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A Contribution to the Understanding of the Combined Effect of Nitrogen and Boron in Grey Cast Iron.

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Abstract

This investigation deals with the combined effect of nitrogen and boron and how it in a simple way is possible to utilize this effect to enhance material properties in heavy grey iron castings.

It is shown that controlled addition of nitrogen and boron in practice can be used to control microstructure of heavy grey iron castings.

A plausible theory for formation of boron nitride nuclei effective for graphite growth is presented.

Keywords: *Nitrogen, Boron, Control, Properties, Grey Iron, Heavy Castings.*

1. Introduction

Inoculation is an essential part of controlling material properties in grey cast iron. Inoculation practice has for decades been based on the addition to the melt of small amounts of elements with strong affinity to O (and S) just before casting takes place. This method is proven - both in theory and in practice - to be effective in most cases. But it has the disadvantage that the nucleation effect fades away over time. Especially in heavy castings (slow cooling) this effect may cause non uniform and unacceptable material properties in some parts of the casting. Nitrogen is also known to influence grey iron microstructure. Both graphite flake formation and matrix formation are influenced. However, the obtained effects differ considerably and unpredictable in practice.

2 Experimental

In an attempt to quantify the effect of N and B on grey cast iron properties the following experiment was conducted.

2.1 Test casting

The test casting is a vertically cast solid cylinder Ø180/200 mm x 460 mm poured in a sodium silicate bonded sand mould with an Ø200x200 mm insulating feeder on top. Total weight ~130 kg.

Slices approximately 35 mm thick were cut and used for different heat treatments and determination of material properties and microstructure. From each slice it is possible to machine 3 tensile test pieces - ISO 185 type B with test diameter Ø16 mm. Those test pieces are also used for determination of material structure and hardness.

The casting was cooled to temperature (T) < 300^0C before shake out took place.

Besides the test casting itself the following test items were made from the melt for control purposes:

- Two white solidified coupons for chemical analysis.
- 2 pcs. separately cast Ø30 mm tensile test pieces (ISO 185).
- One Quick Cup for thermal analysis.

2.2 Melt treatment

The charge was melted in an acid lined 150 kg medium frequency induction furnace. The charge material was made up of (in the following order): pig iron, foundry return, steel plate, and carburizer. When all melted, T was raised to ~ 1500^0C and kept constant for about a 20 min. carbon boil. Thus the melt could be considered as clean and relatively poor of nuclei. The chemical composition (except N) was adjusted by adding the necessary amount of different ferroalloys. The target N content was achieved by adding calcium cyan amide ($CaCN_2$) in bottom of the pouring ladle during metal transfer.

No conventional inoculation was performed.

The test casting was poured at 1300^0C.

2.3 Material investigations

Determination of material properties and microstructural analysis were performed on one as cast slice (designated A2) and on one stress relieved slice (designated A3).

For reference the two separately cast Ø30 mm test pieces were treated likewise.

Stress relieving cycle: Heating to 600^{0}C, 6 h; holding at 600^{0}C for 10 h; cooling in furnace until T < 300^{0}C.

3 Results and discussions

3.1 Chemical composition

Table 1. Achieved metal composition (w %).

C	Si	Mn	P	S	Cu
3.25	1.0	0.44	0.25	0.08	0.44
B	N	Cr	V	Ti	Al
0.026	0.013	0.06	0.017	0.007	0.005

3.2 Mechanical properties

Table 2. Mechanical properties of test casting.

Speci men	Rm [MPa]	Atot [%]	E-modul [GPa]	Hardness HBW 10/3000	Hardness, HV25 g.
A2-1	203	0.73	122	170	Ave. of 5 impressions in pearlite structures of A2-2.
A2-2	200	0.62	146	165	
A2-3	200	0.71	161	NA	
A2	*201*	*0.69*	*143*	*168*	*272*
A3-1	214	0.65	161	164	A3-2
A3-2	204	0.61	153	165	
A3-3	215	0.74	140	NA	
A3	*211*	*0.67*	*151*	*165*	*303*
Ø30	*230*	-	-	*230*	-
Ø30H	*230*	-	-	*180*	-

A2 represents values obtained on an as cast test slice.

A3 are values obtained on a stress relieved test slice.

Ø30 represents values obtained on an as cast Ø30 mm tensile test piece.

Ø30H represents values obtained on a stress relieved Ø30 mm tensile test piece.

3.3 Microstructure

Table 3. Characterization of microstructure - Ø30 mm test pieces.

Specimen	Microstructure
Ø30 as cast	Fine lamellar graphite in a matrix of pearlite surrounded by hard phase steadite . Hard phase share ~ 15 %.
Ø 30 stress relieved	Fine lamellar graphite in a matrix of pearlite. Hard phase share is now reduced to 3- 4 %. The cementite part of the steadite has been broken down to graphite and perlite during the low temperature heat treatment.

Microstructure of the test casting was evaluated using a MAN B&W standardized IAS procedure.

Table 4. Microstructure of test casting. Average ferrite content in both items is measured < 1 %.

Item	Graphite type, distribution, size		Gra-phite no/mm^2	Gra-phite area %	hard phase [%]	
	Type	Size			Av.	Max.
A2-2	I A 3/4/5	3.7	91	8.3	3.4	5.5
A3-2	I A 3/4/5	3.7	85	8.8	3.3	5.3

The high hardness seen in the as cast Ø30 mm test piece indicates that the state of inoculation has been inadequate for the actual combination of metal composition and cooling rate.

In the slow cooling casting the state of inoculation seems to be perfect and the stress relieving heat treatment causes an increase in matrix hardness/ material strength.

4 Conclusions

1. Provided controlled content of vital trace elements is enforced small amounts of boron and nitrogen causes uniform microstructure as well as good material properties all over the cross section of heavy castings.
2. Graphite growth conditions are running in “nitrogen” mode creating short and compact flakes.
3. Dissolved nitrogen - not tied up by hexagonal boron nitride (and TiN, AlN) formation - gives rise to age hardening of the pearlite when heating to > 560^{0}C.
4. Some sort of “over aging” may be a consequence when time at elevated temperature is extended.
5. In phosphorous alloyed wear resisting materials (cylinder liners) it is possible to achieve a specific, constant amount of hard phase evenly distributed in all part of the casting.

It is possible to implement those findings in practical foundry operation without big fuss. The first step will be a routine control of trace elements in the melt. Today’s analysing equipment can do the job together with motivated melting shop operators.

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