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Temperature Patterns and Pouring Limits of High-Strength Cast Iron during Solidification in the Combined Chill-Sandy Mold Box

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The results of experimental research of temperature and duration of high-strength cast iron solidification in four molds consisting of the chill mold and sandy-argillaceous mold are presented. The features of solidification front advance and temperature limit of melt pouring out through-the-cast-thickness are determined.

Keywords: HIGH-STRENGTH CAST IRON, THERMOCOUPLES, SOLIDIFICATION, POURING OUT, CHILL MOLD, SANDY-ARGILLACEOUS MOLDING BOX, ISOCHRONAL

Introduction

The results of experimental research of pouring out 5100 kg of high-strength cast iron from combined molds on one drain pan are presented in [1]. Each casting-form consists of the metal mold Ø500 mm, height 600 mm and sandy-argillaceous molding box Ø350 mm, height 330 mm. Bottom gate with tangential input of metal (Ø90 mm) provides simultaneous receipt of hot iron in sandy-argillaceous molding box and then in the metal mold. Pouring out of molten metal is carried out in 2 minutes 25 seconds, 7 minutes 40 seconds, 23 minutes and 46 minutes. Solidification of cast iron 3.5-6.0 mm thick in the sandy-argillaceous molding box in 2 minutes 25 seconds and then its melting-down in 7 minutes 40 seconds have been observed for the first time. Metal layer 2.7-6.5 mm thick solidified again only in 23 minutes. Asymmetry of solidification process along the cast radius in both chill mold and sandy-argillaceous molding box is determined.

Macrostructural "cuts" in the solidified part of the cast being cooled in the metal mold are observed after pouring out the melt. This can be one of the reasons of hot cracks in large high-strength chilled iron castings.

Methods of pouring out the liquid rest with simultaneous alloy temperature measurement are combined for small-sized casts [2-5]. There are no data about results of similar experiments for large high-strength iron castings cooled in combined chill and sandy-argillaceous molds. The present paper is continuation of work [1].

The task of present research is to determine the effect of solidification processes of heavy high-strength iron casting on the position of boundary line of pouring out in combined chill and sandy-argillaceous mold.

Methodology

10 chromel-alumel thermocouples are located along the radius of chill and sandy-argillaceous mold on a various distance from heat-removal surface. Hot ends of thermocouples are protected by specially developed construction (**Figure 1**) which excludes displacement of thermal insulation on the level because of hydraulic action of metal and prevents cracks in the quartz tube 2 caused by thermal expansion during casting into molds.

Chromel-alumel thermoelectrodes 0.5 mm in diameter and 7-12 m long are isolated from each other by two-channel high-aluminous straws with outside diameter of channels 0.65-0.75 mm. Cold ends of thermocouples are fixed to input terminals of multiple-point potentiometer of type KSP-4 which provides temperature registration in the interval 0-1370 °C [6]. Gaging of devices is carried out using potentiometer PP-63 with accuracy class 0.05. The statistical sensitivity analysis for chromel-alumel thermocouples showed that maximum permissible error was much less than for other types of thermocouples because of higher values of thermo-emf [6]: at 1370 °C for chromel-alumel thermocouples 54.8 mV, platino-rhodic (10 %) platinum thermocouple PR10/0 - 12 mV, tungsten- perrhenic thermocouple VR5/20 – 14.5 mV. The chemical composition of chilled high-strength cast iron is as follows, % mass.: C 3.04; Si 2.10; Mn 0.48; P 0.189; S 0.010; Cr 0.35; Ni 1.08; Mg_{res} 0.03. Interpretation of experimental cooling curve is shown in **Figure 2**.

Thermal arrests of liquidus and solidus near heat-releasing surface are not observed. Therefore their values are accepted according to indications of thermocouples located in the axial zone of casting. Temperature pattern with isochrones and kinetic solidification curve of casting are plotted by results of temperature measurement.

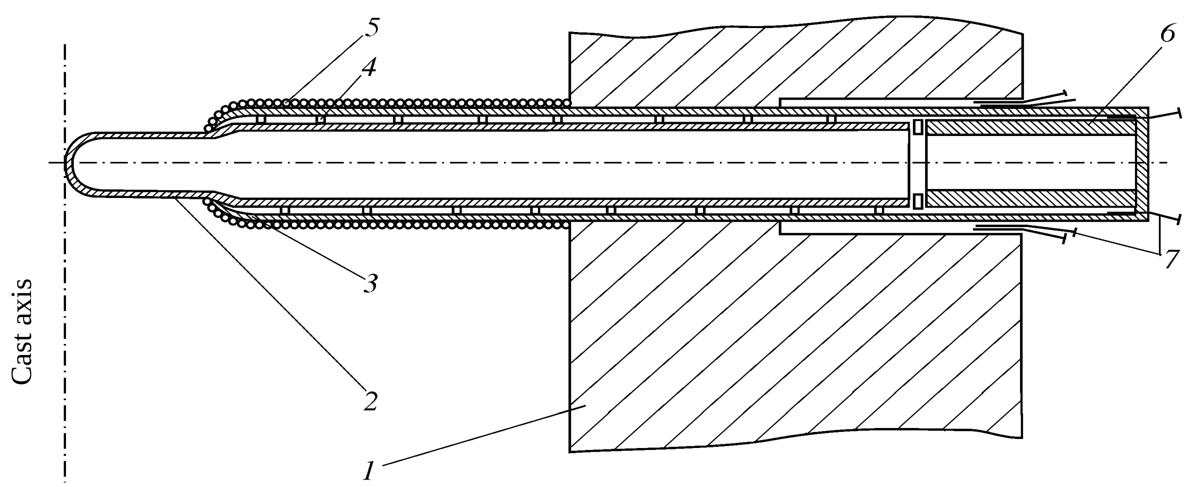

Figure 1. Fastening of quartz tip in the metal mold: *1* - metal mold wall; *2* - quartz tube with longish tip; *3* - canted thin-walled steel tube; *4* - asbestos packing cord; *5* - heat-insulation layer of asbestos cord; *6* - closing sleeve; *7* - pins

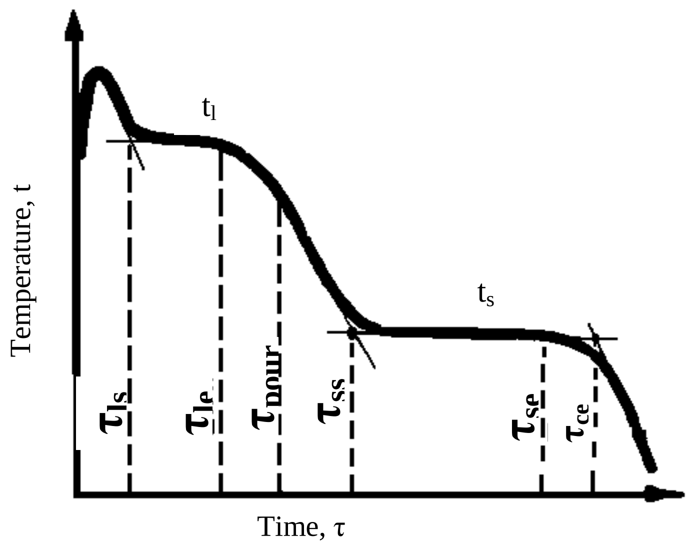

Figure 2. Interpretation of experimental cooling curve: t_l and t_s - liquidus and solidus temperatures; τ_{ls} and τ_{le} - start and end of crystallization hidden heat emission at liquidus temperature; τ_{ss} and τ_{se} - start and end of crystallization hidden heat emission at solidus temperature; τ_{pour} - pouring out of melt; τ_{ce} - the end of crystallization (precipitation of 100 % solid phase)

Results and Discussion

Solidification point of high-strength cast iron in metal mold Ø 500 mm is researched in the radial direction using thermocouples No. 1, 2, 3, 4 located at 10, 90, 180, 250 mm from a metal mold surface respectively (**Figure 3a**). Thermocouple No. 1 does not record the temperature of liquidus line because of high-speed heat removal in the metal mold, and there is a minor kink on the cooling curve at solidus temperature. Liquidus and solidus are precisely recorded by thermal arrests and kinks of cooling curves 2, 3 and 4 at 90, 180 and 250 mm from the metal mold. The total time of cast solidification in the metal mold Ø 500 mm in the radial direction is approximately 112 minutes. Isoliquidus frontal advance is graphically plotted on the kinetic solidification curve (**Figure 3b**): τ_{ls} - start of crystallization hidden heat emission, and τ_{le} - the end; isosolidus: τ_{ss} - start of solidus thermal arrest, and τ_{se} – the end; τ_{ce} - crystallization end; τ_{pour} - line of melt pouring out. Acceleration of solidification front advancing at τ_{le}, τ_{ss}, τ_{se}, τ_{ce}, τ_{pour} to depth of ~90 mm is caused by near heat-releasing surface.

The temperature fall in 5, 15, 30, 45, 60, 75, 90, 105 and 120 minutes is graphically plotted on the cast temperature pattern (**Figure 3c**), which points to consecutive solidification character: from metal mold surface to axial zone of the cast.

The formation of shrinkable defects in the cast begins with the moment of alloy transition from liquid – solid into solid – liquid state at

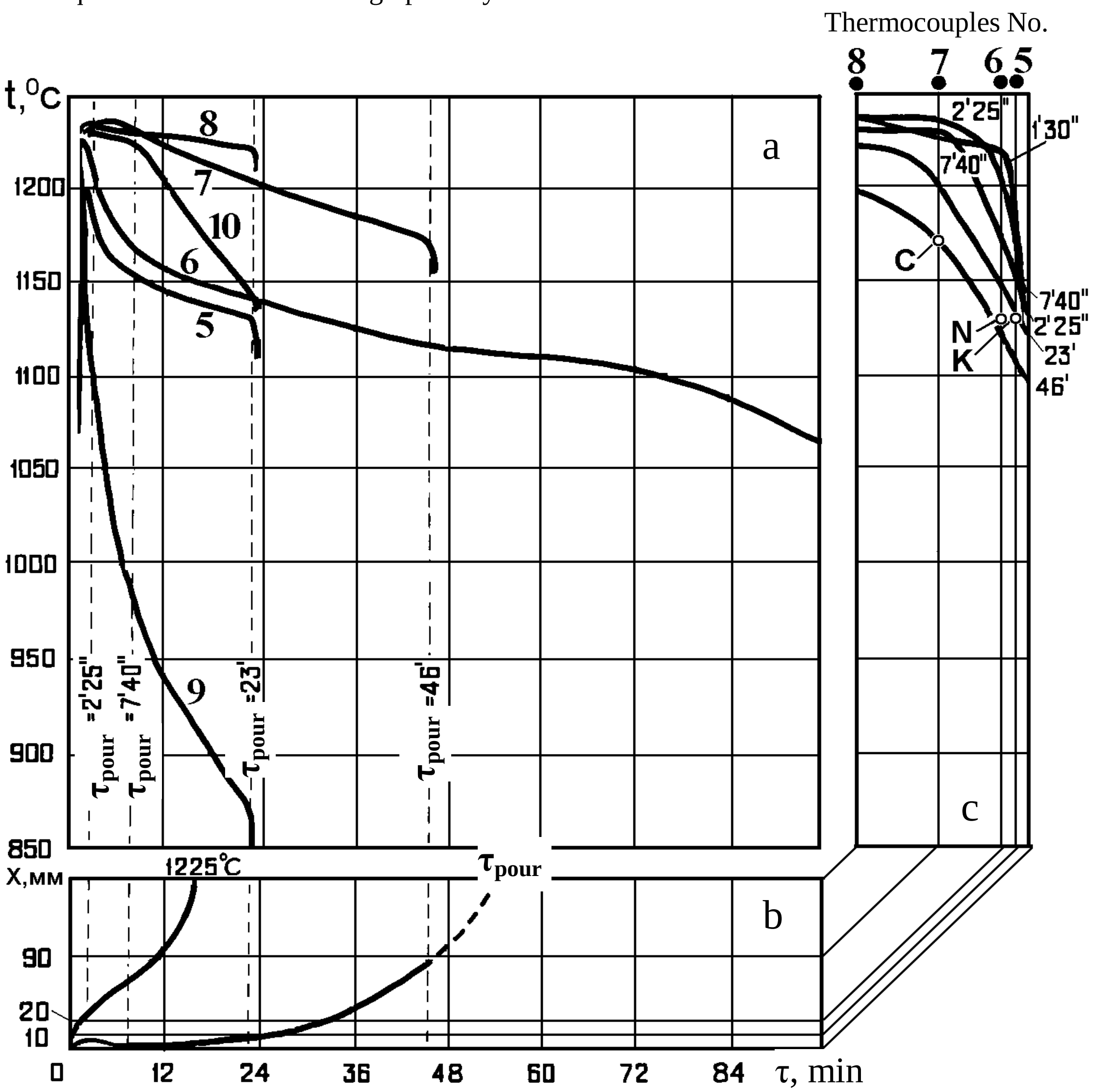

Figure 3. High-strength cast iron solidification in sandy-argillaceous molding box Ø 350 mm: *a* - experimental cooling curves 5, 6, 7, 8, 9, 10, obtained using thermocouples located at 10, 20, 90, 175, 1, 60 mm from the molding box surface, respectively; *b* - kinetic solidification curve with isothermal 1225 °C and pouring boundary line τ_{pour}; *c* - temperature pattern of cast with radius of 175 mm with isochrones 1 min 30 s; 2 min 25 s; 7 min 40 s; 23 and 46 min

precipitation of certain amount of solid phase for each alloy type. It is possible to estimate the features of this process in a first approximation by pouring out the melt and temperature indication. So, graphical combination of experimental curve of melt pouring line (τ_{pour} in **Figure 3b**) with the cast temperature pattern helped define the temperature limit of melt pouring out - transition from liquid-solid to solid-liquid state (τ_{pour} in **Figure 3c**, dotted curve). For a part of the cast cooled in the metal mold the boundary line of melt pouring out varies in the range of temperatures 1230-1165 °C. And, the connection with kinetics of solidification front advance is obvious (τ_{pour} in **Figure 3b**): acceleration of solidification front advance near metal mold surface and in the axial zone of the cast caused temperature increase at which castability is equal to zero. So, at a depth of 10 mm pouring out is completed at ~1230 °C, at a depth of 90 mm - the temperature drops to ~1165 °C, and in the axial zone at a depth of 180 and 250 mm the temperature grows again to 1204-1208 °C.

When investigating high-strength cast iron solidification in sandy-argillaceous molding box Ø350 mm, thermocouples recorded also pouring time (**Figure 4a**).

Isothermal curve 1225 °C and pouring line τ_{pour} (**Figure 4b**) are illustrated on the kinetic solidification curve. And pouring line τ_{pour} records smelting of presolidified layer of cast-iron, slow formation of solid phase near molding box surface and the subsequent acceleration of solidification in the axial zone. Temperature limit of melt pouring out - transition from liquid – solid to solid-liquid

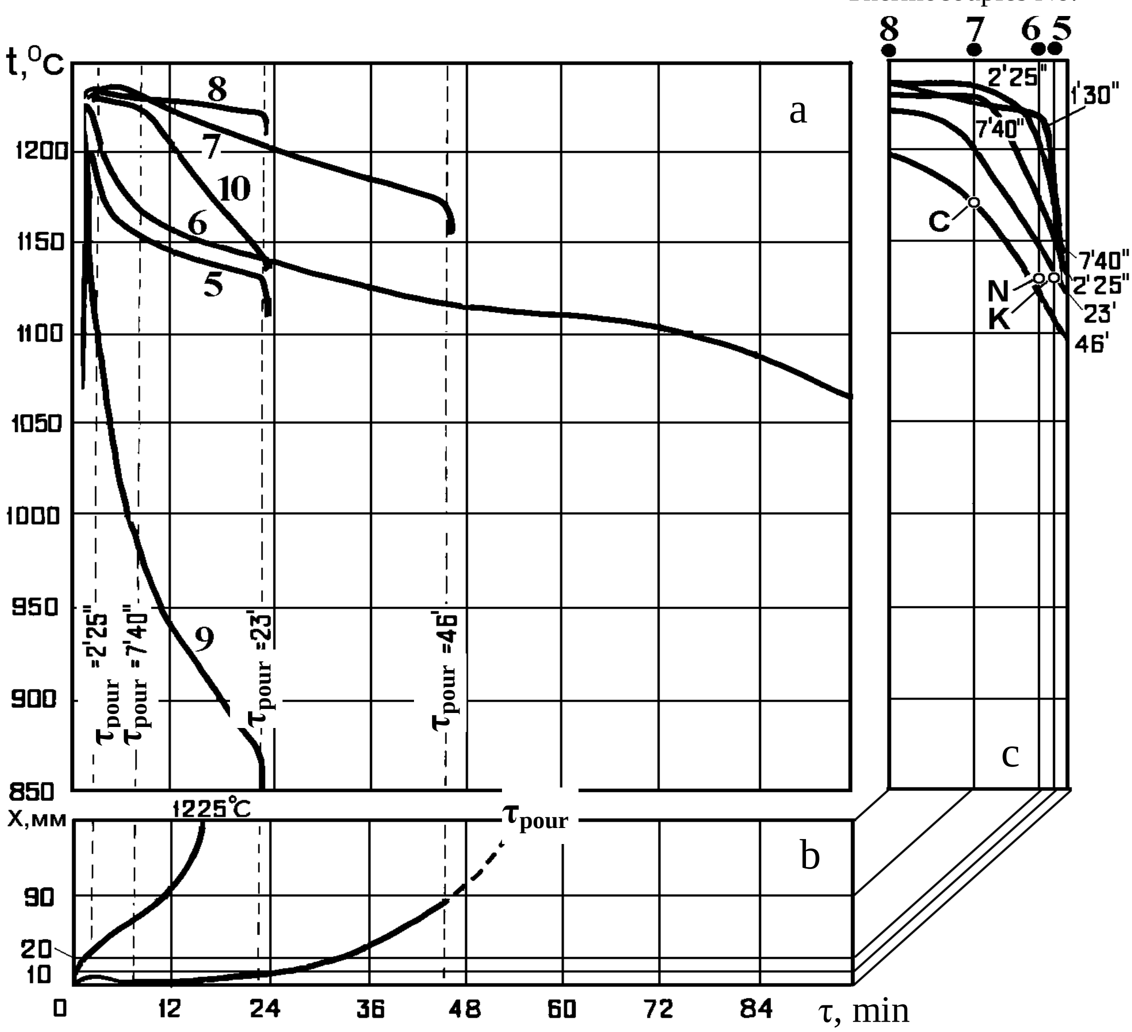

Figure 4. High-strength cast iron solidification in sandy-argillaceous molding box Ø 350 mm: *a* - experimental cooling curves 5, 6, 7, 8, 9, 10, obtained using thermocouples installed at 10, 20, 90, 175, 1, 60 mm from the molding box surface, respectively; *b* - kinetic solidification curve with isothermal 1225 °C and pouring out boundary line τ_{pour}; *c* - boundary line of melt pouring out on the temperature pattern (C, N, K) of the cast with radius of 175 mm with isochrones 1 min 30 s; 2 min 25 s; 7 min 40 s; 23 min and 46 min

state is defined on the temperature pattern of cast with the radius of 175 mm with isochrones 1 min 30 s, 2 min 25 s, 7 min 40 s, 23 min and 46 min by points K, N, C (**Figure 4c**). For a part of cast cooled in sandy-argillaceous molding box the temperature corresponding to boundary line of pouring is ~1135 °C at a depth of 10-20 mm. This temperature grows to ~1170 °C as the speed of pouring boundary line travel increases at a depth of 90 mm.

Conclusions

1. Experimental research defined the temperature and solidification time of high-strength cast-iron in the chill mold Ø500 mm in a radial direction. The features of isoliquidus frontal advance (τ_{ls} and τ_{le}) through-the-thickness of cast, isosolidus (τ_{ss} and τ_{se}), melt pouring out boundary lines (τ_{pour}) and crystallization end (τ_{ce} – precipitation of 100 % solid phase) are determined.

2. Isochrones of temperature pattern specify the subsequent character of solidification from chill mold surface to casting axial zone. Acceleration of solidification frontal advance at τ_{le}, τ_{ss}, τ_{se}, τ_{ce}, τ_{pour} to depth of ~90 mm is caused by closeness of heat-releasing surface, and further delay – by warming up of chill mold. Speed of solidification frontal advance grows again in the cast axial zone ~130-250 mm.

3. The temperature limit of pouring out the melt (t_{pour}) 1230-1165 °C (liquid –solid - solid - liquid transition) on the cast temperature field with radius of 250 mm is determined. Acceleration of solidification frontal advance near the chill mold surface and in the cast axial zone caused rise in temperature of pouring out. If at a depth of 10 mm at high cooling rate the pouring out border corresponds to ~1230 °C , at a depth of 90 mm at delay of speed of solidification frontal advance the temperature goes down to ~1165 °C. At a depth of 180 and 250 mm at increase of solidification frontal advance speed, the temperature of pouring out grows again to 1204-1208 °C in the axial zone.

4. Solidification kinetics and pouring out limit τ_{pour} which records melting of solidified earlier cast-iron layer, then slow formation of solid phase and the subsequent acceleration of solidification in the axial zone are established according to results of experimental research of high-strength cast-iron solidification in sandy-argillaceous form Ø 350 mm.

5. The temperature limit of melt pouring out for a part of casting with radius of 175 mm cooled in the sandy-argillaceous form is determined: at a depth of 10-20 mm the temperature corresponding to pouring out is ~1135 °C; with increase of solidification rate at depth of 90 mm the pouring out temperature increases to ~1170 °C.

6. Defined values of temperature of high-strength cast-iron transition from liquid-solid to solid-liquid state enable to determine the start of contraction cavity formation in the castings. Results of experimental research of cast-iron solidification time in sandy-argillaceous form and chill mold can be used as standards for adaptation of mathematical models of solidification process using software ProCast, AFSolid, etc.

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Температурные поля и границы выливания при затвердевании высокопрочного чугуна в комбинированной кокильно-песчаной литейной форме

Хрычиков В.Е., Меняйло Е.В.

Приведены результаты экспериментального исследования температуры и продолжительности затвердевания высокопрочного чугуна в 4-х литейных формах, состоящих из кокиля и песчано-глинистой формы. Установлены особенности продвижения фронта затвердевания и температурная граница выливания расплава по толщине отливок.