ARCHIVES
of
FOUNDRY ENGINEERING
DOI: 10.2478/afe-2013-0054
Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences
ISSN (2299-2944)
Volume 13
Issue 3/2013
30 – 36

Synergy of Practical Knowledge of Molding Sands Reclamation in Heavy Casting Foundry of Iron Alloys

Z. Ignaszak[a, b]*, J-B. Prunier[b]
[a]Poznan University of Technology, 3 Piotrowo Street, 60-965 Poznan, Poland
[b]Metallurgical Group CIF Ferry-Capitain, France
*Corresponding author. E-mail address: zenon.ignaszak@put.poznan.pl

Received 28.05.2013; accepted in revised form 31.05.2013

Abstract

The paper summarizes research realized by the author in laboratory and industrial conditions (foundries of cast steel and cast iron, castings up to 50 tons) on the effects of the chemically hardened molding sands regeneration using hard/soft rubbing in the dry reclamation. A reference was simultaneously made to advisability of application of the thermal regeneration in conditions, where chromite amount in the circulating (reclaimed) molding sand goes as high as above ten percent. An advisability of connecting standard and specialized methods of examination of the reclaimed sands and molding sands made using it was pointed out. A way of application of studies with the Hot Distortion Plus® method modified by the author for validation of modeling of the thermo-dynamic phenomena in the mold was shown.

Keywords: Furan molding sands, Dry mechanical reclamation, Iron alloy foundry, Heavy castings, Life time of furan sands, Thermo-mechanical databases

1. Introduction

Production of responsible large-size castings in a group of foundries collected in a concern with a centralized melting department (battery of several furnaces from 8 to 17 tons), common for both the cast steel and the cast iron, is a big challenge. The problems of maintaining the high metallurgical quality of particular grades of these two alloy groups, related to use of the same equipment (furnaces, ladles, logistics) are not the only ones that need to be solved. In such foundries, rational and professional management of the volume of the molding sand also needs to be dealt with. Several factors must be taken into consideration: size of the cooling castings (how long they stay in mold), applied technologies, variety of sand matrix and chemically hardened binder systems and also characteristics of devices for sand preparation, for mold knocking-out, for sand transport and sand reclamation and way of managing of the reclaimed sand. Appearing problems very often result from the “historical” conditions of a foundry. Many aspects resulting from theoretical background of knowledge of the molding sands and practical knowledge, on which the author was working, were given particular attention in [1-5]. They were inspiration for starting subsequent researches in the same group of French foundries (volume of the molding sand in circulation system – over 2000 tons), but also in foundries and research units in the country [6-8].

The paper relates to author experiences, which show that there is a necessity of multithreaded, successive analyzing and solving the manufacturing problems. They are usually caused by unexpected perturbations in production of large cores and molds. They are also related to verification of hypotheses regarding disadvantageous influence on their quality state, formulated by specialists of the casting quality. The selected studies have been put together to present problems described in this paper.

2. Why synergic analyzing of parameters in department of reclamation of knocked-out, chemically hardened molding sands is important

The problems raised in the paper are strictly related to a holistic, synergic approach to the casting quality control. How much of the truism is to state that parameters of the regenerate have a relevant influence on the final quality of the casting? And how big is the need for precise indications that will show how and why some specific parameters of the reclaimed sand, and in turn the sand, affect the casting qualities?

Therefore, a setting-up of the expectations regarding the mold can be prepared, regarding ensuring high quality of large-sized castings made out of the cast iron, including ductile cast iron and cast steel. A group of thermal and mechanical properties of the mold prepared totally or with a large percentage of the reclaimed sand should be specified here, and among them:

- erosion resistance in conditions of the large metallostatic pressure during the first stage of the casting formation, e.g. during the mold filling (cast steel, cast iron),
- maintaining (case of furan sands, among others) appropriately high rigidity of the mold in the stage of solidification, resisting high pressure caused by volumetric expansion of the crystallizing graphite, especially for castings made out of the ductile cast iron, which allows to obtain metal yield higher than 80%,
- gradual (controlled) local loss of the mold rigidity during solidification of the cast steel castings, effectively limiting formation of the hot tears in the sub-superficial zones (up to 1 kg of electrodes per 1 ton of the casting), for case of binders from the polyurethane group among others,
- fire resistance of the mold not causing burns and other superficial casting defects disqualifying the casting, including defects consisting in deep penetration of the metal, in case of the inadmissible proportion of the chromite sand in the circulating molding sand (mostly for the cast steel).

Obtaining beneficial properties, primarily mechanical, set in the room temperature (important during preparation of the mold of weight of several or more than ten tons) and thermo-mechanical during phenomena relevant for the quality creation, requires multi-aspect analyzing and controlling the quality of the reclamed sand and molding sand produced with it. The latter can be indirectly inferred about, on the basis of parameters of the reclaimed sand such as: roasting losses, grain analysis with marking of the dust fraction amount, pH value and acidity/basicity indicator. These parameters, in connection with type of the binder system, with percentage of the resin and the catalyst (catalysts) decide about obtaining sufficient mechanical and thermal properties. In the room temperature, mechanical properties are mostly studied as flexural strength of beam samples of 22,4 x 22,4 mm cross-section.

3. Short review of the study methods of the reclaimed sand and the molding sands produced using it

On the example of the furan molding sand, dominant in the foundries described in the paper, complex, systematic study of the regenerate as a raw material and furan molding sand produced in the sand-mill should consist of (limits of certain parameters are presented):

- collecting samples of the reclaimed sand (approx. 5 kg) on the "input" to the sand-mixer, in amount allowing to perform the necessary laboratory testing,
- determination of the regenerate granularity curve, with particular attention paid to amount of the dust fractions below 0,106 mm (0,50% dustiness is allowed), to determine the work effectiveness of the reclamation plant, particularly dust removal systems of the plant,
- marking the roasting loss of the regenerate, to check the effectiveness of the grain rubbing process during dry reclamation (2% roasting loss is acceptable, result above 3% should cause immediate check of the main assemblies of the reclamation system, especially dust removal system),
- marking of pH and need for acid/base (acidity/basicity), to estimate repeatability of conditions of the catalysis in resin-hardener system during the molding sand binding,
- preparation of 6-8 samples for flexural strength testing (Rf) out of the molding sand prepared in the sand-mixer (simultaneously – daily verification of correctness of dosing of the resin and the hardener),
- marking of the Rf parameter after 24 hours (with previous weighing of the samples),
- in case of Rf strength below the assumed level, preparation of the molding sand of identical constitution in the sand-mixer and repeating Rf studies after 24 hours,
- evaluation of correctness of operation of the reclamation and molding sand mixing system, with decision regarding possible corrections,
- in [8, 9] other methods are proposed for testing of quality of the regenerated sand in real conditions of the foundry,
- periodically, special studies should be conducted [10, 11], according to special procedures developed by the author of this paper,
- determination of FIP – index of binding intensity, allowing to precisely estimate the furan molding sand life time (period of usability for molding),
- use of thermo-stated chambers for marking of FIP and Rf, to re-create ambient conditions (summer and winter) in the laboratory, regardless of the temperature in the production hall.

This method of conducting studies allows to react on tendencies of deviations from assumed criteria of the molding sand quality and the mold made out of it. SPC methods (Statistical Process Control) can be of use here.

Regarding thermal reclamation of the mixture of the resin molding sands, preferred in some places, [5, 7] present results of study on molding sands, mostly originating from knocked out molds out of the furan molding sand, but also from molds with portion of the molding sands with polyurethane binder and alpha-set binder (both resins binding in the basic environment). It must be conducted in conditions of necessary division of the matrix of the chromite molding sand performed beforehand (15% of this matrix can be in circulation) [2]. In [5, 7] it is justified, why thermal reclamation in the described foundry is not advisable.

4. Example of the molding sand with furan binder – technological dangers. FIP index

Fulfilling high strength criteria by the furan molding sand (especially those conditioning high rigidity of molds for large-sized castings out of ductile cast iron) and maintaining parameters and proportions of its components (binder approx. 1% + catalyst approx. 0.4%) on an optimal level, will be endangered by perturbations, caused by variability of environment conditions and up keeping parameters of the reclamation plant. It is about temperature of the reclaimed sand fed to the sand-mixer, temperature and humidity of the environment, contamination with grains with remains of the binder coating and insulating-exothermic sleeves, of basic character, including chromite sand etc. Moreover, there are standstills of sand-mixer (breaks), necessary during staged manufacturing of a specific large-sized mold, caused by operations, e.g. of mounting subsequent parties of chills, sleeves and thickening the molding sand around them. Despite all these conditions, how high stability and homogeneity of the mold properties can be achieved?

The processes proceeding during furan molding sand binding are presented below. This binder has appeared first in second half of the 50 s. New types of resin developed in the following years (among others, modification with furfuryl alcohol and silanes, mastering the processes of polycondensation and crosslinking) led to improvement of wettability of the matrix grains (adhesion) and strengthening of the binder bridges (cohesion) and through this – to reduce the amount of the resin below 1% and reducing the molding sand gas production. Water, emitted during exothermic reaction of hardening in required acid environment, and its elimination by evaporation controls the speed of the reaction. Hence the presence of water in the air (humidity), amount of water in the sand and rate of its elimination from the furan molding sand in a state of binding (through drying), together decide of the time of hardening. It is thought (it has to be treated as an approximation) [12], that raising the temperature of hardening by 10°C increases the speed of the reaction twice. At the same time, presence of reclaimed sand originating from the acidic furan process among grains or presence of other impurities of basic character in a quantity difficult to predict affects the kinetics of the binding. Intuitive course of various speeds of sand binding reaction is shown in the graph in Fig. 1.

Influencing the speed of reaction begins from selecting the type of resin, which determines specific manufacturing procedure. Even using the same components in a reactor, depending on course of condensation process, resins with different proportions of free furfuryl alcohol, free formaldehyde and phenol can be obtained.

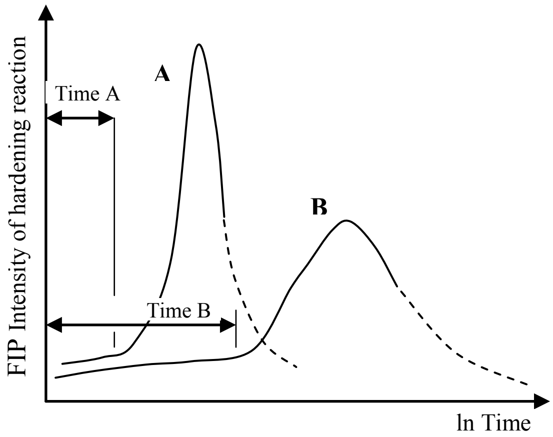


Fig. 1. Scheme of the extreme variability of kinetics of the molding sand hardening reaction (surface layers): A. sufficient life time and relatively quick hardening reaction (Time A – acceptable molding time), B. too low life time and too slow binding (Time B – unfoundedly long acceptable molding time)

Things are similar in case of amount of water in the resin. Value of pH can be also diversified, from slightly base to slightly acidic character. Still, real unknowns appear when the resin starts being affected by the catalyst – hardener (both notions are used in this paper), most often with chemical constitution not revealed to a foundryman, if it comes to components controlling the kinetics of the reaction. It is known that the more furfuryl alcohol, the lower viscosity of the resin, the better laying of resin over grains (wettability, important with short mixing times in the sand-mixer), the faster binding, the higher temperature of bond degradation after metal inflow and the lower gas production. Unfortunately, it increases the price of the resin.

Recommended temperature of binding is 25-30°C (recommended temperature). Some manufacturers attempt to adjust the phase composition of the resin and constitutions of both catalysts to conditions specific for the particular foundry (pH values, dusting of the regenerate, sometimes to the average regenerate temperature and current season), all the time assuming the subtle adjustment of the acidity level of the mixture by concentration of catalysts (this leads to a necessity of having dosing system for two catalysts, so-called slow and fast). Sand temperature below 10°C and cold tooling (models, core boxes), despite the heat of the exothermic reaction, do not favor fixed proportions of catalysts even for mildly higher temperatures, let alone for significantly higher temperatures. Too high sand temperature is also not preferred (it should not exceed 35°C). Neutralization of basic ions, possibly present in the reclaimed sand, also depends on temperature. Superposition of two kinetics of reaction of hardening and neutralization of mentioned ions, dependent on local conditions, is later expressed by influence on the sand life time and its final strength (after 24 hrs). Precise determination of the hardeners proportion (fast and slow) requires mentioned before, running examination in each foundry, including application of thermostated mini-chambers.

Defining the kinetics of the binding is the problem for manufacturers of the furan resin – cataly set. Values of the life time of the furan sand in real foundry conditions (time of usability of the sand to produce a good mold), prepared using the proposed set, named by manufacturers are usually higher than actual values, able to be verified by practice (this is a marketing stunt).

Methods applied by them (and also by foundries) to determine the life time of the furan sand after its mixing in the sand-mixer consist in:

- observation of gradual color change of the molding sand (to dark green),
- observation of grains of sand moving on poured cone,
- application of modified Dietert hardness tester (with very low rigidity of the spring),
- preparation of consecutive strength samples (Rf) in determined time intervals and testing their strength after 24 hours (aim: obtaining a curve of strength decrease in function of time elapsed since the sand was mixed).

Three first methods are of qualitative character.

The last mentioned method appears to be the best to characterize the usability time of furan sand for making mould, with guarantee of limiting value of Rf (2.5 MPa).

Character of the strength decrease curve in function of time elapsed since the sand mixing is presented in the Fig. 2.

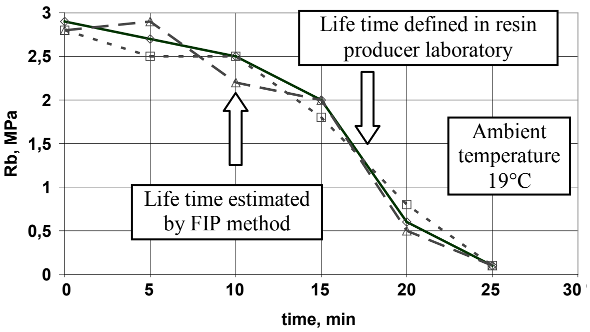


Fig. 2. Character of decrease of furan sand strength Rf in function of time elapsed since the mixing of the sand, in relation to the life time criteria

Below, FIP tests in the industrial conditions are presented – method developed by the author. This method allows to relatively estimate the bond strength of the matrix grains by their indirect measurement in the real time [10]. Tested in conditions of several foundries, it has shown that it can be used for much more precise determination of this process kinetics than methods used beforehand.

As examples of FIP method application for evaluation of kinetics of increase of the bond strength between sand grains as a result of hardening of the binder bridges, the following cases were examined:

- influence of the ambient temperature during the molding sand hardening of selected constitution, in conditions of thermostated chamber (Fig. 3),
- test of influence of the matrix type (new sand, sand from mechanical – dry – reclamation, sand from thermal reclamation, Fig. 4).

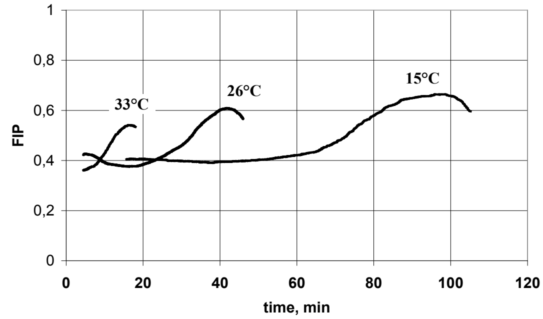


Fig. 3. Variability of the FIP index in time for the same furan sand in ambient temperatures of 15, 26 and 33°C (laboratory chamber, thermostated)

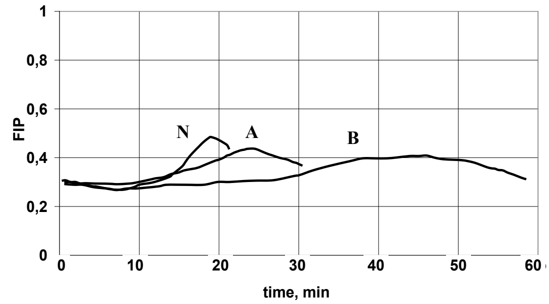


Fig. 4. Variability of the FIP index in time for the furan sands for three different sand matrices (A – mechanical, B – thermal, N – new sand) and for the same set of binder 1% + „slow" hardener 0,4%, ambient temperature approx. 22°C

The study results presented in the Fig. 3 were obtained by using the thermostated mini-chambers. Aim was to determine the influence of the temperature on three levels: 15, 25 and 33°C on speed of the bond activation for molding sand made out of the sand reclaimed mechanically with application of 100% of the "slow" catalyst. The molding sand life time was decreasing from 60 to 7 min. and maximal bond strength appeared accordingly in time of 95 to 17 min. It is worth adding that introduction of the "fast" catalyst for thermostated temperatures of 7°C and 32°C, life times obtained were 23 to 1.5 min. It was found that when the life time of 40 min was exceeded, Rf strength dropped drastically (below 0,5 MPa).

Test with results shown in the Fig. 4 was about evaluation of the solution with application of, depending on the need, a fresh sand, sand from the mechanical regeneration and/or sand from the thermal regeneration. Presented graphs allow to state, among other things, that increase of concentration of the acidic ions decreases differences in values of life time and time of the maximum bond speed. Of course, application of only the "slow" hardener increased the life time twice for molding sands based on the new sand and the mechanically reclaimed sand, and four times for the thermally reclaimed sand.

Method of the FIP index determination is fast and unequivocal. It does not give the Rf value directly, but thanks to its use, an effective scenario of Rf strength finding can be developed, especially in environment of estimated life time. Whole realized studies of the FIP index of the furan molding sands is presented in the [23].

5. Examination of the thermo-mechanical properties index in condition of dynamic heating. Hot Distortion Plus ® method

Thermo-mechanical interactions between the casting and the mold are intuitively and not quite quantitatively identifiable. It is known, that these phenomena decide about indirect and final state of stress in the casting. In special cases, deformation or fractures in the casting can appear. This state is dependent on an alloy type, the casting shape (shrinkage restraining) and on the technology of the mold and its material. The rigid (durable) molds are practically non-flexible. The single-use (ceramic) molds are characterized with variable flexibility, which is dependent on the mold material, usually a thickened (and possibly hardened) molding sand. In the literature, citations can be found from the classic reference sources about the very high rigidity (cement molding sand – practically unused in foundries) and very low rigidity (green sands thickened using classic molding machines, with low pressing pressure). No numerical data are given anyway.

Behavior of the mold material is related to the variability of its components properties with temperature and applied load. Temperature of sintering, index of fire resistance, roasting losses, permeability in conditions of hot air flow and surface irradiation are only a several of the normalized (sometimes standardized) measurements in increased and high temperatures. They do not allow to estimate wanted, mentioned above values of the thermo-mechanical characteristics.

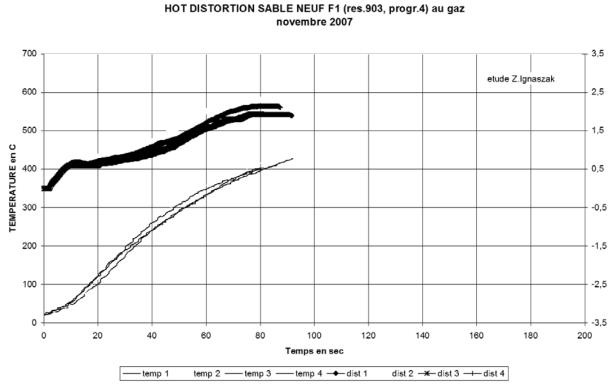
Measuring methods inspired with e.g. static compression or tensile test for testing the behavior of materials of the mold subjected to simultaneous influence of temperature or temperature and force are rare [13, 14, 15].

As a matter of fact, re-creation of thermo-mechanical conditions which the mold or core heated by the liquid alloy is subjected to and developing assumptions to build an appropriate apparatus must be based upon a number of simplifications, with a simultaneous attempt at standardization and obtaining a repeatability of the test.

Out of the methods developed by the British institute BCIRA, the particular attention needs to be paid to the one, which utilizes heating by gas and the Bunsen burner. The contact method, in which the sample was heated using the block of temperature equal to 950°C has not proven itself to be valuable. In [16, 17], methodical background and interpretation of the Hot Distortion tests are shown.

Heating using the gas burner is beneficial thanks to a high heat exchange coefficient between the flame and the sample. A proper and repeatable intensity of the gas flow, constant distance from the burner to the sample is a condition of the stability of energy transferred subsequently to examined samples.

A rule of the BCIRA test was assumed to build a Polish professional DMA device, named by its creators as an apparatus to study high-temperature phenomena in foundry cores [18, 19]. The author modified some of the solutions from this apparatus, changing the heating method from the halogen radiator to classic burner heating and has also prepared a station allowing extended recording of the temperature fields in the heated sample [20].



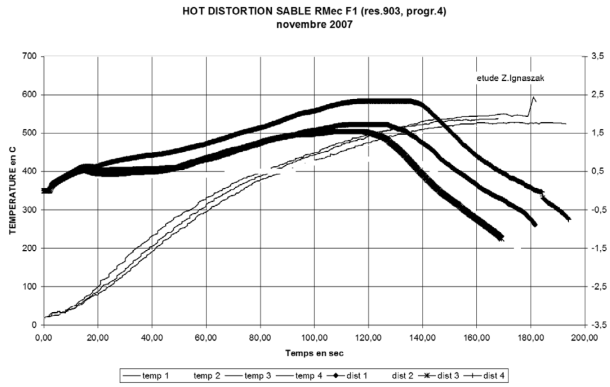


Fig. 5. Comparison of the Hot Distortion Plus® curves and the sample temperature increase at the side heated by the burner flame for the furan sands: 1% resin, 0,4% hardener (together „slow" and „fast"), recorded for two groups of molding sands (3 measurements each) for matrices: top – 100% new quartz sand, bottom – 100% reclaimed sand

The furan molding sand out of the new sand was proven to be definitely less resistant to the thermal degradation of the bond set in comparison with the mold based on the reclaimed sand (Fig. 5)

It proves, that the significant portion of the adhesion phenomena related to the regenerate grains state not only influence the strength in the ambient temperature (Rf is always lower for these molding sands than for molding sands from the fresh sand). Influence of the matrix type and grain surface state can be seen distinctively in the character of the properties of the relation: bridges rigidity – softening of the binder bridges.

6. Application of the thermo-mechanical properties in modeling

Virtualization in foundry and simulation systems dealing with it are increasingly popular. However, application of software for prediction of stress and fracture-endangered zones in castings is developing relatively slow. An important reason for this state is uncertainty regarding high-temperature thermo-mechanical parameters needed in this modeling. It especially concerns the molding sands. The molding sand and single-use molds and cores made out of it have always played a major role in interaction with the course of phenomena deciding about the casting quality. Studies of sands and materials for molds are neither coherent, nor systematic, unlike studies of castings and alloys. Standard tests of materials and molding sands do not give sufficient foundation to formulate the description of their behavior in thermal conditions during casting and remaining of the casting inside the mold. Methods fully applicable for metals (elasticity modulus, yield point, Poisson ratio, dilatation ratio) are not useful for the molding sands. Even for variability of the strength indexes (Rc, Rf, Rr) in function of temperature, there are still no normalized methods and appropriate devices.

In [21, 22] results of work aimed at virtualization of the HD sample (COMSOL Multiphysics system) were published. Details regarding assumptions during modeling and shape of the thermo-mechanical behavior model in the sample can be found there. The below figures present selected results of these studies (Fig. 6 and Fig. 7). The aim is of course to go further and use the data in form of variability of the molding sand coefficient, present in the simplified model assumed by the Comsol system: conventional elasticity constant E = (E)T) and expansion coefficient α=α(T).

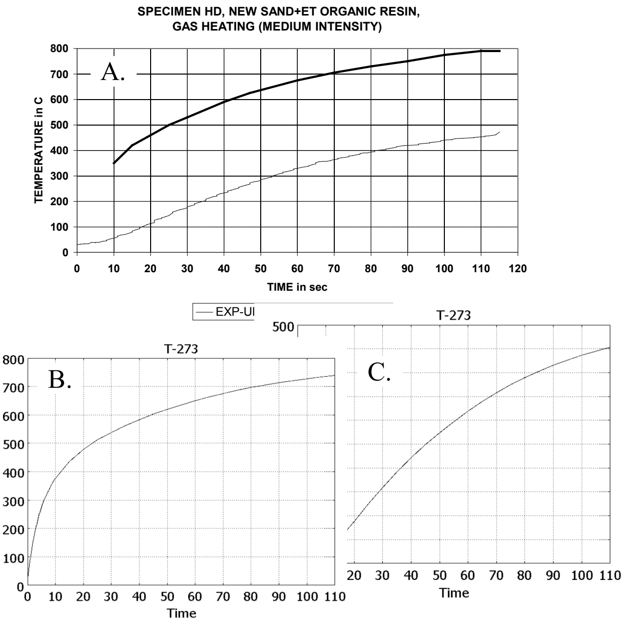


Fig. 6. Comparison of experimentally determined temperatures (A) and simulation results (COMSOL Multiphysics) of thermal balance of the HD Plus® sample heated with the gas flame (B and C) as a result of a positive validation of the thermal parameters (substitute heat conductivity, heat capacity)

In [23], a report can be found from extended studies of validation of models describing thermo-mechanical behavior of the molding sands. It was found, that application of the mechanically simplified model (elastic link and elastic-plastic link) and assuming substitute, temperature dependent thermo-mechanical parameters for the mold as a specific porous body of high instability of properties during its rapid heating allowed to obtain a satisfying compatibility of displacements from the experiment and from the simulation.

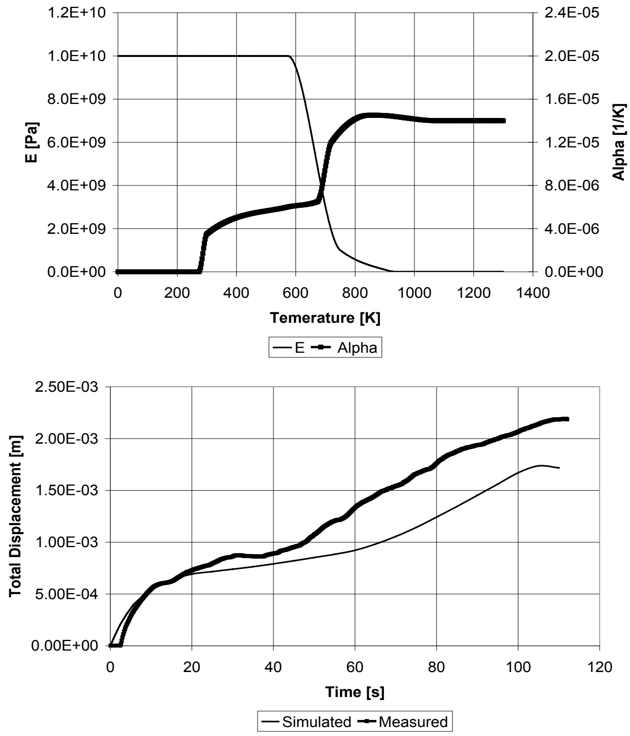


Fig. 7 Final formulas of E = (E)T) and α=α(T) variability and the best result of comparison of the experiment of the thermo-mechanical phenomena according to the HD Plus® method.

These thermo-mechanical parameters can be successfully used as a database element in systems for stress simulation for molds out of the quartz sand bond using the furan resin.

7. Summary

The paper summarizes studies realized by the author in laboratory and industrial conditions (foundries of cast steel and cast iron, castings up to 50 tons) about the effects of the chemically hardened molding reclaimed sands hard/soft rubbing in the dry reclamation. A reference was simultaneously made to advisability of application of the thermal regeneration in conditions, where chromite amount in the circulating molding sand goes as high as above ten percent.

The paper justifies a need of multi-aspect approach to the problem of reclamation of the quartz molding sands bound by chemical hardening, with particular attention paid to the furan molding sand, mixed after knocking-out with molding sands of different – in the chemical sense – character of bonds. These basic admixtures and presence of the chromite matrix in the knocked-out molding sand require constant and multi-aspect analyzing of quality of the reclaimed sand. Also, on examples of the industrial applications, it was shown that these actions are real and possible. Several types of studies were indicated, including both standard parameters of the reclaimed sand (granularity distribution and dust fraction portion, pH, acidity/basicity) and their influence on the mechanical and thermo-mechanical properties mostly of the furan molding sands. It was signalized, that there is a necessity of evaluation of the influence of the acidity/basicity state of the regenerate on the speed of the molding sand strength increase, which decides about its life time and properties in ready to pour mold. Weight of dynamics of changes of the thermo-mechanical properties of molding sands with the reclaimed sand was particularly underlined. These dynamics were studied using method developed in BCIRA in 70s, applying an author expansion to this method (additional instrumentation of the method – Hot-Distortion-Plus®) and a device developed in the country, from the Multiserw company. It was stated, that during the molding sand heating there is a change of character of thermal degeneration of the resin adhesive-cohesive bonds between the regenerate grains, in comparison with the grains of the fresh sand. It was indicated, that the information about the mold behavior from molding sands examined using the HD Plus® method can be used in simulation of stress in the castings using the modules STRESS, introducing more realistic parameters of chemically hardened molding sands to the database of the simulation system.

Because of the limited volume of the paper, some problems were merely touched, but importance of their synergy was attempted to be emphasized. Interested specialists should check the contents of the supplied bibliography.

Acknowledgements

The research was partially supported by Metallurgical Group CIF Ferry-Capitain, France.

References

[1] Ignaszak, Z., Herzog, T., Millot, A. & Prunier, J-B. (1995). Etude sur les hypthèses et les perspectives de la régénération et de la valorisation des sables usés de fonderie). In International Conference Modern Foundry Technologies. Environmental Protection, 6-8 September 1995. Kraków, Poland: AGH.

[2] Ignaszak, Z., Millot, A., Prunier, J-B. (1997). Recovery of chromite from the mass circulation. Aspect of technological and ecological. In II International Conference Modern Foundry Technologies. Environmental Protection, 3-5 September 1997. Kraków, Poland: AGH.

[3] Ignaszak, Z., Prunier, J-B. & Piault, R. (1999). Operational experience in the air transport system under French foundry. *Solidification of Metals and Alloys*. 40.

[4] Ignaszak, Z. (2000). Thermal Regeneration of chemically-bonded sand. The example of the furan. In III International Conference Modern Foundry Technologies. Environmental Protection, 7-9 September 2000. Kraków, Poland: AGH.

[5] Ignaszak, Z., Prunier, J-B. & Piault, R. (2002). Thermal regeneration and recycling of resin sand using pneumatic transport. *Archives of Foundry*. 5, 64-73.

[6] Ignaszak, Z., Stark, U., Ziętkiewicz, S. & Nieskurski, B. (2005). Identification of system parameters resin regeneration thermal mass in the foundry alloys. *Air Transport 2005,* 104-118.

[7] Ignaszak, Z. & Prunier, J-B. (2006). The practice of optimizing the quality of the masses of sand reclaimed furan in ferrous foundries. *Foundry Review*. 7-8, 310-314.

[8] Dańko, J. & Dańko, R. (2011). Reclaimability of the spent sand mixture – sand with bentonite – sand with furfuryl resin. *Archives of Foundry Engineering*. 11(2), 13-18.

[9] Szlumczyk, H., Janerka, K., Homa, D. & Myszor, A. (2007). Pneumatic moulding sand reclamation in the linear regenerator system. *Archives of Foundry Engineering*, 7(2), 53-56.

[10] Ignaszak, Z. (2010). Recherche et etude de la production des pièces en fonte a graphite spheroidal. Raports, Non published. *Archives of Ferry-Capitain Group*, *1995-2010.*

[11] Ignaszak, Z., (2009). The recycling problems of resin bonded ceramic materials in foundry industry. In V International Material Symposium "Materiais 2009", 5-8 Avril 2009. Lisboa, Portugal.

[12] The study of Institute CTIF, Manuel des sables à prise chimique (de la mise en œuvre au recyclage). Edition by Centre Technique des Industries de la Fonderie. Sèvres, 1994.

[13] Ramrattan, S.N. and others (1997). Thermal Distortion in Process Control of Chemically-Bondes Sands. *AFS Transactions*. 152, 152-165.

[14] Lewandowski, L. (1991). *Molding and core*. Warszawa: PWN.

[15] Samsonowicz, Z. (1963). Permeability measurements molding at high temperatures. Scientific Papers – Wroclaw University of Technology. *Mechanics*. IX(56), 93.

[16] Morgan, A.D. & Fasham, E.W. (1974). A new hot distortion tester for chemically bonded sands. *Report of BCIRA*.

[17] BCIRA Hot distortion tester. Operating instructions. 1975.

[18] http://www.multiserw-morek.pl/pl/indexpl.htm

[19] Jakubki, J. & Dobosz, St. M. (2003). Mass thermal deformation analysis using the DMA machine. *Archives of Foundry*. 3(9), 246-251.

[20] Ignaszak, Z. (2008). Chosen aspects of thermo-mechanical phenomena in resin bonded sands by use of Hot Distortion tests. *Archives of Foundry Engineering*. 8(1), 137-142.

[21] Ignaszak, Z. & Popielarski, P. (2011). Sensitivity Tests of Simulation Models used in Chosen Calculation Codes on Uncertainty of Thermo-Mechanical Parameters during Virtual Mechanical Stress Estimation for Ferrous Alloy Castings. *Defect and Diff. Forum*. 312-315, 758-763.

[22] Ignaszak, Z., Popielarski, P. &. Stręk, T (2011). Estimation of Coupled Thermo-Physical and Thermo-Mechanical Properties of Porous Thermolabile Ceramic Material using Hot Distortion Plus® Test. *Defect and Diffusion Forum.* 312-315, 764-769.

[23] Ignaszak, Z. & Popielarski, P. Application of simplified inverse solution to estimate the thermo-physical parameters of granular porous materials bonded by different resins. *Defect and Diffusion Forum.* 326-328, 605-611.