ARCHIVES
of
FOUNDRY ENGINEERING
DOI: 10.2478/v10266-012-0063-4
Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (2299-2944)
Volume 12
Issue 2/2012

211 – 214

Assessment of the Low Alloy Cast Steel Inoculation Effects with Chosen Additives

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Received 25-05-2012; accepted in revised form 31-05-2012

Abstract

Structure, and thus the mechanical properties of steel are primarily a function of chemical composition and the solidification process which can be influenced by the application of the inoculation treatment. This effect depends on the modifier used. The article presents the results of studies designed to assess the effects of structural low alloy steel inoculation by selected modifying additives. The study was performed on nine casts modeled with different inoculants, assessment of the procedure impact was based on the macrostructure of made castings. The ratio of surface area equivalent to the axial zone of the crystals and columnar crystals zone was adopted as a measure of the inoculation effect.

Keywords: Constructional Cast Steel, Modifying Additives, Macrostructure

1. Introduction

Additives used to modify the iron alloys are divided into type I and type II inoculants. This division results from the nature of the impact of the modifier on the kinetics of the crystallization process. Type I modifiers increase the rate of nucleation, and modifiers of the second kind reduces the linear growth rate of embryos. As a result, these impacts occur to the fragmentation of the structure.

In the literature you will encounter the assertion of the impact of certain modifiers combines both of these influences that parallel will determine the speed of crystallization.

Increasing the rate of nucleation is achieved by introducing into the liquid metal high melting metals particles and their micro alloying compounds to react with the liquid solution components resulting in the formation phase for heterogeneous nucleation (I) [1]. Inhibition of crystal growth and thus reducing the size of phase crystallization, is explained by the formation of the crystallization front layer of a liquid solution with higher alloy content of the micro addition (concentration barrier), which impedes the growth of crystallization phase (II).

When selecting the inoculants the heterogeneity of the construction of liquid metal solutions should be taken into account.

In their construction we can mention:

- A cluster zone, geometrically associated with the structure of liquid metal,
- A zone of activated carbon, while included in the cluster and having increased energy and mobility,
- Zone of free volume (containing the rupture area of inter-cluster joints constantly emerging and disappearing in the process of thermal fluctuations and fluctuations).

Impurities dissolved in the zone of active atoms, and poorly soluble in coagulated phase or type II modifiers (substances which alter the crystallization process without changing the internal structure of clusters) can be divided by the value of force "modifying activity" described by the formula (1).

$$\mu = \frac{U_{ef}^{M} - U_{ef}^{e}}{C_{kl}} \tag{1}$$

where:
U_{ef}^{M}, U_{ef}^{e} – effective ionization potential, of the metal and the additive,
C_{kl} – solubility of the additive in the cluster.

Comparison of μ for different elements can determine differences in the strength of their impact. On the basis of the sign of μ it is divided into the modifiers "+" and demodifiers "-".

2. Materials and conduct of the study

The evaluation of the effect of modifying additives were selected by specifying the size of the equi-axed crystals zone evenly in the casting model. The shape of the casting is shown in Figure 1.

Casts were made of cast steel modeled in terms of chemical composition, to the cast steel L20HGSNM. The chemical composition and mechanical properties specified in the Polish standard were shown in Table 1.

The cast steel melts were prepared in crucible furnace of a neutral lining with a capacity of 50 kg, the mass of molten cast steel was 45 kg. In the course of three heats, nine cast were made by subjecting the cast steel to inoculation by introducing inoculants into the ladle, using different modifying additives (Table 2).

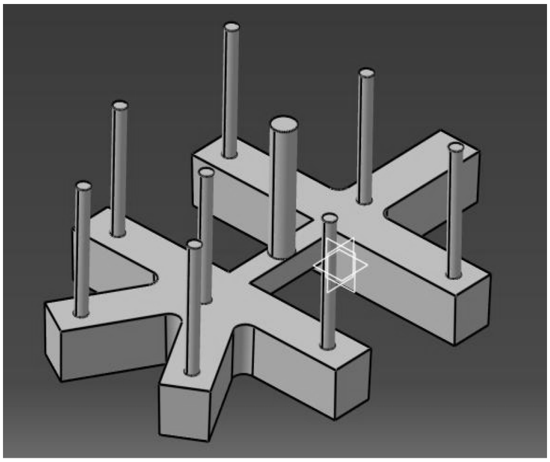

Fig. 1. Experimental casting geometry

Table 1.
Chemical composition and mechanical properties of L20HGSNM cast steel [%]

C	Si	Mn	P	S	Cr	Mo	Ni	R_m [MPa]	R_{eH} [MPa]	A [%]	Z [%]	HB
0.18-0.25	0.7-1.0	0.8-1.1	<0.035	<0.03	0.6-0.9	0.1-0.2	0.9-1.2	1300	1100	6	22	388-477

Table 2.
μ value and form of used additives

el.	μ	form
V	-44.4	FeV
Nb	-22.6	FeNb
Ti	+20.8	FeTi
Zr	+26.0	FeZr
Ca	+2000	FeCaSi
Si	-20.0	FeCaSi
Na	$+(10^4 \div 10^5)$	Na (met.)

The value of the μ size and type of "media" material for the inoculating additives used in the studies were presented in Table 2. The additives were chosen because of the large diversity of their inoculating activity and nature [1 - 3].

Chemical composition of castings made and of each inoculative addition, were shown in Table 3. Cast 1_1 was not modified, and the structure of this model was cast was used as some kind of a benchmark.

Table 3.
Chemical compositions of melted cast steel

Melt No	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Cu	Ti	Zr	V	Nb	
1_1	0.32	0.84	1.03	0.022	0.017	0.83	0.79	1.24	0.030	0.17	0.008	0.008	0.050	0.038	-
1_2	0.27	0.81	1.10	0.020	0.019	0.83	0.77	1.22	0.009	0.17	0.006	0.007	0.247	0.043	FeV
1_3	0.24	0.77	1.02	0.018	0.016	0.81	0.75	1.20	0.004	0.18	0.009	0.010	0.093	0.191	FeNb
2_1	0.32	0.78	0.97	0.016	0.024	0.95	0.78	1.23	0.063	0.16	0.007	0.035	0.088	0.073	FeZr
2_2	0.30	0.60	0.96	0.014	0.026	0.94	0.78	1.33	0.037	0.16	0.222	0.008	0.088	0.070	FeTi
2_3	0.30	0.69	0.97	0.014	0.022	0.94	0.76	1.22	0.019	0.16	0.022	0.009	0.087	0.060	FeCaSi
3_1	0.24	0.96	1.01	0.015	0.027	1.12	0.78	1.11	0.056	0.15	0.064	0.029	0.025	0.002	FeTi+FeZr
3_2	0.23	0.88	0.99	0.017	0.028	1.17	0.78	1.11	0.019	0.15	0.016	0.011	0.122	0.104	FeV+FeNb
3_3	0.22	0.87	0.94	0.016	0.026	1.14	0.77	1.12	0.02	0.15	0.010	0.011	0.038	0.016	Na met

3. Results

From each cast a sample was cut so that the cut surface ran as close as possible to the local heat center. Cut surfaces of samples were subjected to grinding and polishing, and etching with the Adler reagent. Photos of sample macrostructures are shown in Figures 2÷4. Then the surface area of the zone of columnar crystals, S_{kol} and surface area of the zone equi-axed S_{ros} were measured. The measurement results for all test castings were summarized in Table 4.

Fig. 2. Macrostructure of sample casting no 3_1

Fig. 3. Macrostructure of sample casting no 3_2

Fig. 4. Macrostructure of sample casting no 2_2

Table 4.
Results of macrostructure measurements

Melt No	S_{ros} [cm^2]	S_{kol} [cm^2]	S_{ros}/S_{kol}
1_1	1.8	15.01	0.12
1_2	0.38	16.42	0.02
1_3	0.19	16.61	0.01
2_1	2.66	14.15	0.19
2_2	3.83	12.96	0.30
2_3	4.36	12.44	0.35
3_1	3.14	13.67	0.23
3_2	1.13	15.68	0.07
3_3	1.54	15.27	0.10

4. Summary and conclusions

In the presented research inoculants that could be classified as Type II modifiers were used, both demodifiers (V, Nb, Si) and modifiers (Ti, Zr, Ca, Na). Assessing their impact in terms of the accepted criterion of the greatest impact on changing the structure of the metallic calcium silicon additive combined action with a modifier (Ca) and a demodifier (Si). Beneficial effects were also observed for Ti and Zr added separately or together in smaller quantities. Compared to the microstructure of cast iron supplement reference vanadium and iron, niobium, both separate and joint had a negative impact on the structure. Similarly, the introduction of the metallic sodium metal bath, although the highest value that modifies the activity did not cause great changes. Furthermore, addition of sodium and metallic calcium silicon, despite the diffusion and slush deoxidation caused significant gassing castings. Summing up the study and the results obtained the following conclusions.

- The biggest change in the structure causes the cumulative addition of the modifier and demodifier (FeCaSi), but also caused severe gassing of metal.
- Positive influence on the structure caused the addition of Ti and Zr (modifiers "+"), both separate and joined without any side effects.
- Addition V and Nb (demodifier "-") caused deterioration of the structure of test castings casting compared to the reference.
- Addition of metallic sodium in spite of the highest value that modifies the activity did not cause noticeable changes in the structure, which in the context of the difficulty of placing a metal bath (low boiling point) and cause gassing metal disqualify it as a modifier cast steel.

Acknowledgements

Scientific work financed from the budget for science in 2010-2013 as a research project N N508 585139.

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