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Determination of Feederless Casting Limits by Thermal Analysis in Cast Iron

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In this study the determinations of melt quality was carried out by thermal analysis of ductile iron. The aim of the study was to determine the limits of feederless casting after the determination of inoculation quality in cast iron. Production method of pouring into a sand mold in the entirety and without using feeder systems has been investigated. Forms of the solidification and volume change have been investigated with simulation program as functions of inoculation quality, type of resin in the mold and mold rigidity. Results of the analysis have been compared with the results of experimental iron casting.

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1. Introduction

Ductile cast irons are formed of two phases, which are graphite nodules and surrounding matrix. The matrix phase can be ferritic, pearlitic, martensitic or a combination of these phases. During solidification, the matrix phase shrinks, whereas the carbon phase expands due to the density difference between the soluted in melt and free forms [1, 2]. Thus, the process of solidification of cast iron is complex and is different from those of steel and aluminum, due to simultaneous shrinking and expanding behavior [3]. The plot of temperature dependence of iron density is shown Fig. 1a.

The graphite expansion can compensate the total shrinkage of melt. Thus, the feederless casting is possible without macro shrinkage. However, this is not enough to have a sound casting with feederless design. The binder of mold sand is also important for the geometrical stability of mold cavity against the expanding casting. If the mold does not have enough rigidity, the cavity of the mold increases and shrinking-expanding balance fails. The mold design has a vital importance for required cooling of the fed metal between the casting and the solidus temperatures. Bottle type feeder or the runner can fulfill this requirement. In order to provide feeding, the ingate has to have enough thickness. Another issue of the design, is the location of hot spots. If the last solidified spots are near the surface, the suck-in defect occurs on the outer casting surface. The eutectic and hypereutectic compositions are weaker, because a very thin solid wall occurs on mold surface during the solidification. The pouring temperature also affects the shrinkage volume due to increase of difference between the volumes of melt and of solidified metal. Thus, the pouring temperature must be as low as possible.

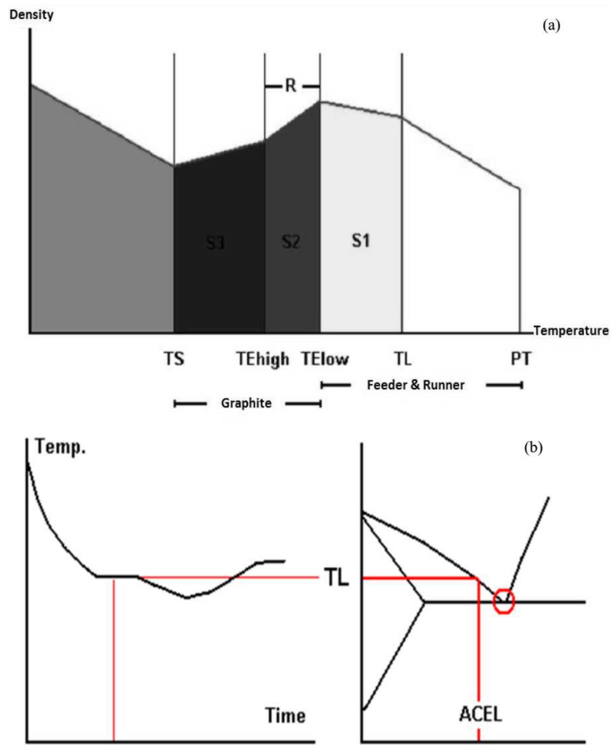

Fig. 1. The dependence of density of iron on temperature (a) and finding of active carbon equivalent from the from cooling curve (b).

Finally, the inoculation quality, which is the subject of this study, is the most important parameter. In the experimental study adaptive thermal analysis system (ATAS) was used for investigation of the effects of inoculations versus time and of the pouring temperature on shrinkage formation. With ATAS, the active carbon equivalent can be determined.

The spectral analysis can detect carbon in both, free and compound form. However by the analyses of cooling curve, the active carbon equivalent can be found with

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higher accuracy (Fig. 1b). In literature there are studies that include the effect of the amount of inoculants on cooling curve and the eutectic cell size of a specimen in the sand mold, the isolated mold and the chilled mold. Results show that with the increase of inoculants the number of cells also increases. Thus, the increase on the minimum recoalesence temperature has been reported [4].

2. Materials and equipment

In the experimental study the thermal analysis system was used for the determination of the fading of inoculation effect with time for the iron melt, composition of which is given in Table I. From thermal analyses data, the shrinkage and the expansion parameters were calculated and the limits of feederless casting were examined. The test specimen was a cylindrical block with the diameter of 150 mm and height of 210 mm (Fig. 2). For such block a minimum 2.5 cm thickness of sand mold on both sides is recommended for the required rigidity. As binder for the silica sand mold, appropriate amounts of Alphaset resin were used. The inoculation was applied in 300 kg ladle (Fig. 2). For 300 kg melt, 3.4 kg of noduliser were applied in the ladle with pocket and 900 g of inoculants were applied while transferring the melt to the casting ladle. The chemical composition of cast iron is given in Table I and the chemical composition of noduliser and inoculants are given in Table II, respectively.

TABLE I

Chemical composition of iron.

C	Si	Mn	Mg	P	Ce
3.6	2.3	0.05	0.04	0.05	0.028

TABLE II

Composition of noduliser and inoculants.

	Si	Ca	Mg	Al	RE	Ba
Noduliser	47.5	1.65	5.74	0.79	0.87	-
Inoculants	73.8	1.61	-	1.24	-	2.51

Thermal analyses have have been done using the standard analysis cup made of shell sand. The first analysis has been made after nodularization but before the inoculation and the rest of analyses were carried out after inoculation and after the time intervals of 1 minute and 15 seconds. The test specimen was cast 3 min 45 s after the inoculation. Figure 3 shows the cooling curves, which were obtained using the thermal analysis system; (a) before inoculation, (b) after innoculation, (c–e) and f are the cooling curves which are taken from every 75 seconds after innoculation.

Figure 3d shows the analysis of the sample taken right before the specimen part casting. On the thermal analyses cooling curve (Fig. 4), in the S1 region, the primary austenite crystals have formed. For the minimum macro

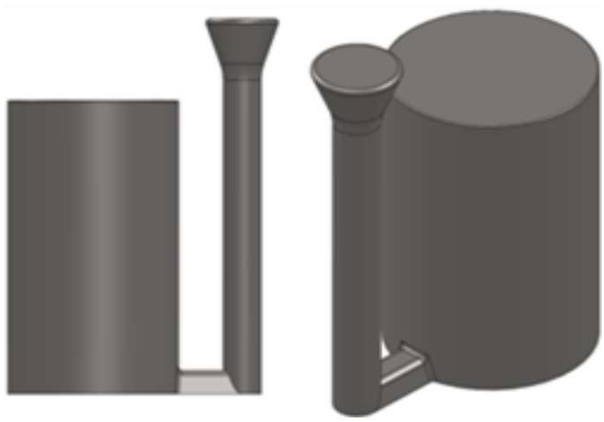

Fig. 2. Test specimen and casting system.

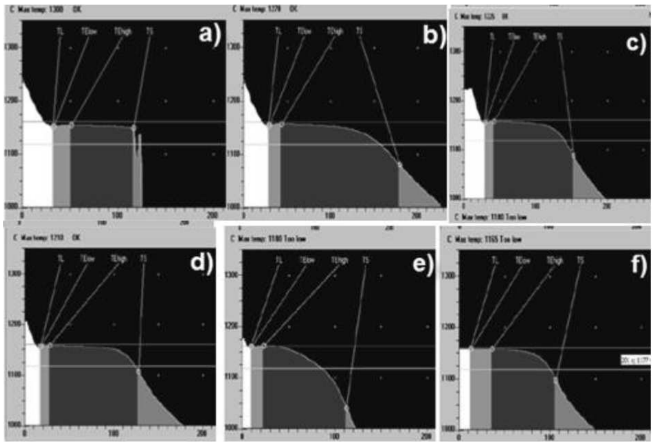

Fig. 3. The cooling curves of (a) uninoculated sample and (b–f) samples taken in 1 min and 15 s intervals.

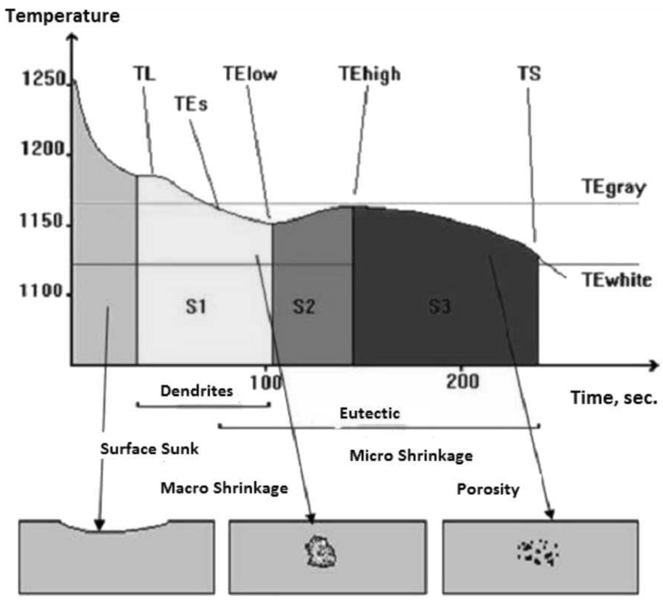

Fig. 4. The parameters determined from the cooling curve and from shrinkage formation.

shrinkage, the S1 region has to be as small, as possible. In S2 and S3 regions the graphite precipitation occurs. S2 and S3 regions have to be large in order to prevent macro shrinkage. The meaning of this, is that the solidification has to be eutectic. It is very easy to see that S2 and S3 regions are large for both curves. Figure 5 shows the derivative of the cooling curve (Fig. 5a) and the volume change from melt phase to austenite phase per unit time (Fig. 5b).

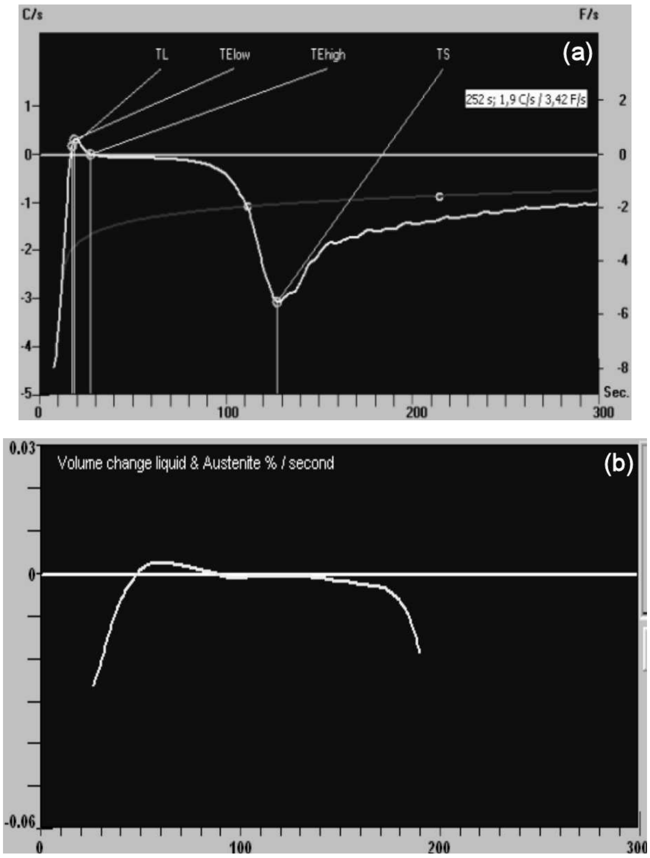

Fig. 5. The derivative of the cooling curve and the volume change from melt phase to austenite phase, per unit time.

The ATAS thermal analyses system can calculate the free graphite and shrinkage-expansion percents, related to pouring temperature, from the active carbon equivalent. For the analyzed curve, between 1210 °C–1149 °C there is 1.3% of shrinkage, at 1149 °C, 0.1% and from 1149 °C to 1132 °C, 6.9% of expansion was determined. Based on these values, 1.2% of shrinkage was calculated for minimum feeding (Fig. 6). Simulation using Nova Flow & Solid simulation database, calibrated with these parameters was carried out. In simulation results, the thermal modulus was determined to be 2.5 cm and shrinkage was at the top of the casting part. In same conditions in order to have a sound casting without feeder, the casting has to be fed from runner system. A thin ingot solidifies early and blocks the feeding. But a thicker ingot can feed the casting due to its longer solidification time. In Fig. 7 the simulation result of casting with thicker ingot using calibrated database is shown. The shrinkage is seen only in runner. Before the total liquid phase 80.7%, the runner system feeds the casting. After this point, the graphite expansion is enough to fulfill the shrinkage totally.

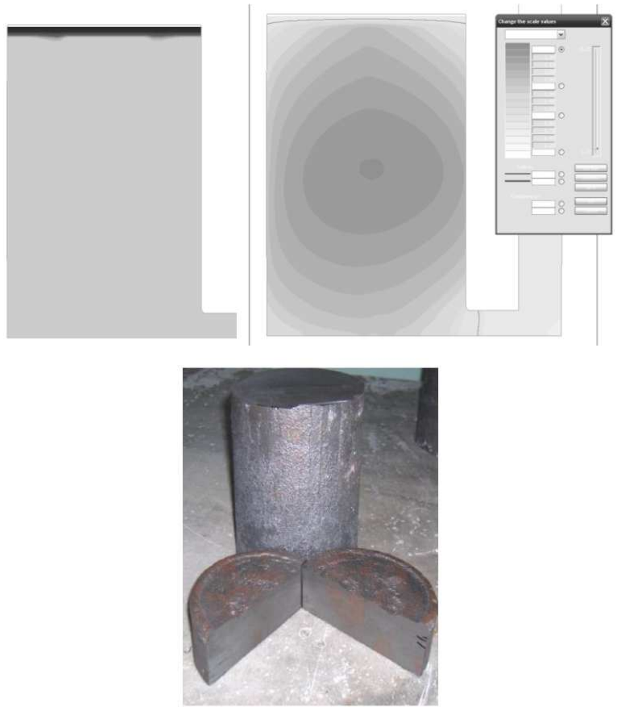

Fig. 6. The shrinkage, thermal modulus views from simulation and from the sample casting.

Fig. 7. The feeding from runner system.

3. Results and discussion

The iron can be cast using feederless design due to the graphite expansion. The shrinkage and the expansion of iron melt can be determined using thermal analyses. If the molding and design requirements are accomplished and with the stable inoculation conditions, the melt feeding from runner system is also possible. The use of thermal analyses in research and development studies provides benefits for foundry practice. The reduction of scrap rate due to more efficient casting method causes economical and environmental benefits. The calibration of simulation database using thermal analyses reduces the cost of trial-error and prototype control time losses. If the calibration is applied in foundry conditions, the simulations becomes a very efficient engineering tool.

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