sand. In some catalogues, FEM value for a specific material and dimension case is expressed by a ratio of riser solidification module in each sleeve to the same module in a quartz moulding sand. The FEM index is useful mostly for classic engineering calculations of a sequence of a feeding path: riser – intermediate wall – thermal center (named hot spot). The most reliable FEM values are obtained by recording the cooling curves of alloy and determination of solidification times of test castings e.g. of a cylindrical shape in a properly instrumented mould (thermocouples, data acquisition center) [1.2]. This method allows to compare recorded temperature curves with numerical calculation results (using selected simulation code, e.g. Magmasoft, NovaFlow&Soild, Procast) and then iterative selection of basic substitute coefficients: thermal conductivity, specific heat and apparent density fulfilling energetic and temperature condition of conformity. If a studied material contains exothermic (internal) sources of heat – they also should be identified iteratively (by solving a simplified inverse problem).

There are certain difficulties here that need to be overcome, related to specific conditions and techniques of instrumentation of the casting-mould layout, as well as influence of static and dynamic measurement errors, especially using liquid cast steel during the experiments.

2. Full procedure tests. Reference to author's studies

This research was conducted recently, in years 2013-2015 in industrial conditions, per a methodology developed by the author. The experiments consisted in making a mould containing studied materials, both insulating and insulating – exothermic (Fig. 1 and 2).

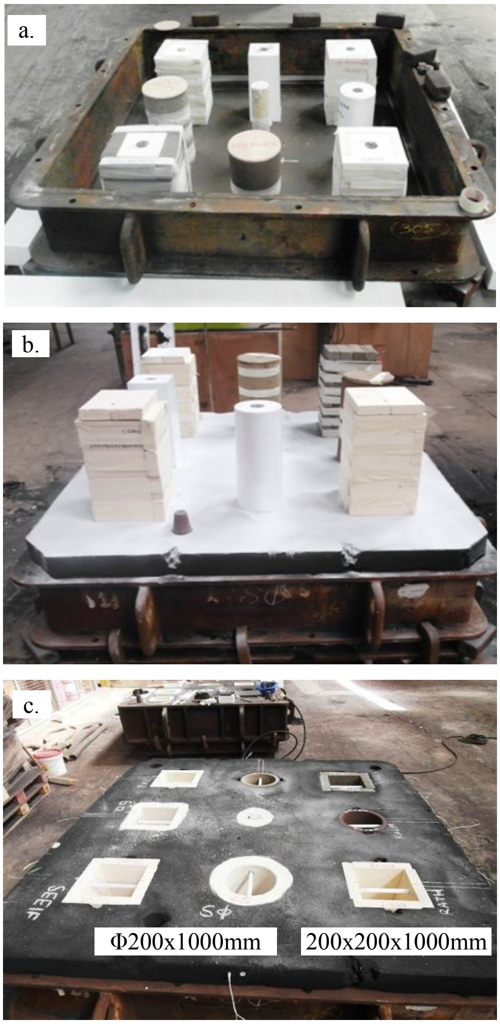


Fig. 1. Selected stages of producing a mould containing tested materials: iso-exo sleeves and insulating bricks.
a – patterns with assembled materials – lower (drag) mould), b – preparation of upper (cope) mould, c – mould instrumentation

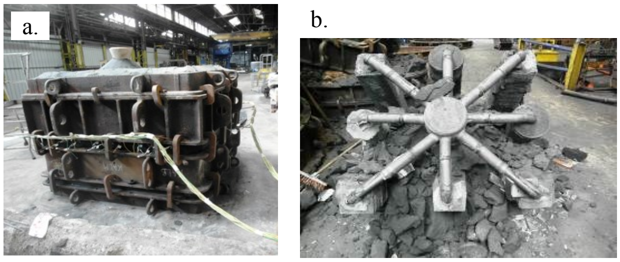
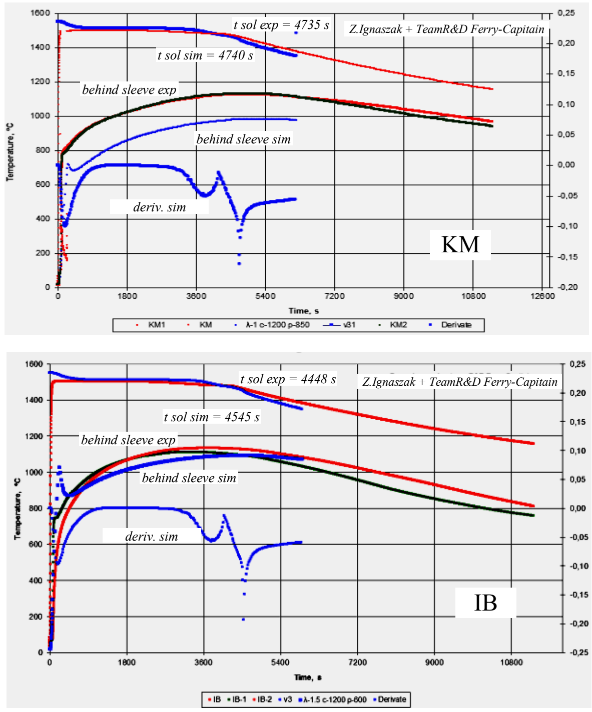


Fig. 2. View of a mould ready for pouring, with visible group of compensating cables (a) and castings after knocking out (gating system side). Total mass of castings with the gating system – approx. 2700 kg

Figures 3 and 4 presenting examples of results obtained from experimental and simulation studies of two selected sleeve types, shown in Fig. 1.



Substitute parameters	KM	IB
τ_{sol} – exp/simul [s]	4736/4740	4448/4545
λ [W/m/K]	1,0	1,5
c [J/kg/K]	1200	2000
ρ [kg/m^3]	850	600
L_{exo} [kJ/kg]	1200	2200
T_{burn} [^{0} C]	300	300
t_{burn} [s]	180	180
τ_{sol}-time of solidification, λ-thermal conductivity, c-specific heat, ρ-bulk density, Lexo-latent heat exo-reaction, T_{burn}-burning temperature, t_{burn}-time of exo reaction		

Fig. 3. The comparison of experimental/virtual solidification and heating curves for two iso-exo sleeves (KM and KB). Table: Parameters calculated by inverse solution method

The presented methodology is used mostly by industrial research laboratories, possibly for studies ordered by foundries or sleeves' producers. The appropriate experience of researchers, equipment and apparatus are required. Such studies are frequently omitted because of their costs. In case of new sleeves introduced to the market, proposed by the producers, foundries are supplied with documentation containing FEM parameters (very rarely with λ, c and ρ parameters, necessary for credible computer simulation of solidification of a casting fed from a riser with a given sleeve). Similar study procedures were applied in [3,4], expanding the methodology with validation of pipe shrinkage location in real risers, feeding cast steel castings in cube shapes. Can another solution allowing quick and without metal using evaluation of sleeves quality regarding their heat-protecting capabilities be found?

3. State of art – suggestions of studies per the simplified procedure

Some producers and users, in cooperation with university laboratories or with other specialized centers undertake described studies of mentioned parameters, with application of the full procedure described above. The author realized such studies for many years in many domestic and foreign foundries. Observations made during those studies boil down to the following conclusions:

1. FEM values of sleeves out of materials of identical name produced in 90s are higher than FEM of sleeves made after 20 years (1914),
2. foundries have no technical possibilities of testing and possibly questioning of subsequent sleeve batches. Results from application of a given batch of sleeves and statement of their proper influence on the feeding process do not settle the matter of sleeve quality evaluation. A hypothesis can be proposed about sleeve producers investigating new "innovative" composition formulas (components, processing technology), which does not have to translate into maintaining the insulating capabilities,
3. there is no reliable method for quick evaluation of sleeve quality directly after shipping from the producer, without use of liquid metal (these studies can be conducted at a later time, using full procedure test if preliminary study results would indicate worse parameters than in case of previous supplies).

In [5], an action initiated by French Institute of Foundry in Sevres (CTIF) is described. Several meetings with users of sleeves across the whole France allowed the CTIF as initiator of this action to define unified conditions of studying sleeve materials, possible to carry out inside a foundry, without use of a liquid ferrous alloy. The whole studies were conducted mostly in temperature below initiation of exothermic reaction, up to 400° C (heating in a laboratory special system). Valuable values of thermophysical coefficients concern a range of temperatures below an average temperature of sleeves heating (above 1400° C for cast steel), but in a comparative scale they may become useful. This paper cites results of tests carried out by one of the top producer of sleeves, in the subject of course and intensity of the exothermic reaction [6]. The results presented there refer to methodology of half-quantitative studies, consisting in putting a sleeve on a flat specimen of a liquid cast iron poured into an open mould (of diameter higher than the external diameter of a sleeve) and observation of a rising ignition front (a narrow region of exothermic reaction). The following times are being measured: beginning of the exothermic reaction, ending of this reaction and sometimes maximal temperature achieved. Similar studies conducted by the author (Fig. 4) confirmed their spectacularism and possibility of determining times regarding beginning/ending of the reaction and allowed even to determine temperature fields during sleeve heating (using an infrared camera).

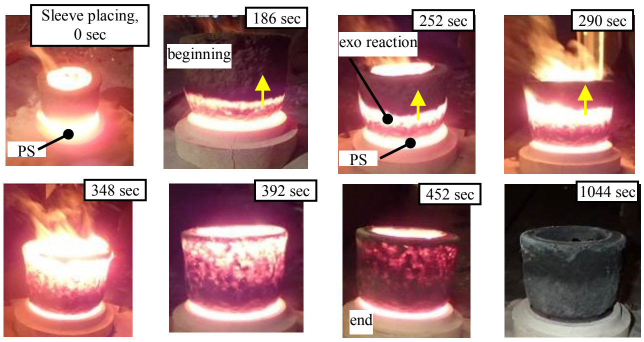


Fig. 4. Sequence of selected steps of exo reaction progress for iso-exo sleeve diam.120mm placed on a liquid cast iron plate specimen (PS). The arrows show the direction of the exo reaction

The greatest challenge is determination of heat efficiency of latent heat of the exothermic reaction. These studies were undertaken in a specialized domestic laboratory, with use of a bomb calorimeter. However, it was problematic to perform ignition of a sleeve material (mixture of various components of organic origin, natural fibers and substrates determining the occurrence of exothermic reaction). Even in presence of an oxygen atmosphere, specimens could not be ignited.

Independent attempts in form of ignition tests in ambient atmospheric conditions (approx. 20% oxygen) are presented in Fig. 5 and 6.

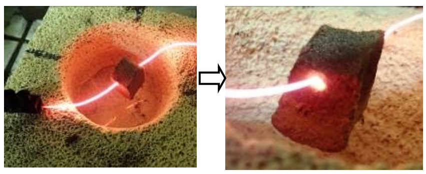


Fig. 5. Ignition test of an iso-exo sleeve material (resistance wire temperature: about 800° C). After 30 minutes of heating no ignition did take place, only material gasification around the wire resistance was present (increasing diameter of the hole)

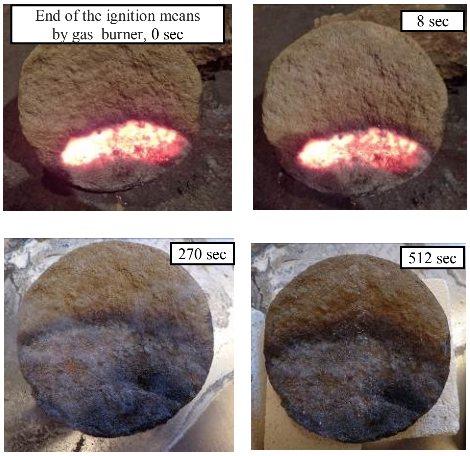


Fig. 6. Ignition test of an iso-exo material by gas burning heating. The initiated exo reaction extinguishes after about 500 s

To approximate properties of sleeves in a complex manner, conditions of initiation and finishing the exothermic reaction must be created.

4. Proposition of innovative laboratory procedure, results and discussion

Referring to conclusions from the previous part of the paper, a new procedure of specimen preparation from sleeve for the studies and determining their thermophysical properties was proposed (Fig. 7).

Fig. 7. Method of cutting a 20x20x20 mm specimen out of a sleeve and installation of a sheathed K thermocouple in its geometrical center

A specimen with an installed K thermocouple was placed in a chamber furnace heated up to 500°C (stable, adjustable temperature). The heating curve was recorded through a period until stopping of heat exchange after the exothermic reaction appeared.

Fig. 8 presents two heating curves, juxtaposed for two types of materials (KM and IB sleeves). Their courses prove that each sleeve material has different dynamics of exo heat emission and that maximal temperature in a specimen center is variable.

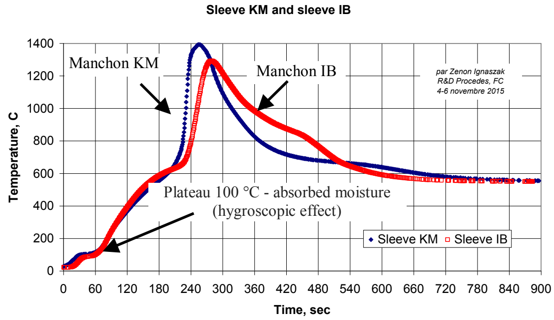


Fig. 8. Juxtaposition of temperature curves recorded for two materials of KM and IB sleeves (compare with Fig. 3)

After finishing the heating process and heat exchange in a specimen – chamber furnace layout, a specimen is cooled outside the furnace down to ambient temperature and then heated one more time in a furnace of temperature of 500° C. Obviously, an effect related with the exo source will not appear in the heating curve again.

The next Figure presents difference in course of both curves (with the exo effect and without it) for a selected material (KM).

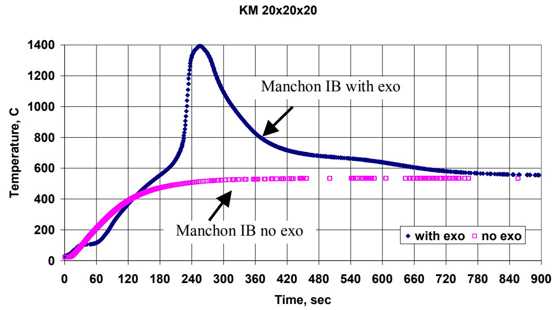


Fig. 9. Comparison of temperature curves recorded for the KM sleeves material with the exo effect and without this effect

An area between these two curves can be treated as proportional to a total amount of heat emitted during the exo reaction. It is therefore a reference to the differential thermal analysis (DTA) method, while a curve without the exo effect comes from the same specimen (not from a separate reference specimen).

The further procedure consists in conducting simulation studies and, by solving an inverse problem, leading to determination of thermophysical parameters giving the best conformity with experiment.

Figures 10 and 11 present geometrical model of a specimen – furnace – ambient layout and a principle of meshing of the 3D space, with indication of arrangement of virtual thermocouple sensors (1 to 5).

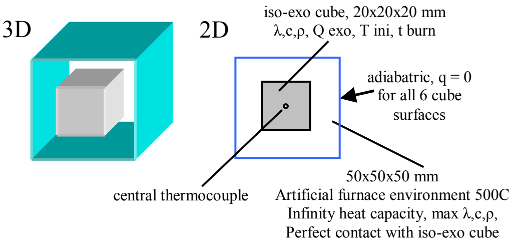


Fig. 10. Schematic geometries (3D and 2D) used in simulation tests

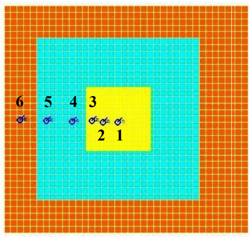


Fig. 11. 3D discretization of specimen (yellow, 1,2,3) – furnace (blue, 3,4) – ambient (orange, 6) layout and posi- tions of virtual thermocouple sensors (1 to 5), NF&S CV 6.0

Iterative approach to solving of an inverse problem, by a trial and error method was aimed at achieving satisfying compatibility between real and virtual thermal curves, with energetic validation – determination of time of obtaining maximal temperature in period of maximal emission of the exo reaction energy [2].

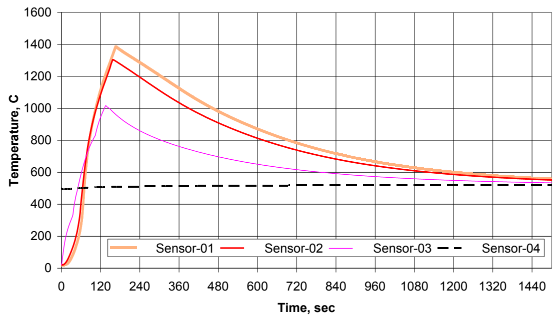
Figure 12 presents simulation results of the above-mentioned cases of heating of the same specimen (KM material, with exo, Fig.12a) and without exo = not exo, Fig.12b) in form of curves representing variability of temperatures in points indicated in Fig. 11. Under the Figure, a Table is placed, containing values of substitute thermal parameters, obtained using the trial and error method (the best approximation of the experiment).

Values of the mentioned parameters (Fig.12, table) are different than those obtained during studies with the full procedure (compare chapter 2), with use of liquid metal.

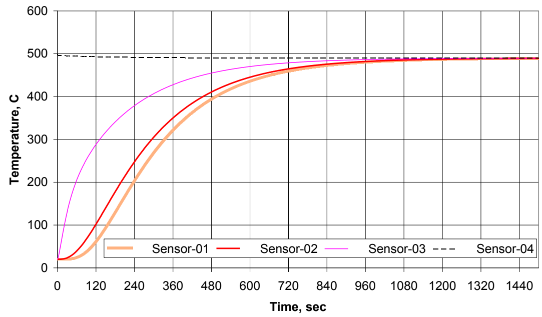
This problem requires a comment. Difference between parameters is caused by a fact, that conditions of ignition and dynamics of an exothermic reaction of an iso-exo material depend on presence of oxygen around substrates taking part in the reaction. Conditions of oxidation in a real mold and while heating a sample of the same material in a furnace (the new method) are not identical. Besides, considering that initiation of an exo reaction in conditions of a real mold poured, for example, with cast steel is conducted during very rapid heating of a sleeve, temperature profile is different than the one presented in Fig. 9. Maximal temperature value can exceed 1600°C, which, due to presence of quartz fluxing agents among sleeve ingredients, causes melting of a quartz protection tube of a thermocouple and leads to destruction of a PtRh-Pt thermocouple. This procedure was tested by the author in this way. It was confirmed, that thermal analysis of exo or even iso-exo materials in their interior (through thickness of a sleeve wall) is not efficient and brings reliable results only on the exterior (interface – quartz mold side) surface of a sleeve, where temperature increase is no higher than 1200°C.

It needs to be emphasized, that if an inverse problem (trial and error method) was solved using the same model (out of the NFS CV system), along with its simplifications regarding phenomena in two different real layouts, re-created thermophysical databases may differ between each other.

a.



b.



Substitute parameters	KM with exo	KM no exo
λ [W/m/K]	0,3	0,3
c [J/kg/K]	1500	1500
ρ [kg/m^3]	850	700
L_{exo} [kJ/kg]	2000	–
T_{burn} [^{0} C]	400	–
t_{burn} [s]	100	–

Fig. 12. Results of simulation calculations obtained during virtual heating tests of a KM sample – in sensor points 1 to 4 (temperature values in points 4 to 6 are practically identical) a – original sample (first heating), b – the same sample (second heating)

4. Summary

First part of the paper refers to classical methods of testing properties of special ceramic and ceramic-fibrous materials, possibly containing substrates of the exo reaction. Commonly used in form of sleeves or porous bricks they are used to increase thermal modulus of risers, especially in ferrous alloys foundries. Studies of thermophysical parameters with use of liquid alloys admittedly bring valuable results, but are also expensive and require specialized equipment, apparatus and a vast amount of specialized work. The proposed innovative method of examining specimens o This method allows to determine of basic parameters f sleeve material in laboratory conditions, with use of chamber furnace heated up to a temperature above the ignition temperature (beginning of the exothermic reaction) allows to determine basic parameters of each batch of new sleeves supplied to a foundry in comparable thermal conditions. It allows relatively quick and cheap evaluation of their quality, by comparison with results of sleeves from previous supplies or with sleeves proposed by new providers. Applied experimental methodology, connected with inverse problem solving using the NovaFlow&Solid or other simulation system turned out to be an effective way, possible to realize in typical foundry laboratory equipped with a small chamber furnace. A database for sleeve materials coming from suppliers (producers) as well as new proposals, e.g. [7,8], will allow to preliminarily rank the sleeves according to criteria of their predicted effectiveness in a real mould.

Acknowledgements

The research was partially supported by Poznan University of Technology support 02/25/DSPB/4312 and by Metallurgical Group – Ferry-Capitain CIF Company.

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