www.czasopisma.pan.pl PAN www.journals.pan.pl

ARCHIVES of FOUNDRY ENGINEERING

ISSN (2299-2944)
Volume 18
Issue 2/2018

141 – 145

DOI: 10.24425/122517

25/2

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

Discussion on the Methodology and Apparatus for Hot Distortion Studies

Z. Ignaszak
Poznan University of Technology, 3 Piotrowo Street, 60-965 Poznan, Poland
Corresponding author. E-mail address: zenon.ignaszak@put.poznan.pl

Received 25.03.2018; accepted in revised form 23.05.2018

Abstract

The paper refers to earlier publications of the author, on identification of properties of thermomechanical, chemically hardened core/mold sands. In that earlier period, first version of the original DMA apparatus, produced by a Polish company Multiserw-Morek, was used. The Hot Distortion (HD) study results, published by the author in 2008, referred to phenomena accompanying a thermal shock in real conditions of thermal interaction of a liquid alloy on a mold, in reference to a shock possible to obtain in laboratory conditions, without use of liquid alloy as a heat source, with analysis of solutions applied in the DMA apparatus. This paper presents author's observations on testing a new, innovative version of the LRu-DMA apparatus, containing a module allowing the Hot Distortion (HD) study. Temperature of specimens achieved in the case of the gas burner heating reaches values definitely above 800°C on the heated side and 610°C on the other side. Using an electric radiator, with maximal temperature of 900°C allows obtaining temperatures in between 225-300°C.

Keywords: Core sands, Thermomechanical phenomena, Pyrometer/Thermovision camera

1. Introduction

In the foundry, studies in laboratory conditions focus mainly on parameters of a cast alloy, mostly regarding identification of its metallurgical quality and its impact on structural components, defects and final properties of castings. This final quality is obviously influenced by phenomena resulting from mutual interactions between the metal and the mold. Thus, studies of properties of mold materials, their particular components and/or ready mold and core sands are conducted according to a scenario used in laboratory of a given foundry, while testing alloys and castings.

Studies of mold and core sands, both green with bentonite and chemo- or thermo-hardening, are carried out according to standard procedures, that have been mostly known for a few dozen years already, but with use of a new generation of equipment. These studies are usually conducted at the ambient temperature. Their results enable control and evaluation of stability of mold sands preparation processes. The aim is to maintain a required level of strength and processing parameters of molds. Results of these studies do not give sufficient foundations to predict significant phenomena in high-temperature thermal conditions of a real mold-casting system.

Even the strength variability ($R_{compression}$, $R_{flexion}$, $R_{tensile}$) in function of temperature is not standardized in terms of methods and equipment. These parameters, determined especially in the high-temperature range, at least around approx. few hundred degrees are missing.

In [1], there is a description of the first version of the original DMA apparatus, produced by the Polish company Multiserw-Morek [2]. Results of the studies on it [1], published in 2008, refer to phenomena accompanying a thermal shock under the real conditions of thermal interaction of a liquid alloy with a mold, referring to a shock possible to obtain in the laboratory conditions, without application of a liquid alloy as a heat source, with analysis of solutions applied in the DMA apparatus. This paper presents author's observations performed during launch and testing of a new version of the LRu-DMA apparatus, containing a

module for Hot Distortion (HD) testing [2]. This apparatus is contains some interesting, innovative solutions in terms of control of course of the HD test.

Two sources of heat for a HD-BCIRA specimen were tested and analyzed. During the tests, a broadened range of recording of variability of temperature fields of a heated specimen was applied, using a pyrometer and a thermographic camera.

2. State of art of thermomechanical phenomena identification in mould-casting system. Chosen examples.

It is a well-known fact that thermomechanical phenomena decide about casting quality features, including fulfillment of dimensional tolerances by a raw casting, as well as defects in reference to its intermediate and final state of stress. In some cases it may manifest itself by deformation or even fractures. This state is dependent on the alloy type and shape of the casting (inhibition of the shrinkage), as well as on technology of mold and its material. Another problem worth of indication is cores' susceptibility to be knocked out , especially regarding castings out of Al-Si alloys (with a relatively low temperature of binder degradation), of complex configuration and relatively thin walls, e.g. engine heads (Fig. 1) [3]. This problem requires constant awareness of a given foundry and proper selection of resin binders, to prevent lack of patency of water jackets in an engine.

Fig. 1 Example of an Al-Si-Cu cylinder head with complex thin-walled inner cores. [3]. Indication of knocking out ability problem

An effective methodology of identification of thermomechanical parameters of core sands, necessary, among other things, as databases for simulated calculation of stresses (e.g. in Magma or NovaFlow&Solid systems and their Stress modules) has still not been developed so far. There are only few propositions of meeting this challenge, using HD test results, for example, as described in [4].

The first group of studies of thermomechanical phenomena accompanying dynamical heating (thermal shock) is realized using liquid alloys as heat sources. Examples of these studies can be found in literature [5,6,7]. An example of a technological sample of knock out ability of mold sands are described in [8], among others.

The second group of studies consists in use of artificial heat sources for creating conditions affecting specimens made of molding / core sands, similar to conditions of a real system to a various extent. These studies are performed in laboratory conditions. These examples are given more attention. Prof. Samsonowicz [9] designed and implemented a method, that concerned an attachment to a classic device for permeability measurement. The studies are conducted in an increased temperature, with use of a resistive element made of Kanthal, for heating air, which is flowing through a specimen. In this method, amount of emitted energy is not measured – only the permeability and the air temperature is recorded. In [10], certain methods are described, along with analysis of obtained results, in conditions of use of a resistance heater with SiC (maximal temperature of 1200°C), for studies of an apparent thermal conductivity of mold sands in a stationary and a non-stationary state. Amount of thermal energy is constantly recorded, along with dynamically changing temperature fields.

Artificial energy sources are used also for determination of the Hot Distortion characteristics, including the one created in 70s of the XXth century by a British institute BCIRA, wherespecimens made of mold sand, sized 115 mm x 25 mm x 6 mm, were heated with use of gas and a Bunsen burner. The contact method, in which specimens were heated by a block having a temperature 950°C, did not prove itself useful. In [11,12], basics of methodology and interpretation of the Hot Distortion results are presented. The publications [13,14,15] present use of results obtained using a newer version of the BCIRA apparatus (Fig. 2), among other things.

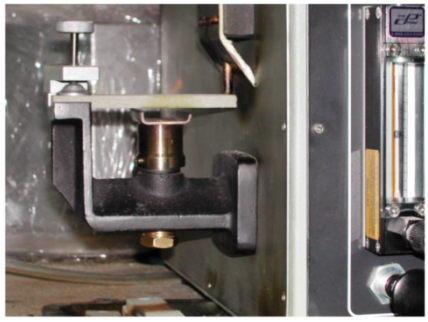

Fig. 2. Measurement module of the BCIRA test apparatus

The Simpson company has developed an apparatus, which is basically identical with the BCIRA version, containing a set for flame control with a gas flowmeter (an important novelty), with a displacement sensor. Readings from the curve can be used to provide an indication of the thermal expansion, hot brittleness, burnout rate and thermo-plasticity. The time required to break the specimen is an indication of the binder's hot strength [16].

The Hot Distortion Tester (VHD) described in [17] is also based on the BCIRA principle and contains a fully automated, foolproof heating mechanism, a recording and sensing mechanism of up to 0.01mm accuracy and a fully automated burning mechanism to heat the specimen to get a Hot Distortion curve.

A similar approach is valid in polymer processing. It is known as Deflection Temperature Testing of Plastics (ASTM D 648 and analogous ISO 75). This principle is also based on measurement of deformation of a sample of similar shape and dimensions to the BCIRA specimen, but supported on both sides, with placement of the specimen in a chamber of a preprogrammed temperature, along with a measured deformation force [18].

Back to the core sands, an original method of studying characteristics of the H(T)DT – Hot (Thermal) Distortion Test

was developed in the Western Michigan University. Using a sample of sand of 50 mm diameter and 8 mm thickness, the thermal distortion tests can be used to simulate a specific temperature setting; for example 760°C for aluminum, 1210°C for brass, and 1375°C for cast iron, with specimen loading from 3,5 to 5N. The deformation (a concavity related to the loss of mass) is determined using a 3D scanner [19,20].

The BCIRA test principle was also assumed in design of a Polish professional DMA tool, named by its creators as *an apparatus for studying high-temperature phenomena in the casting cores* [2,21].

Even this first prototype, an innovative solution (previous version was used by the author, as presented in [1]) fulfilled functions of an automatic measuring system in a complex way. It contained, among other things, a microprocessor-based system for programming of heating parameters, an automated drive of specimen movement with auto-positioning, as well as a super-precise position converter (sensor sensitivity of 1 micrometer).

3. Testing of a new LRu-DMA apparatus and method functionality analysis

The new version maintained functions of the previous DMA. An important methodological novelty in this apparatus is replacement of a heat source in form of a 1 kW halogen radiator with two special heaters (radiators) of 0,5 kW power each (maintaining a possibility of heating a specimen from the bottom or/and the top). Design of the heater was changed – radiation is only possible through a window of 10x35mm^2 size.

Measurement of temperature in the space above the radiator was kept (by an internal, mineral-insulated, sheathed thermocouple). Unfortunately, temperature measured in such a way still has no reference (apart from the fact, that the radiator emits energy).

This problem has been a topic of discussion with the DMA apparatus creators for more than 10 years. During the discussions, possible methods of real temperature fields of a specimen during the heating process were considered [1].

To appreciate the modifications in the LRu-DMA apparatus, good direction of corrections and expansion of its functionalities (by the LRu module) must be emphasized.

Regarding the suggestions listed in [1], they should be ordered in reference to the LRu-DMA apparatus.

Observations made during the HD measurements using the DMA apparatus have allowed to state, that for the same type of a binder, two perturbing, barely controllable phenomena occur:

- evident influence of the matrix type, or, to be more exact, the emissivity coefficient (for instance - color, granularity) of a studied sand on an amount of the absorbed energy - a cause of limitations regarding methodology of the HD studies,
- lack of measurement of energy obtained by the specimen,
- influence of thinning of the specimen in a zone of prolonged heating (e.g. for sands agglomerated with a furan resin), by gravitational fall of sand grains, free from bindings, that have lost their power to bind with the specimen volume (oxidizing atmosphere, as a result of ambient air getting in).

It can be concluded, that to obtain repeatability of the radiating energy absorbed by specimens, appropriate assumptions should be made. If this is not considered, then comparison of, e.g., new sand and reclaimed sand behavior should not be made. Such a limitation is not present when a gas burner is used as a heat source.

A maximal bending moment and stresses are, of course, present in specimens, in a location near to the clamping point. They are dependent on a single specimen weight (depending on the matrix type), combined with a constant weight of a sensor (9,3 g). Decrease of a single specimen strength (degeneration of resin bridges) will be the fastest in the narrow zone of maximal temperature. In the LRu-DMA apparatus, the energy actually gets out only through a rectangular hole (area around 350mm^2) in the radiator cover. The interaction field is fundamentally smaller than in the previous DMA version. That is why comparability of dynamics of destructive transformations of binding bridges cannot exist here.

In the LRu-DMA apparatus, modifications identical with previous versions of the DMA apparatus were made (introduction of an additional gas heating). The modification allowed alternate application of the basic and the additional heat source. It enabled comparative studies in the both cases.

Measurement of a single specimen temperature on both its sides, along with its recording, was realized with a thermographic camera and a pyrometer.

Next Figure presents photographs of heating sources in both the cases (a radiator and a gas burner), as well as organization of a work stand and measurement systems (Fig. 3). A comparative study of a specimen out of Croning sand was performed. The results are presented in diagrams – Fig. 4.

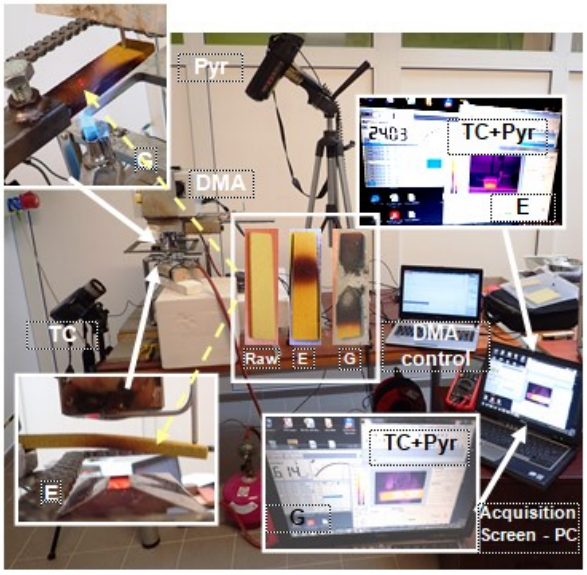

Fig. 3 Modified Hot Distortion measuring stand and information on the test details. DMA - HD control unit, TC - Thermovision camera, Pyr - Pyrometer, E,G - heating by electric radiator/gas burner, Raw-E-G - state sequences of Croning sand samples after heating by E (Electric) and by G (Gas) method

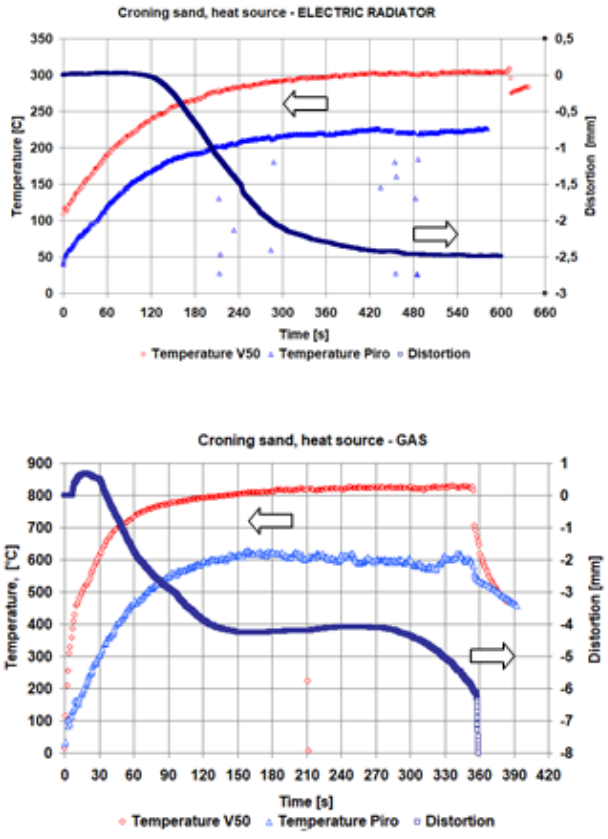

Fig. 4 Comparison of HD results and temperature changes on the bottom (by termovision camera V50) and upper (by pyrometer) surface for Croning sand (MRC). Heating by electric radiator - E (up), heating by bass burner - G (bottom)

The author's assumption was correct. Regarding conditions of a specimen heating using an original electrical radiator (E), this temperature is significantly different than real specimen temperature on the side of influence of the radiating energy. Simultaneous use of upper radiator obviously intensifies energy absorption (still undetermined quantitatively). It accelerates phenomena of degradation of the binding bridges. However, due to symmetry of the dilatation phenomena, they are neutralized. This does not happen while heating a layer of a sand in a real mold cavity.

In the HD-themed publications, linking variability of sample deformation with its reference to temperature achieved by the radiator requires high caution in interpretation [22]. Adjustable temperature of the electric radiator – approx. 900°C (maximal) – made the MRC specimen (colored yellow in the beginning of the test) absorb part of this energy (impossible to determine quantitatively), what finally resulted in its maximal temperature of 300°C. This temperature does not correspond with the pouring conditions of most foundry alloys. Simultaneously, it must be emphasized, that temperature recorded by a thermocouple of K type, approx. 4 mm in diameter, hung in a space above the radiator, shows temperature dependent on the emissivity coefficient of sheath of the thermocouple and can, in the best case, have a significance of qualitative type – this temperature absolutely does not represent a real temperature of the specimen.

4. Summary

The system of the LRu-DMA apparatus allows recording of deformation, the radiator temperature (with the temperature regulator working very well), the thermocouple temperature (this measurement is not useful), all in the function of time.

It must be added here, that the most important condition of reference of deformation (distortion) dynamics of a free end of a specimen is a reliable information on the temperature field variability in time, on both sides of the specimen. This is possible only with use of an additional temperature measurement system, the temperature representative for the specimen. Such a solution has been presented in this paper.

Temperature of specimens achieved in the case of the gas burner heating reaches values definitely above 800°C on the heated side and 610°C on the other side. Such a temperature range is much more close to a profile and value of a real temperature, for instance of a core placed in a mold cavity, poured with a ferrous alloy.

One-sided heating of a specimen of Croning mold sand with a quartz sand matrix, using an electric radiator, with an assumption of an acceptable maximal temperature of 900°C allows obtaining temperatures in between 225-300°C. Such a conditions, obviously, did not allow obtaining a significant bending of a specimen (maximally 2,5 mm), the failure of the binder bridges was also not possible.

Acknowledgements

The presented research results, were co-funded with grants for education allocated by the Ministry of Science and Higher Education in Poland (PUT - 02/25/DSPB/4402 and (for LRu DMA apparatus purchase) from a scientific European project “Robust and FLEXible CAST Iron Manufacturing, FLEXICAST” (FP7-2012-NMP ICT-FoF).

References

[1] 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.
[2] http://Multiserw-Morek.pl /products.
[3] https://www.magmasoft.com/en/company/partners-and-projects/amap.
[4] 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 (pp.312-315, 764-769).
[5] Zych, J. & Mocek, J. (2015). Destruction of Moulding Sands with Chemical Binders Caused by the Thermal Radiation of

Liquid Metal Volume. *Archives of Foundry Engineering*. 15(4), 95-100.
[6] Mocek, J., Zych, J. & Chojecki, A. (2004). Study of erosion phenomena in sand moulds poured with cast iron. *International Journal of Cast Metals Research. British Cast Iron Research Association*. 17(1), 47-50. ISSN 1364-0461.
[7] Zych, J., Mocek, J. & Kaznica, N. (2018). Kinetics of Gases Emission from Surface Layers of Sand Moulds. *Archives of Foundry Engineering*. 18(1), 222-226.
[8] Izdebska-Szanda, I., Angrecki, M. & Matuszewski, S. (2012). Investigating of the Knocking Out Properties of Moulding Sands with New Inorganic Binders Used for Castings of Non-ferrous Metal Alloys in Comparison with the Previously Used. *Archives of Foundry Engineering*. 12(spec.2), 117-120.
[9] Samsonowicz, Z. (1965). Measurements of molding sand permeability at high temperatures. Wrocław: Zeszyty Naukowe Pol. Wrocławskiej, Mechanika IX, Nr 56.
[10] Ignaszak, Z. (2002). *Virtual Prototyping in the Foundry. Databases and Validation. Monograph*. Poznań: Edition of Poznan University of Technology. (in Polish).
[11] Morgan, A.D. & Fasham, E.W. (1975). The BCIRA Hot Distortion Tester for Quality Control in Production of Chemically Bonded Sands. *AFS Transactions*. 91, 73-80.
[12] BCIRA Hot distortion tester (1975). Operating instructions.
[13] Showman, R.E., Harmon, S.B. (2012). *Further Evaluations of Anti-Veining Sand Additives*. Edition of American Foundry Society.
[14] Thiel, J., Ziegler, M., Dziekonski, P. & Joyce, S. (2007). Investigation into the Technical Limitations of Silica Sand Due to Thermal Expansion. *AFS Transactions*. paper 07-145
[15] Cheah, S.F., Ramrattan, S.N., Guyer, O.B., Fisher, K.M. (2004). AFS Transactions © American Foundry Society, Des Plaines IL USA, Paper 04-122(04).pdf, pp.2-7.
[16] Catalog Simpson Technologies – Hot Distortion Tester Model 42114. http://www.simpsongroup.com.
[17] Catalog Versatile Equipments Private Limited. http://sandtesting.com/product/hot-distortion-tester.
[18] Data sheet on Deflection Temperature Testing of Plastics. http://www.matweb.com/reference/deflection-temperature.
[19] Ramrattan, S., Khoshgoftar, A.M., Konkel, M., Muniza J. & Pike A. (2014). Improvements to Disc-Shaped Specimens for Control of PUCB Sand Systems. *AFS Transactions*. 14-061.
[20] Derrick, S., Oman, A. & Ramrattan, S. (2012). Casting Trials Measuring Thermo-Mechanical Defects in Various Chemically Bonded Sand Systems. *AFS Transactions*. 12-107.
[21] Jakubski, J. & Dobosz, St.M. (2003). Analysis of thermal deformation of masses using a DMA apparatus. *Archives of Foundry*. 3(9), 246-251.
[22] Stachowicz, M., Granat, K. and others. (2018). Modified Hot Distortion Test to Investigate the Effect of the Inorganic Binder Kind on the High-Temperature Behaviour of Moulding Sands Hardened by Physical Methods. *Archives of Foundry Engineering* (in print).