Use of experimental casting equipment for research of castings crystallized through individual cooling procedures

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The research is devoted to development of experimental foundry pattern equipment, allowing to obtain two or more castings in a sand-loam mould; these casting are crystallized via individual cooling procedures within structurally sensitive intervals (dendrite, eutectic crystallization and recrystallization). Influence of scale factor is excluded in this case and it makes possible to obtain control and pilot castings, which have equal sizes; influence of chemical composition is excluded as well, because all castings located in a mould have common gating and feeding system. It provides the same temperature and casting speed for two or more castings in one mould with different compositions and technological properties of moulding mixtures for each of the comparing castings. Thereby, variable cooling rate, which is individual for each casting obtained in the experimental mould, remains the main factor having influence on forming of structure, mechanical and operating properties of cast metal. Possibility of investigation of rise of mechanical and operating properties of castings owing to only adjusting of cooling rate without use of alloying and modification appears in this case. Increase of the cooling rate in local temperature-time crystallization intervals is provided by blowing with cooling gases which are fed in the mould via the stand (receiver). Retarding of cooling rate occurs as a result of mould heating during thermal oxidizing destruction of exothermal carbon-containing additives which are specially introduced in the facing layer of moulding mixture. It is necessary to mention that variation of cooling rate can be conducted via the procedures which are individual for each casting located in the experimental mould. Developed and fabricated experimental foundry equipment was used for testing of the concrete cooling procedures of thin-walled castings made of grey cast iron. Pressure of cooling compressed air, which was fed during the process, and amount of exothermal carbon-containing additive, which was introduced in composition of the facing layer of moulding mixture for pilot castings were varied. As a result, the efficient cooling procedure was selected; it allowed to rise tensile strength for the pilot casting by 13 %, to improve cast iron quality (quality index) by 23 % and to increase structure dispersity of primary austenite by 21 % without introduction of alloying elements and modifiers in cast iron composition.

Key words: casting, ferrous-carbon alloys, crystallization, solidification, cooling rate, eutectic transformation, eutectoid transformation, tensile strength
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Introduction

Many scientific researches, which are directed on improvement of castings metal quality in the process of metal casting in sand-loam moulds are conducted at present time. It is necessary to provide that the conditions of obtaining of comparing castings were identical. These conditions should include chemical composition of the casting alloy, casting temperature and speed, gating and feeding system, cooling rate, size of castings, composition of facing sand and heap sand moulding mixtures etc.). Different moulds [1-10] or common mould for two or more castings [11-16] are usually used for investigation and comparison of pilot and control castings, meaning the same preset conditions of the effect of external factors on investigated castings. It does not allow to cast simultaneously pilot and control castings with common gating and feeding system (from one side) and with individual cooling procedures (from other side).

Development of the experimental foundry pattern equipment for investigation of control and pilot castings with individual cooling procedures for each casting in one mould is the aim of this work. This foundry pattern equipment should provide:

- possibility of conducting parallel testing of control and pilot castings, which have the same size and chemical composition;
- the same casting temperature and casting rate for control and pilot castings;
- common gating and feeding system for researched castings with equal size of ingates;
- possibility of obtaining of two or more castings in one mould with different compositions and technological properties of mixtures;

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- possibility of use of different compositions of heap sand and facing sand moulding mixtures simultaneously for each casting;
- possibility of simultaneous temperature measuring for each casting and (if required) of temperature of facing sand and heap sand moulding mixture;
- possibility of varying the cooling rate for each casting at any time;
- possibility of varying pressure and consumption of gas which is fed to each casting;
- possibility of use of local cooling for shape castings with non-uniform wall thickness.

This pattern equipment is necessary for conduction of laboratorial examinations of influence of differently directed cooling on the structure and mechanical properties of different alloys, which are sensitive to thermokinetic effects.

Methods and materials

Development and fabrication of experimental foundry patter equipment for investigation of control and pilot castings in the process of casting in sand-loam mould were included in the general technique of investigation. Afterwards, conduction of comparative researches of metal quality in castings, which were obtained in one mould with individual cooling procedures, was planned. The technology of individual differently directed cooling can be applied to thin-wall castings with dominating wall thickness from 4 to 15 mm. Cast iron with hypo-eutectic composition and eutectic degree 0.83 was selected for investigation. Control and pilot castings were cast in the common mould with gating and feeding system for two castings at the temperature 1420 °C ± 10 °C. The castings were obtained in the mould made of bentonite clay BS1T2 (6 % mass.), quartzite sand $2K_2O_2 02$ (94 % mass.) and additionally water (3 % mass.). Exothermal carbon-containing additives (CA) in the amount more than 0.3-0.5 % mass. were introduced in the composition of facing layer of pilot castings. Gases which were extracted during thermal destruction of CA, as well as compressed air fed by compressor through the lower semi-mould under pressure 0.2-0.5 MPa, are removed from the casting via air gate and gas removing channels in the upper semi-mould. The mould consisting of two semi-moulds is mounted completely and hermetically on the stand (receiver). Size of castings was 120×60×15 mm. Thickness of the blown layer of moulding mixture from drag portion of the lower semi-mould to casting (0.155 mm) and square of the blown cross-section of the mould (0.25 m^2) were equal in all cases. When the mould size varied, the pressure of compressed air should be calculated according to the Darcy filtration rule, taking into account varying of resistance of the moulding mixture layer in the mould [17]. Obtained castings were used for cutting and preparing of specimens for determination of the following mechanical properties: tensile strength according to the GOST 1497-84 [18], hardness according to the GOST 9012-59 [19] as well as metallographic analysis of the primary structure – the distance between 2nd order dendrite branches of primary austenite, using modular optical microscope «Olympus BX51M» with software «OLYMPUS Stream™».

Results and discussion

The developed foundry pattern equipment is shown of the **Fig. 1**. It allows to form two or more castings (control and pilot ones) during differently directed cooling. These castings are located in different heat-insulated segments of the lower semi-mould with different composition of moulding mixture. Control and pilot castings are provided with different cooling conditions. The foundry pattern equipment contains two semi-moulds, stand *1* (fabricated as two sections *2* which are isolated from each other); these sections are equipped with gas feeding devices – connections *3* with gear boxes *4* for gas feeding control. Perforated plate *5* (gas distributor to provide possibility of increase of local cooling rate for shape castings) with sealer *16* for hermetic mounting of a mould is located on the stand. This mould consists of the lower semi-mould *6* (separated by heat-insulated partition wall *7* into two identical autonomous segments) and the upper semi-mould *8* (forming hollow spaces for manufacture of castings *14*). Common gating

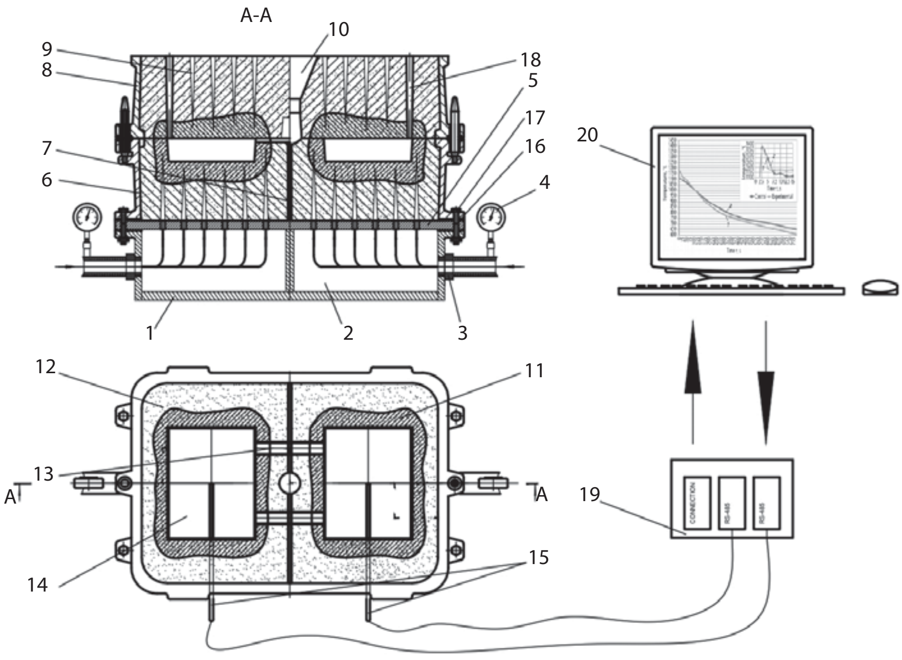

Fig. 1. Experimental foundry pattern equipment for production of castings in the conditions of different directed cooling

and feeding system *10* is connected with the both hollow spaces for castings *14*, having the same shape and size and encircled by the same moulding (facing) mixtures *11* in the medium of heap sand mixture *12*. Common gating and feeding system consists of ingates *13* and sprue base (located in the lower semi-mould *6*) and metal crucible, stand pipe and trough (located in the upper semi-mould *8*). Pinholes *9*, providing efficiency of gas blowing for castings *14*, were made in the medium of facing *11* and heap sand *12* mixtures within the semi-moulds *6* and *8*. Air gates *18* were done in the upper semi-mould *8* for improvement of gas emission from castings. Connection with thermocouples *15* is provided for control of castings cooling rate within the semi-moulds 6 and *8*. It is recommended to use bolt connections *17* with hermetic processing to provide hermetic fixing of semi-moulds with each other and of assembled mould with the stand.

Separation of the lower semi-mould into two autonomous segments as well as presence of two sections (independent one from other) for feeding of different gases allows to vary cooling rate of obtained castings in desired directions. It means increase of cooling rate (e.g. blowing by cooling gas) or its retarding (e.g. via thermal oxidizing destruction of CA). To rise efficiency of gas blowing and creation of favourable conditions for its emission, pinholes were done both in the upper and lower semi-moulds. This separation also makes it possible to use different compositions of heap sand and facing mixtures for varying of cooling rate and other parameters.

Experimental foundry pattern equipment for examination of castings solidification operates in the following way. The melt with preset chemical composition and temperature is cast in the common gating and feeding system *10*. Then the melt simultaneously and with equal speed through ingates *13* moves in two hollow spaces which are separated from each other by heat-insulating partition wall *7*, where the castings *14* are formed. Individual crystallization and consequent cooling procedures are appointed for each casting *14* in the structurally sensitive intervals, based the tasks of the investigation. The blowing procedure (pressure, gas consumption) for each of casting *14* is adjusted by gear boxes *4* for gas control and feeding. Gas is accumulated on the sections *2* of the stand *1* and then moves under pressure through perforated plate *5* to the layers of heap sand *12* and facing *11* mixtures to castings *14* (in the case of cooling with variable wall thickness). To provide efficient gas acceptance to a casting and gas emission from a casting, pinholes *9* were done both in the upper *8* and lower 6 semi-moulds, as well as air gates *18* in the upper semi-mould. Control of metal solidification kinetics in a casting is conducted via cooling curves which are written via the "Complex for temperature control and measurement and thermal analysis of steels and alloys", including intelligent analog-digital converter for measuring the temperature of solidifying metal in a casting mould (thermal resistance transducer «ZET 7121 – TermoTR-CAN» with interface converter «ZET 7176») *19* and possibility of visualization of measurements results to the PC *20*. It allows to assess influence of different solidification conditions on structure and properties of obtained castings from the melt with preset chemical composition and temperature of a casting.

As a result, crystallization and consequent cooling of each casting occurs in individual conditions. Thereby, two and more castings with different structure and properties are obtained from the melt having one chemical composition and equal temperature and casting speed.

Pilot melts of cast iron with hypo-eutectoid composition were carried out using develped and fabricated pattern equipment (**Table 1**). metal melting was conducted in the "Induction melting unit for steel and iron" (VTG-30-22). This series of experiments was aimed on improvement of

Table 1. **Chemical composition of cast iron in pilot melts**

Content of the elements (mass. %)										S_e*
C	Mn	Si	P	S	Cr	Ni	Cu	Mo	V	
3.2	0.51	1.71	0.074	0.111	0.173	0.118	0.162	0.01	0.013	0.83

*Se = C/4.3 - (0.3(% Si) + 0.027(% Mn) – 0.3(% P) – 0.4(% S) + 0.063(% Cr) + 0.015(% Mo) – 0.053(% Ni) – 0.074(% Cu) + 0.135(% V)) [20]

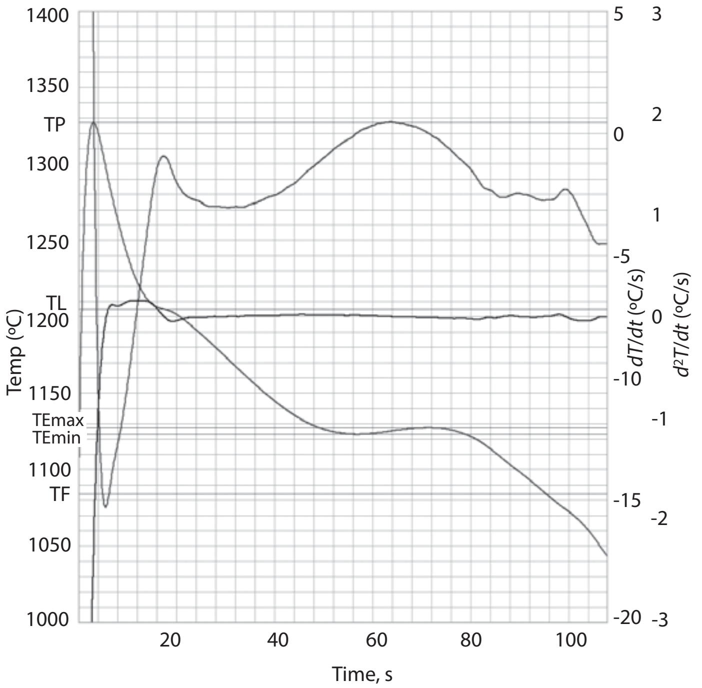

Fig. 2. Determination of the local temperature and time crystallization intervals for cast iron via thermographic analysis:
TP (°C) – peak temperature of the melt; TL (°C) – liquidus temperature corresponding to appearing of primary austenite crystals in the melt; TEmax (°C) – maximal temperature of eutectic transformation; TEmin (°C) – minimal temperature of eutectic transformation; TF (°C) - finishing temperature of crystallization

Table 2. **Results of metallographic analysis and testing for mechanical properties of obtained castings**

Melt	Varying parameters		Properties of casting metal			
	Compressed air pressure, MPa	Amount of introduced CA, % (mass.)	Hardness (HB)	Tensile strength ($\sigma_в$), MPa	Quality parameter, K [23]	Distance between 2nd order brances λ, μm
1	0.3	0.5	257 ± 4	238 ± 3	0.92	33 ± 0,2
2	0.4	1.0	243 ± 3	241 ± 2	0.99	32 ± 0,2
3	0.3	1.5	237 ± 3	248 ± 3	1.04	30 ± 0,3
4	0.4	2,.0	233 ± 2	249 ± 2	0.98	31 ± 0,2
5	0.3	3.0	227 ± 3	271 ± 3	1.18	29 ± 0,1
Control	–	–	248 ± 4	240 ± 2	0.96	37 ± 0,6

quality parameters (quality index) of gray cast iron owing to forming of fine-dispersed dendrite structure of primary austenite and prevention of ledeburite forming. Experimental conditions provided differently directed cooling in the preset structure sensitive intervals of cast iron crystallization, without use of microalloying modifying.

To determine temperature and time parameters of the structurally sensitive solidification and cooling intervals of cast iron, investigations with use of the "Complex for thermographic cast iron analysis", including the sensor for thermal analysis «Quik-LAB E IV» and software complex «MeltControl 2020-Win» for processing of the results of thermal analysis were conducted (**Fig. 2**). The cooling curves for the control and pilot castings were registered and visualized on PC screen. Cooling rate within the interval of dendrite crystallization (from the start of primary austenite deposition to the temperature of eutectic transformation beginning) was determined directly by the experimental cooling curves of pilot and control castings ($\Delta T/\Delta\tau$), which were processed by software.

Increase of the cooling rate of the pilot casting was realized via feeding of compressed air in the beginning of dendrite crystallization under excessive pressure; it was finalized after deposition of primary austenite crystals. Control casting was conducted under normal conditions, without air blowing and cooling rate adjusting. Blowing of the mould with compressed air was started in all experiments at the temperature 1300 ± 7 °C, what corresponds to start of deposition of primary austenite dendrites, and was finished at the temperature 1150 ± 6 °C, what corresponds to the temperature of eutectic transformation in the stable system of forming of austenite-graphite eutectics (**Table 2**). Compressor «CB 4/F-500 LB 75» with capacity 950 l/min (0.016 m^3/s) was used for blowing of the mould with compressed air.

Testing of the concrete procedures for mould blowing with compressed air as well as choosing of required amount of exothermal carbon-containing additive were conducted during the investigation (Table 2). Fuel oil M-100 was taken as this exothermal carbon-containing additive [21, 22]. The specimens for metallographic examination and mechanical testing were cut from the obtained castings. Parameters of different melts 1-5 depending on varying with excessive blowing pressure value, amount of introduced exothermal carbon-containing additives as well as the data characterizing testing conditions for iron castings are also presented in the Table 2 (the average values obtained on the base of results of at least three experiments). Primary austenite structure dispersity was evaluated by the standard parameter λ – the distance between second order dendrite branches.

Feeding of compressed air under less pressure does not have any effect on increase of the cooling rate within the interval of dendrite crystallization, while larger pressure leads to forming of cementite eutectics. Introduction of exothermal carbon-containing additive in the amount exceeding the mentioned range provides casting rejects caused by blowholes; if this amount is less – no retarding of the cooling rate in the eutectic temperature interval takes place. The data of the melt 5 in the table 2 testifies that maximal effect is achieved during mould blowing with compressed air under pressure 0.3 MPa, accompanied with introduction of exothermal carbon-containing additive of fuel oil M-100 (3.0 %) in composition of facing layer of moulding mixture.

Conclusions

Experimental foundry pattern equipment is developed as well as its requirements for investigation of castings during comparative testing of the pilot and control castings. This pattern equipment allows to provide differently directed effect on cast iron cooling rate for initially equal casting conditions.

The efficient cooling parameters for grey iron castings with wall thickness 15 mm were revealed. They allow to increase tensile strength by 13 %, to improve cast iron quality parameter (quality index) by 23 % and to increase structure dispersity of primary austenite by 21 % due to decrease of the distance between second order dendrite branches, without introduction of alloying elements and modifiers in cast iron composition. CIS

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