ISSN 1392–1320 MATERIALS SCIENCE (MEDŽIAGOTYRA). Vol. 9, No. 3. 2003

The Risk of Ductile Iron Post-inoculation for Heavy Section Castings

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Received 10 September 2002; accepted 10 October 2002

The post–inoculation realised during the cast iron casting, is known as the one of techniques the most often used in the foundry. The aim of this operation for the cast iron with nodular graphite is the control of structure formation, including nodular graphite, and the prolongation of Mg advantageous action during the spheroidisation disappearance effect. The influence of post–inoculation on the decreasing of undercooling level during solidification and the counteraction the metastable crystallisation as well as counteraction the formation of primary carbides is known.

The hardness, mechanical strength, elongation, machinability of ductile iron is affected by the structure components such us perlite, carbides, count and shape of graphite nodules.

Keywords: ductile iron, castings, nodule graphite, post-inoculation.

1. INTRODUCTION

It is widely known, that according to the information referring to the theory and practice of iron casting, it is considered that there is a necessity to apply this operation because of the evident benefits. Especially the operation of so-called post inoculation is, among other things, an efficient way to restore the ability of graphite nodule crystallisation. Does this influence, examined for the case of thin wall castings, show any similarity to the same operation in thick wall castings? This question is not a rhetorical one. It appeared that the answer of the structure does not meet our expectations.

It's known that the chunky graphite cell as deteriorates nodule graphite is bigger than other types of graphite cells. Chunky graphite is complicatedly interconnected and frequently branched in the cell [1, 2]. The trace of dendrite arm is also observed in the cell. Next to spherical graphite nodules there exists a small–dispersion graphite phase, with cracked surface that makes the mechanical and utilitarian properties of cast ductile iron worse.

It has been observed, that in the structure of heavy – section ferritic ductile iron castings (the thickness of walls from 75 – periodically, and over 100 mm – permanently), executed even in chemically bonded sand mould, in their central regions chunky graphite appears.

If the casting wall is getting thicker, the probability of the graphite degenerated and chunky graphite presence is also growing. It takes place in the thermal centre regions of castings. There are several theories of formation of chunky graphite [2, 3]:

- local destruction of primary formed regular spherical eutectic cells by around residual liquid,
- destruction due by high internal stresses,
- branching and increase of fine graphite caused by the presence and segregation of calcium (Ca) – decrease of surface energy liquid – graphite.

According to literature and practical knowledge the causes of such a state of affairs are mainly:

- low temperature gradient,
- presence of mishmetal and cerium,
- high purity of liquid alloy,
- too high magnesium content,
- insufficient inoculation**.**

Because of the last point, the correction is being advised: ”optimal inoculation in order to obtain high density of nodules/mm cube, best by post inoculation”. The observations; made by author; caused that this advise will be the subject of research described in this article.

2. EXPERIMENTAL PROCEDURES

Controlling the quality of thick wall casting, it has been noted that the presence of chunky graphite in the structure can be connected not only with the thickness of the wall casting, cooling capacity of mould material, and pouring temperature, but also with applying the inoculation [4].

The aim of the research was the estimation of efficiency of post inoculation in application to castings from nodular cast iron (ductile iron) 400-15 with thickness from 25 to 150 mm.

Elaboration of the research methodology included the choice of post inoculation methods, kind and quantity of inoculants, the manner of placing, geometry and quantity of test castings in the mould, choice of gating system.

Cast iron was melted in an induction furnace, 50 Hz frequency, from following charge: liquid metal – 2000 kg from special pig iron L-S, special pig iron L-S – 1300 kg, scrap steel – 200 kg, ferrosilicium – 30 kg. Pig iron made 88 % of charge. Maximum temperature in the furnace was 1546 °C, temperature of ladle pouring – 1496 °C and mould pouring temperature – 1327 °C.

For magnesium treatment there was used 54 m of core wire, for 2 tones of cast iron in the ladle. Parameters of core wire: FeSiMg powder with average weight 241 g/m, Mg – 25 %; Si – 35 %; Tr – 5.9 %; rest Fe.

The inoculation was also accomplished by core wire method. Length of FeSi75 wire – 40 m, average weight – 307 g/m, well inoculation 0.15 %.

Chemical composition after magnesium treatment and primary inoculation is shown in Table 1.

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Table 1. Composition of poured ductile cast iron

C	Si	Mn	P	S	Cr	Cu	V	Mo	Ni	Ti
3.65	2.73	0.173	0.041	0.008	0.016	0.017	0.005	0.003	0.010	0.018

Al.	Co	Sn	As	Pb	B	Bi	Mg	Te	CE	SC
0.0052	0.0019	0.0033	0.0026	–	–	0.0019	0.051	0.0008	4.35	1.07

The draft of the mould contained 3 cavities is shown in Fig. 1.

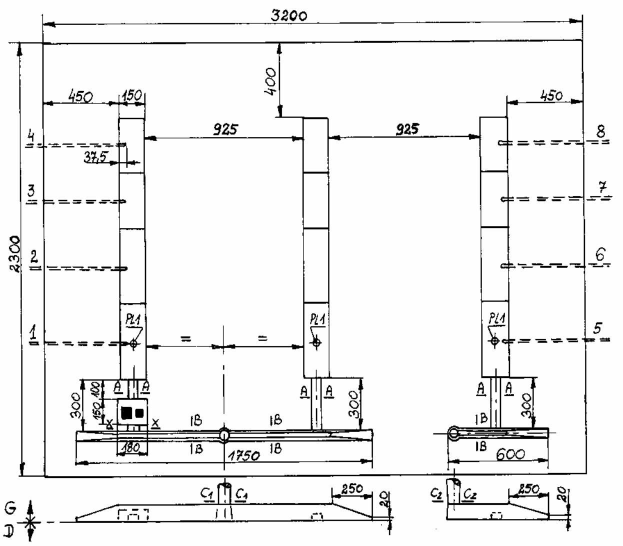


Fig. 1. Step–plate casting and gating system design. Down sprue inoculation by means of A product (left), inoculation by means of B product (center), without inoculation (right). 1 – 8 positions of thermocouples

The gating system consists of the reaction chamber chamber, in which the inoculant A has been placed (in the form of ingots 0.5 and 0.3 kg). Inoculant B has been introduced to the neighbouring niche in the loose form, with granularity of 0.2 – 0.7 mm, in the amount of 0.6 kg by pouring basin.

Chemical composition of A inoculant: 2.5 – 4.5 % Al, 0.3 – 1.5 % Ca, 70 – 78 % Si, rest Fe. Chemical composition of B inoculant: 1 – 1.5 % Al, 1.3 – 1.8 % Zr, 2 – 2.5 % Ca, 72 – 78 % Si.

Mould has been produced from furan sand: quartz sand 100 %, furan resin 1 %, and hardening acid agent 0.4 %.

The thermocouples PtRh-Pt and NiCr-Ni were placed in the ceramic tubes.

Cast iron with temperature 1327 °C was cast into a form with tilting ladle.

With the use of PC data acquisition recorder, the registration of the cooling curves in the castings was executed. After the trial castings had been cooled, there was some tests on their compactness, their structure and mechanical properties (X-ray examination, penetrative, durability and metalographical inspections).

The results of subsequently executed simulation experiments (computer modelling) of processes: pouring and solidification have been compared with the results of experiments.

3. RESULTS AND ANALYSIS

Registered cooling curves for every step–plates have been shown at the Fig. 2. Analysing first derivatives of those curves, it has been assumed that their minima allow to determine the times of solidification. Those times have been used for the energetic validation of a model, applied for the description of filling and solidification. In order to achieve this aim, some computer simulations of the process have been executed, and the set of thermo physical parameters giving the best approximation of the real solidification time for each step, has been determined

At the Fig. 2 the chart of cooling curves coming from experiments and simulated calculations for the central points of chosen steps have been compared. In the table 2 the times of solidification set in the described way in those places have been listed.

Table 2. Experimental and simulated values of solidification time for 4 centre points of step-plate casting

Thermocouple number	Wall thickness [mm]	Solidification time	
		Experiment	Simulation
T5	150	144 min	150 min (70 min)*
T6	75	46 min	50 min
T7	50	30 min	28 min
T8	25	7.5 min	8 min

*calculated solidification time for sample No 8 (Fig. 3)

Comparison of those values shows satisfactory compatibility. It can be assumed, that local times of solidification calculated only with the simulation methods as far as map of other thermal parameters as temperature gradient (*G*), cooling rate (*R*), temperature profiles, in the casting volume correspond to reality.

Virtual prediction on the basis of the presence of shrinkage defects is more likely, although algorithm of definition of their location and intensity depends on creators of simulation codes.

They suggest furthermore, that on the basis of calculated thermal results; the parameters of cast iron structure (participation of phases: pearlite, ferrite, ...) can be also predicted. In the similar way, the mechanical properties (min. *Rm* – tensile strength, *Re* – yield limit, *A5* – elongation) can be estimated. This estimation proceeds on the basis of empirical rules of type *Rm*, *Re*, *A5* = *f*(*G*, *R*).

Their usefulness depends not only on calculated *G* and *R* values, but also on derivation of those dependences. The appearance of the chunky graphite in the structure is not enclosed in these type of procedures, so the estimated properties depart considerably from the real values.

In order to examine that problem and estimate the influence of post inoculation at the structure and mechanical properties from made step–plate casting at the same time, the samples have been cut (look Fig. 3) and subject to tests.

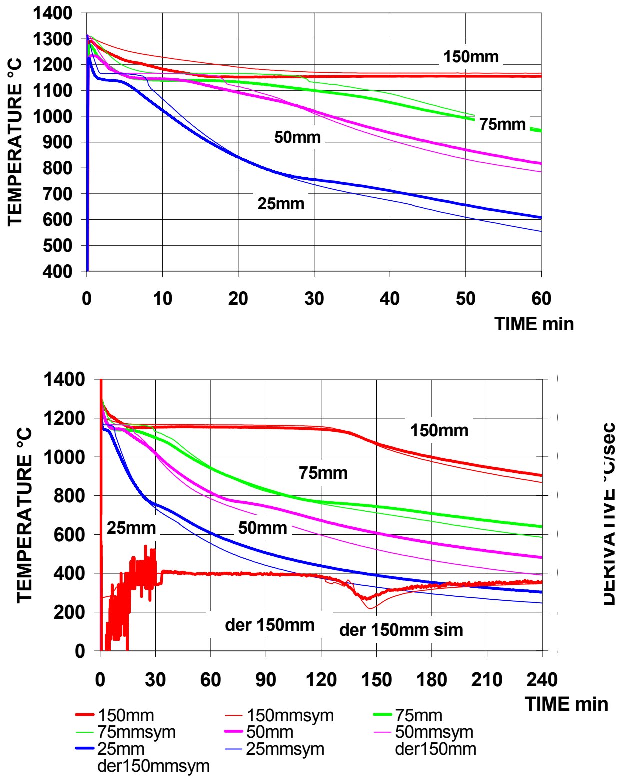


Fig. 2. Cooling curves in the 4 centre points of step-plate casting (examples of first derivatives are presented)

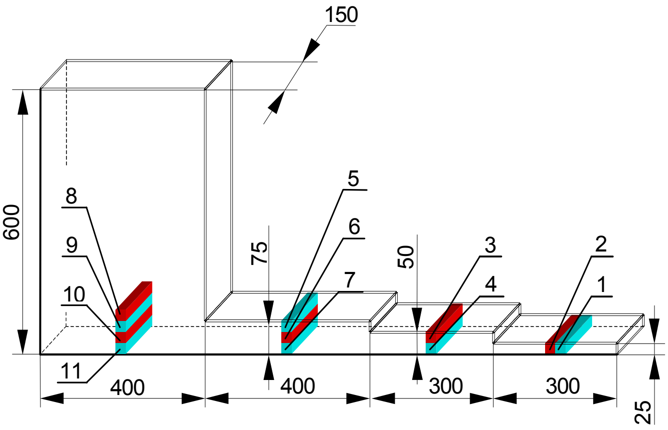
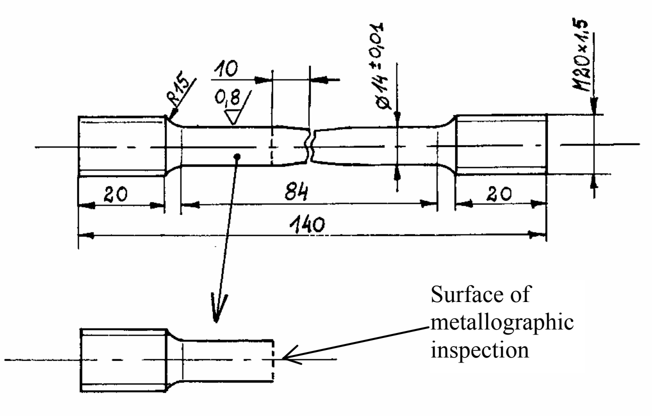


Fig. 3. Schema of the step–plate casting and location of strength tests

The place of metallographic examinations at this sample is shown at the Fig. 4. The results of metallographic study are shown on the Fig. 5. Mechanical tests results are shown on the Fig. 6.

Considering every step–plate casting; following regularity in the structure; can be observed. Together with the increase of thickness of walls from 25 to 150 mm with the increase of casting modulus, the number of nodules is decreasing and their size is growing. For the wall thickness of 25 mm the number of graphite nodules is the biggest, and of the smallest sizes. It has the crucial influence at the mechanical properties that are shown among other things at the Fig. 6.



Surface of metallographic inspection

Fig. 4. Position of metallographic specimen in the mechanical test sample section

Comparing the structure of those 3 steps having the same thickness of walls, one can observe, that adding the inoculant A or B has caused the size decreasing and number increasing of nodules, but simultaneously the degenerated chunky graphite appears in the structure, of which the biggest amount occurs in the cast with the wall of 150 mm.

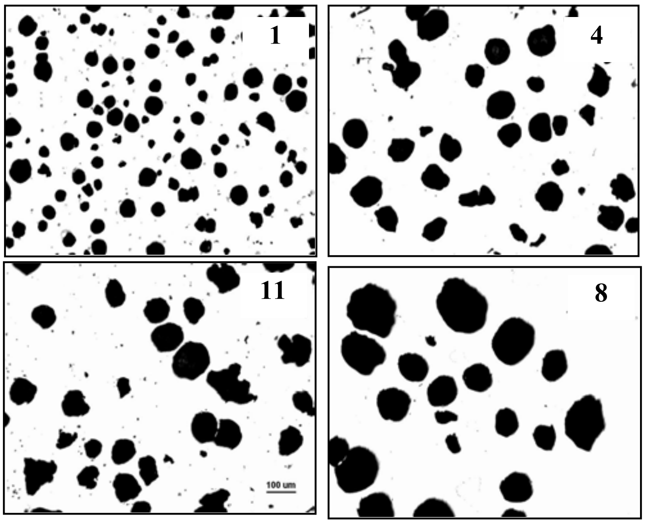
In the case of lack of post inoculation, we deal with big nodules (1.5 – 2 times bigger), but actually in the cast regions that are being analysed, the degenerated chunky graphite has not been observed.

Transferring it to the mechanical properties, above mentioned observations have been confirmed by higher plastic properties for the thickness of walls 25 and 50 mm using post inoculant A or B ($A5$ = 15 – 20 %).

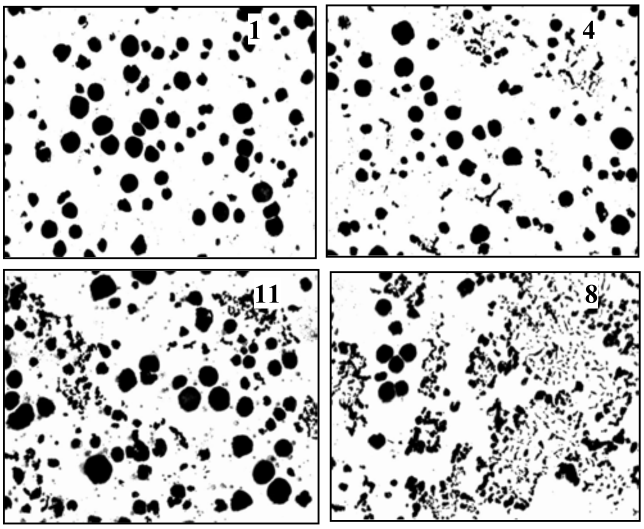
By this thickness of walls degenerated graphite has also appeared, but its number was not essential. That is why those properties are higher than those for the step without post modification, where $A5$ = 12 – 14 %.

Next, for the thickness of walls 75 and 150 mm the casting, in which the post inoculation has not been applied, owes strongly higher plastic properties and it has bigger nodules in its structure. Big amount of degenerated graphite (over 50 % of surface of metallographic specimen), for the thickness of walls 150 mm) which appears in the structure of post inoculated cast iron causes the decrease of tensile strength (in walls 150 mm to the value approximately 350 MPa (and $A5 < 5$ %), where in case of lack of post modification the values Rm are approximately 420 MPa (and $A5 > 10$ %).

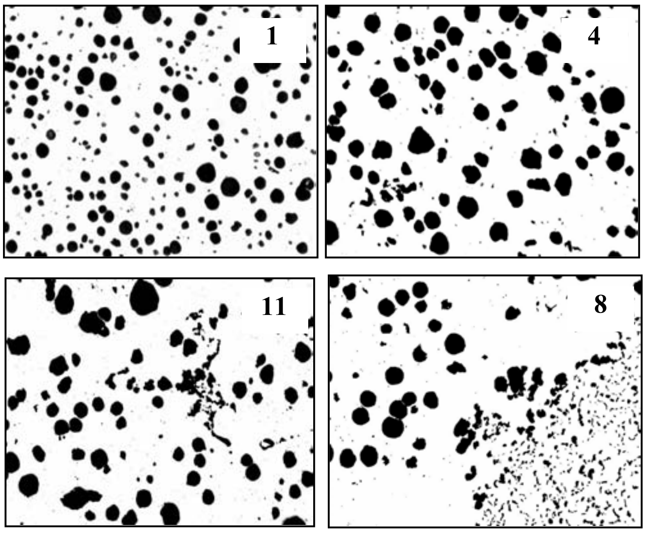
To sum up, the presence of degenerated graphite (chunky) in examined cast regions, caused by adding the inoculant A or B has decreased significantly the ductility and tensile strength of cast iron, by the section of cast wall with the thickness of 150 mm (long time of solidification). Those inoculants improved the plastic properties for the thick walls, where the time of solidification was considerably shorter.



WITHOUT INOC 200 µm



INOC A 200 µm



INOC B 200 µm

Fig. 5. Comparison of microstructure (graphite distribution) for 3 post inoculation cases (without post inoculation, with inoculant A, with inoculant B). 1, 4, 11 and 8 – number of chosen sample (Fig. 4)

4. CONCLUSIONS

In examined thick – walls – castings from the ductile cast iron 400–15 and in the terms of its fusion and metallurgical treatment, our previous observations about good influence of crystallisation nuclei coming from inoculants A or B for creation of chunky graphite have been confirmed. It is a new, precious observation that can be put in opposition to uncritical promotion of using the inoculant for such cases of casting. The aim of that work was not yet conducting of a proof of hypothesis regarding the mechanism of destruction of properly developing eutectic cell, which in the first period of solidification can have properly developed nodule and undergo kind of "explosion".

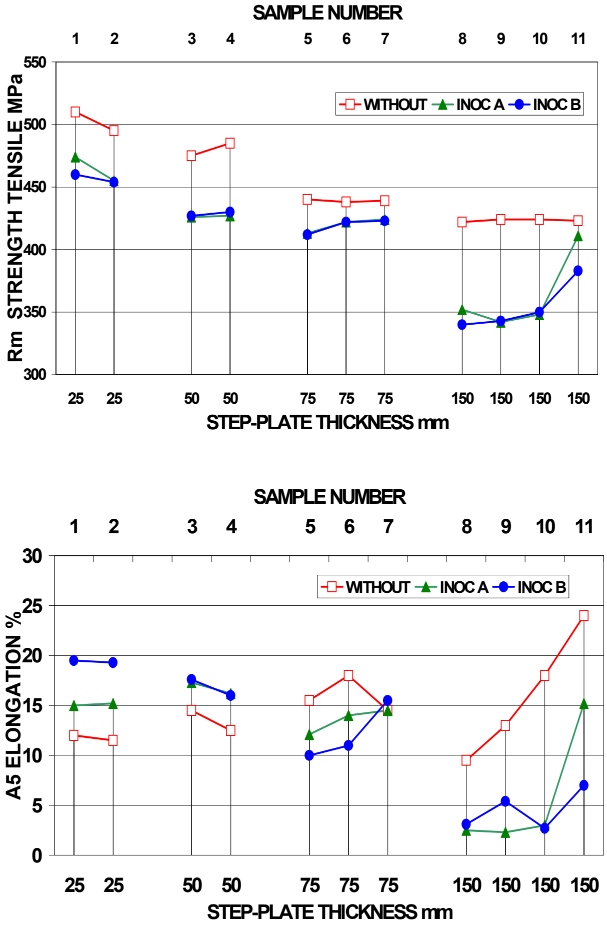


Fig. 6. Mechanical properties (*Rm* and *A5*) for 11 samples cut from step–plate casting

Another, probable mechanism lies in that chunky graphite starts to form at austenite–residual melt, liquid Mg–residual melt, and inclusion–residual melt interface, or among all of them [1]. However these give only initial site for the chunky graphite nucleation. After the nucleation, austenite shell have the key to form chunky graphite.

At the example of our research it has only been proved, that artificial nuclei inserted together with inoculant (A or B), have short life time (durability in time) and determine the efficacy crystallisation centres for initialisation of growth of proper spherical graphite and eutectic cells only in walls with the restricted thickness (solidification time). Moreover, the presence of those artificial nuclei does not allow activating natural nuclei properly, left after fusion process. It should be tend in the first place towards restriction of time of solidification and first than use adequate the inoculation or/and post inoculation method.

Described anomalies are not yet possible to predict with the use of empirical formula of structure prevision used in simulation codes. The only way, which is given, is the validation of thermal model, (essential condition) and calculation of the correct value of local solidification time every wall sections [5]. For foundry technology project, only this time limitation permits to prepare the appropriate technological study of casting. For the post–inoculants studied in this work the risk of structure degeneration is high from 75 mm of thickness. Only the use of chill system, adequately calculated (e.g. by computer simulation codes), and with application of correct physical data base for thermal simulation models can to guarantee the proper nodular structure and properties of ductile iron heavy section castings [6].

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Paper presented at the XI International Baltic Conference
"Materials Engineering & Tribology - 2002",
November 14 - 15, 2002, Kaunas, Lithuania