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

ARCHIVES of FOUNDRY ENGINEERING

DE GRUYTER OPEN

DOI: 10.1515/afe-2017-0043

ISSN (2299-2944)
Volume 17
Issue 2/2017

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

15 – 20

Influence of Boron on Crystallization and Microstructure of Ductile Cast Iron

R. Dojka *, A. Studnicki
Department of Foundry, Silesian University of Technology , Towarowa 7, 44-100 Gliwice, Poland
*Corresponding author. E-mail address: rafal.dojka@polsl.pl

Received 05.09.2016; accepted in revised form 11.05.2017

Abstract

The objective of the research was to determine the influence of boron on the crystallization process and microstructure of ductile cast iron. In the case of ductile cast iron it is a vital issue because even as little as trace presence of boron changes the properties of ductile cast iron in a significant way. With the use of a new ATD-4 (TDA) tester and CRYSTALDIGRPAH converter it was possible to measure the crystallization process parameters of the same alloy with four different contents of boron in one mould. Four samples with different boron contents were extracted, their microhardness was measured and quantitative analysis of microstructure was conducted. Obtained results allowed to state that with increasing content of boron the amount of graphite precipitates decreases, the amount of pearlite precipitates increases, the shape of graphite precipitates deteriorates and hardness increases. It is also planned to perform additional testings with boron contents between previously tested values.

Keywords: Solidification process, Metallography, Ductile cast iron, Boron, TDA

1. Introduction

It is undeniable that ductile cast iron is still an alloy with great potential to grow what is visible in the domestic and world foundry industry. Nevertheless, the development level is so high that to accomplish new goals and push the scientific knowledge further the basic research is still indispensable even to analyse basic problems such as the alloy chemical composition. That is why this research focused on the influence of boron in the ductile cast iron as this phenomenon is not fully tested throughout and it is a problematic issue for many foundries. It was proved proven that B addition affects the crystallization process as it increases the effect of overcooling and it decreases the difference between liquidus and solidus temperatures [1,2]. Increase of B content results in increase of alloys hardness [3], it decreases tensile strength [4-6] and improves alloys wear resistance [7].

The motivation to deal with this topic came from industrial area where very small, almost unnoticeable contents of B resulted in significant change in properties of ductile cast iron. In that foundry charge materials often contain high strength steels, scrap from automobile industry, which might contain B additions and be the source of the problem.

2. Methodology of studies

In order to analyse crystallization process of four samples with four different contents of B without the necessity of using four different moulds new ATD-4 tester for the TDA was designed. New tester consists of a downsprue connected with four mould cavities by four running gates. In each running gate a portion of FeB was placed so the molten metal flowing through the running gates would take it to the mould cavity in which thermocouples were placed. Method used in ATD-4 tester is analogical to the in-mould spheroidization method. After the filling four cylindrical samples with ø 30 mm and 95 mm high were obtained. Figure 1 shows the test stand with ATD-4 tester.

Experimental melt was executed in medium frequency induction furnace with capacity of 25kg. Obtained samples were examined with the use of metallographic microscope, SEM, their microhardness was measured and quantitative analysis of microstructure was conducted.

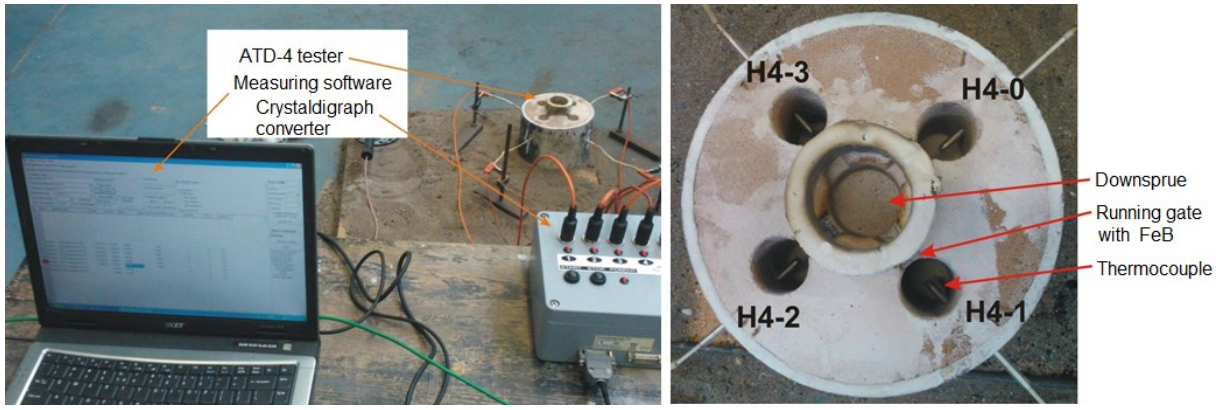

Fig. 1. Test stand with ATD-4 tester

3. Research results

3.1. Chemical composition

Table 1 presents the chemical composition of analysed ductile cast iron, table 2 shows the B content in each sample.

Table 1.
Chemical composition of examined ductile cast iron, % wt.

C	Mn	Si	Cr
3,87	0,424	1,76	0,026
Ti	**Nb**	**V**	**Zr**
0,006	0,028	0,008	0,002
Ni	**Mo**	**Cu**	**Al**
0,035	0,002	0,019	0,012
W	**Mg**	**P**	**S**
0,005	0,051	0,017	0,002

Table 2.
B content in each sample, % wt.

No	H4-0	H4-1	H4-2	H4-3
B	<0,00005	0,00088	0,00182	0,01231

3.2. Crystallization analysis

Analysis of temperature (T=f(t)) and crystallization (T'=dT/dt) curves shown on figures 2-5 obtained with the use of TDA method allowed to designate characteristic temperatures and times of ductile cast iron crystallization process shown in table 3. Table 4 shows eutectic recalescence (ΔT_R), and overcooling (ΔT) of examined samples.

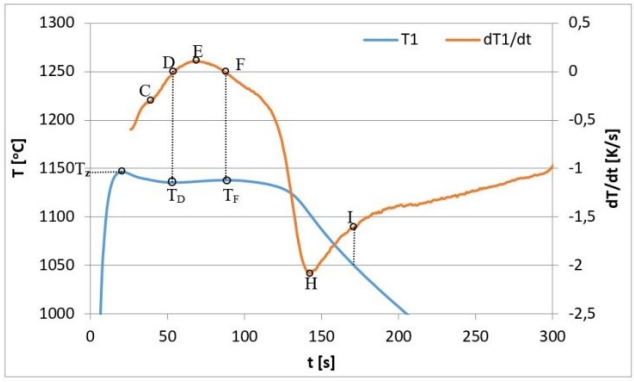

Fig. 2. TDA curves of H4-0 sample

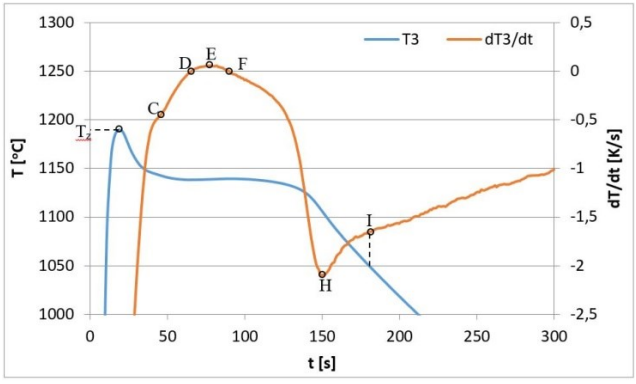

Fig. 3. TDA curves of H4-1 sample

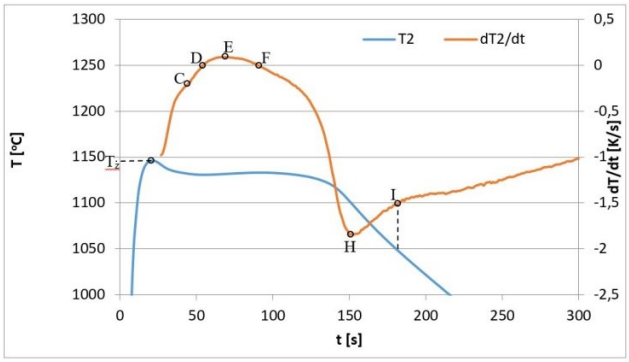

Fig. 4. TDA curves of H4-2 sample

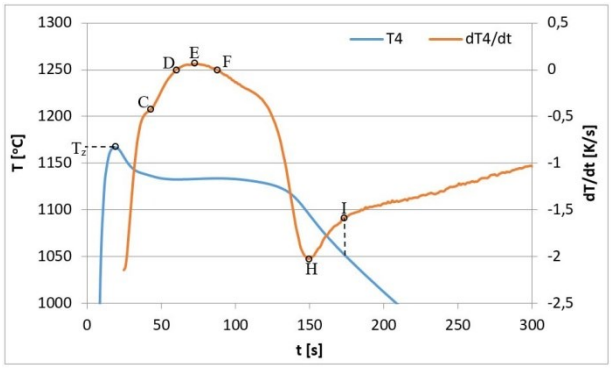

Fig. 5. TDA curves of H4-3 sample

Table 3.
Characteristic temperatures and times of ductile cast iron crystallization process

No.	T_z	C			D			E		
		T_C	t_C	K_C	T_D	t_D	K_D	T_E	t_E	K_E
	°C	°C	s	K/s	°C	s	K/s	°C	s	K/s
H4-0	1146,5	1138,2	39	-0,303	1135,5	55	0	1136,5	69	0,110
H4-1	1146,2	1131,6	46	-0,182	1130,7	54	0	1131,6	68	0,090
H4-2	1189,8	1142,4	47	-0,425	1138,6	67	0	1138,9	76	0,059
H4-3	1167,1	1136,3	44	-0,413	1132,7	61	0	1133,2	72	0,058

No.	F			H			I		
	T_F	t_F	K_F	T_H	t_H	K_H	T_I	t_I	K_I
	°C	S	K/s	°C	s	K/s	°C	s	K/s
H4-0	1137,9	87	0	1099,8	144	-2,063	1050	173	-1,594
H4-1	1133,2	90	0	1092,9	155	-1,833	1050	181	-1,512
H4-2	1139,6	90	0	1104,5	151	-2,090	1050	182	-1,646
H4-3	1133,9	88	0	1095,0	150	-2,023	1050	176	-1,568

Where characteristic point of the crystallization process determine:
T_Z - maximal temperature of liquid metal,
C - change of cooling intensity,
D – equilibrium in terms of heat emanation to the environment in the first stage of eutectic crystallization in temperature of metastable eutectic crystallization,
E – maximal heat effect of eutectic crystallization,
F - equilibrium in terms of heat emanation to the environment in the second stage of eutectic crystallization in temperature of stable eutectic crystallization,
H - end of primary crystallization,
I - characteristic solid state (temperature 1050°C).

Table 4.
ΔT_R and ΔT (T_{Cr} , T_{Er}) of examined samples

No.	B, % wt	Eutectic recalescence	T_{Cr}	T_{Er}
H4-0	<0,00005	2,4	32,51	25,00
H4-1	0,00088	2,5	39,00	29,83
H4-2	0,00182	1,0	28,10	22,39
H4-3	0,01231	1,2	32,99	27,51

3.3. Metallographic and quantitative analysis

Figures 6 present the microstructure of obtained samples, figures 7-9 present fracture surfaces of obtained samples.

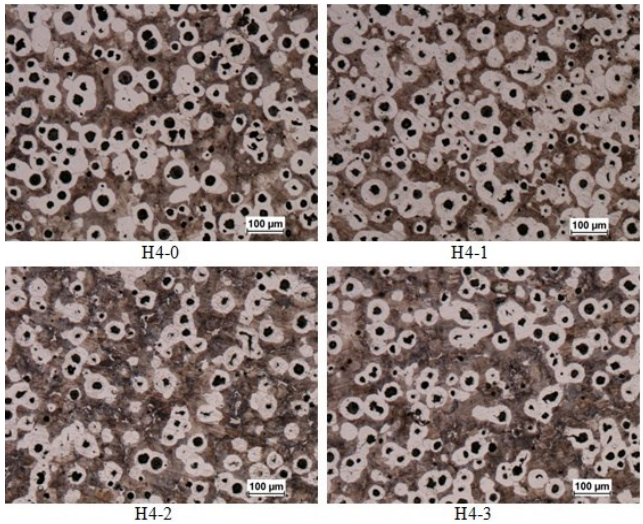

Fig. 6. Microstructure of examined samples

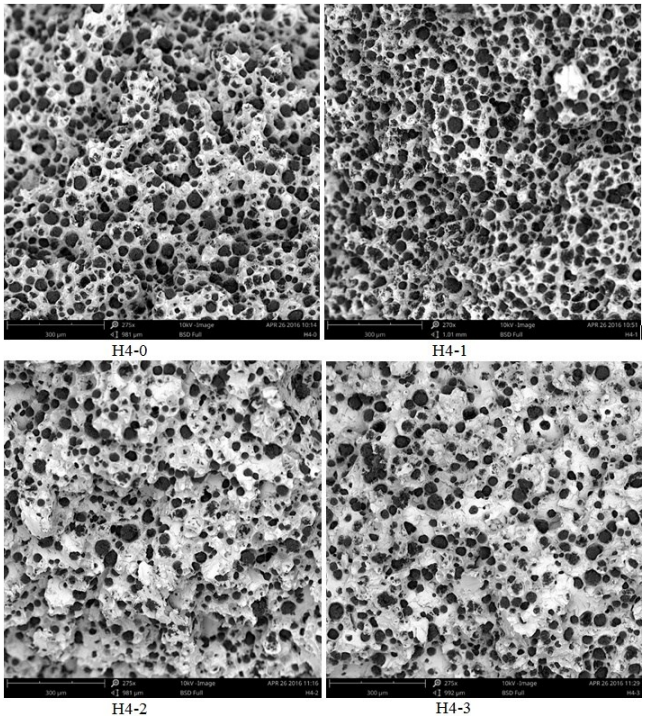

Fig. 7. Fractures of examined samples, SEM

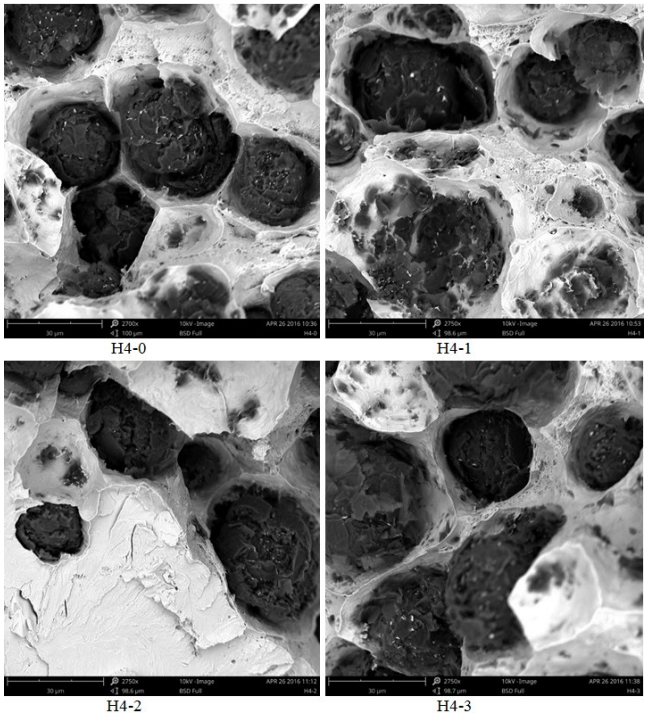

Fig. 8. Fractures of examined samples, SEM

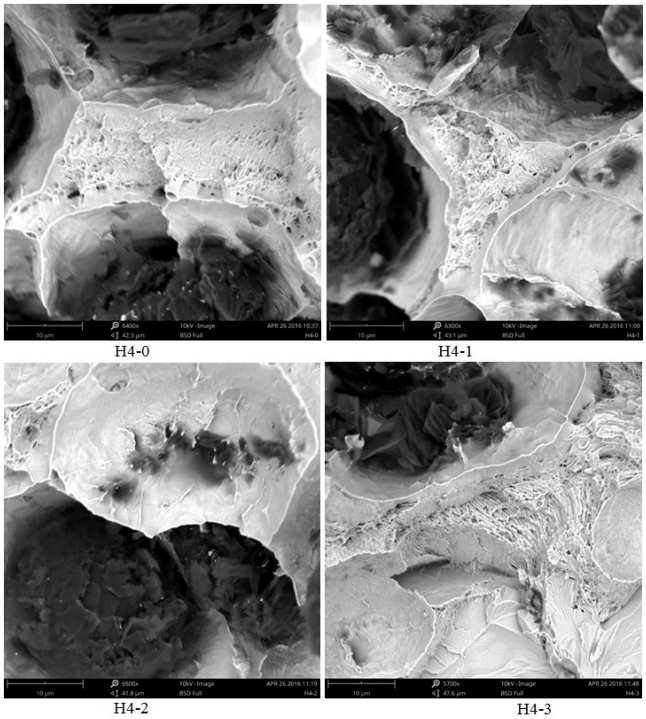

Fig. 9. Fractures of examined samples, SEM

Table 5 shows the results of quantitative analysis of graphite precipitates, table 6 presents percentage distribution of graphite, pearlite and ferrite in examined samples. Figure 10 shows the amount of graphite precipitates as a function of their surface area.

Table 5.
Results of quantitative analysis of graphite precipitates

No.	area, µm²	circumference, µm	length, µm
H4-0	206,92	50,9	18,08
H4-1	166,29	45,6	16,35
H4-2	219,36	54,71	19,47
H4-3	146,45	41,29	14,78

Table 6.
Percentage distribution of graphite, pearlite and ferrite in examined samples

No.	graphite	ferrite	pearlite
H4-0	8,8	50,2	41,0
H4-1	6,6	50,8	42,6
H4-2	7,8	46,9	45,3
H4-3	5,0	45,0	50,0

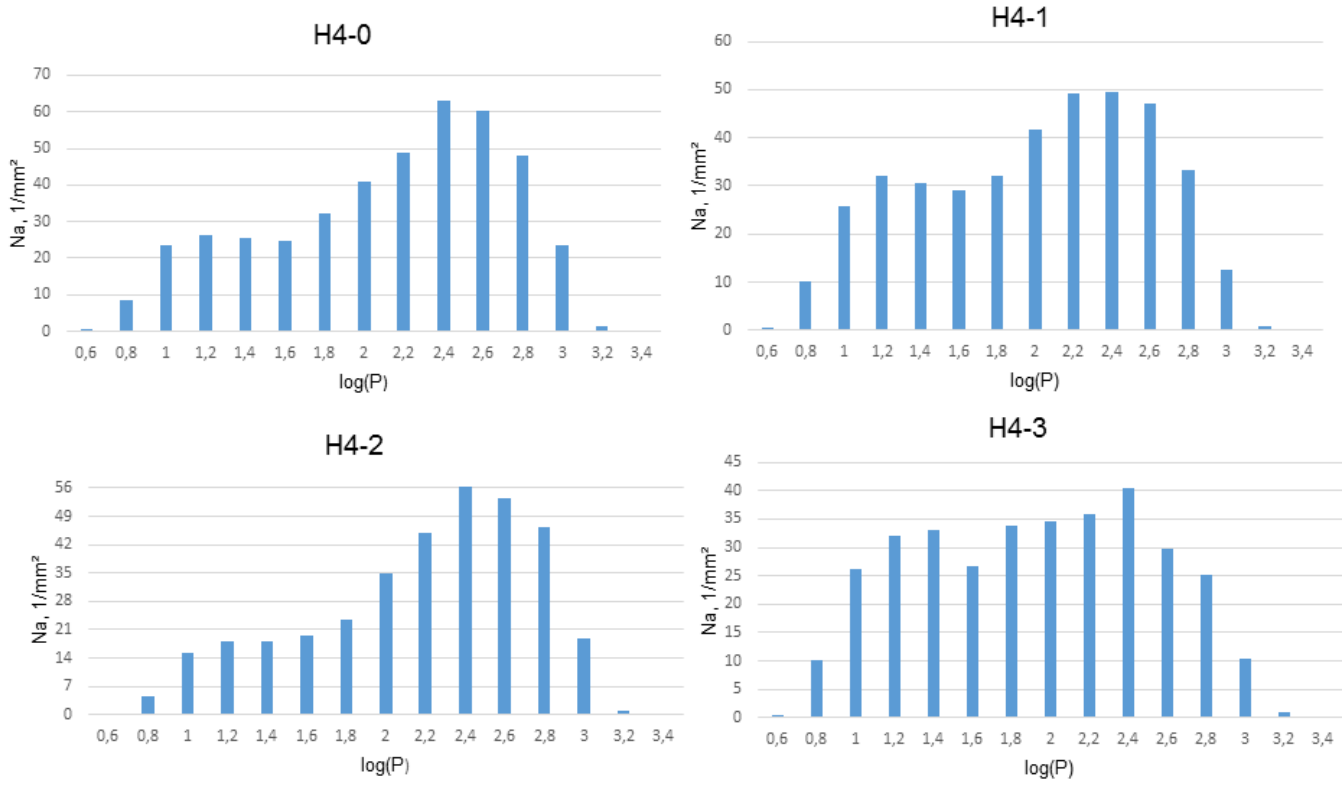

Fig. 10. Amount of graphite precipitates as a function of their surface area

3.4. Hardness and microhardness measurement

Table 7 presents microhardness of examined samples, table 8 shows hardness of examined samples.

Table 7.
Microhardness of examined samples

No.	microhardness, HV		
	1000G load	50G load	
		ferrite	pearlite
H4-0	168,13	181,33	328,77
H4-1	180,83	184,7	284,1
H4-2	195,00	203,6	338,03
H4-3	192,83	196,8	297,00

Table 8.
Hardness of examined samples

No	H4-0	H4-1	H4-2	H4-3
Hardness, HB	175,66	191,33	180,33	190,00

4. Summary

ATD-4 tester was proven to be suitable tool for performing studies concerning analysis of crystallization process.

Even microscopic contents of B have strong influence on crystallization kinetics of ductile cast iron.

Amount of B increasing over 0,00088% highly decreases eutectic recalescence. In order to form a credible dependence between content of B and eutectic recalescence further analysis including boron contents between previously tested values should be performed.

In samples H4-1 and H4-3 the graphite precipitates have the smallest area and circumference, but it might be related to the smaller amount of graphite and higher amount of pearlite in those samples.

Analysing the shape factor calculated from the formula: $C = O_k / O_w$ while $F_k = F_w$

where:
O_k – perimeter of a circle,
O_w – perimeter of the precipitation,
F_k – area of a circle,
F_w – area of the precipitation,
it was noticed that sample H4-0 had the best shape factor, then in order samples H4-1, H4-3 and H4-2.

Increasing amount of B decreases the graphite precipitates and ferrite quantity while increasing the content of pearlite.

Addition of B results in increase of hardness and microhardness of ferrite in each examined sample. The smallest and the highest contents of B resulted in reduction of pearlites microhardness.

References

[1] Sakwa, W. (1974). *Cast Iron.* Katowice: Śląsk. (In Polish).

[2] Krynitsky, A.I. & Stern, H. (1949). Effect of the structure and some physical properties of plain cast irons. *Journal of Research of the National Bureau of Standards.* 42(5), 465-479.

[3] Ankamma, K.J. (2014). Effect of Trace Elements (Boron and Lead) on the Properties of Gray Cast Iron. *Journal of The Institution of Engineers.* 95(1), 19-26. DOI: 10.1007/s40033-013-0031-3.

[4] Izui, S., Furumiya, N., Horie, H., Kowata, T. & Takahashi T. (1994). Effect of Small Amount of Boron on Matrix Structure of Spheroidal Graphite Cast Iron. *The Journal of the Japan Foundrymen's Society*. 66(10), 745-750. (in Japanese).

[5] Zou, Y., Ogawa, M. & Hideo, N. (2012). Interaction of Boron with Copper and Its Influence on Matrix of Spheroidal Graphite Cast Iron. *ISIJ International*. 52(3), 505-509.

[6] Zou, Y., Ogawa, M. & Nakae H. (2011). Influence of Boron on the Matrix of Spheroidal Graphite Cast Iron and Its Counteraction Method. *Materials Science (MS&T).* 1, 409-416.

[7] Singh, L.B. (2009). Improvement in properties of grey iron after boron additions. In 57th IFC 2009, 13-15 February 2009 (pp. 166-171). Kolkota, India.