APPLICATION OF ALUMINUM FOR INOCULATION OF CAST IRON.

Jiří HAMPL[a], Tomáš ELBEL[a], Tomáš VÁLEK[b]

[a] *VSB-Technical University of Ostrava,Ostrava, Czech Republic, EU, jiri.hampl@vsb.cz*

[b] *Vítkovické slévárny spol. s r.o., Ostrava, Czech Republic, EU, Valek@vitkovickeslevarny.cz*

Abstract

Aluminium has various uses of iron metallurgy. It is often used as an alloying additive to increase the mechanical or improve physical properties. Known are cast with an aluminum content of 3-8%, but the Al content is between 28-30% used in the refractory cast iron for temperatures up to 1000 ° C. In small quantities, is used for deoxidation, possibly as part of preparations for inoculation gray cast iron or spheroidal graphite. In this paper, we evaluated the test results of the metallurgical processing of cast iron, where it was used for inoculation of cast iron, aluminum complex inoculant and pure aluminum combined with elements of boron and rare earth metals.

Keywords: Aluminium, inoculation, cast iron

1. INTRODUCTION

Aluminum, as well as in steel is an important alloying and accessory element in cast iron. Small quantity of Aluminium added in the ladle, effects on deoxidizing and reduces chill. A higher content from 0.01 to 0.2 % may cause hydrogen pinholes. When is contain of Aluminum in range about 2 - 3 %, is talking about aluminium's cast irons [1]. The quantity of Aluminum is comparable with the quantity of silicon in cast iron with lamellar and spheroidal graphite. Strauss [2] divides a cast irons with a high content of aluminium into four groups according to their structure: pearlitic with a content of 9% Al, white cast iron with 11 till 19 % Al, ferrite cast iron with 21 till 26 % Al, cast iron which are changing on the ledeburitic with 28 till 32% Al.

These alloyed cast irons have a high thermal resistance, a high electrical resistance or a ferromagnetic properties. The Authors of this paper are investigated the influence of Aluminum on the creation of pinholes and also for inoculation of irons. In this context, there were discovered interesting facts, which will be discussed further.

2. QUANTITY CHANGES OF ALUMINUM DURING CASTING

Recent work by authors of the paper [3] focused on the research creating of pinholes in a compacted graphite casts, which were cast into green sand forms. The Experiments were made at laboratory. There were cast sticks with long trajectory flow of the liquid metal. The experiments confirmed some literary knowledge about the influence of Al on the pinholes creation in cast and ductile irons. It was confirmed that with Al content over 200 ppm, there is a strong probability of the creation of pinholes in vermicular iron, practically regardless of the humidity of the mold. However, it was found a large difference between the number of pinholes in the modification of iron in the form and in the ladle. More pinholes created at the modification in the ladle, whereat there ware use larger quantity of modifier and there ware more products of reaction formation. This was reflected in a variety of shapes pinholes by the SEM observation. We found out that a mechanism called exogenous hydrogen pinholes from the morphology of defect. A small amount of aluminum of about 200 ppm spread out water vapor from the mold. It leads to an increase of the hydrogen quantity in the liquid metal. This element is therefore necessary for the monitoring of the management of pinholes. We also observed that the surface of castings with Al content about 2000 ppm appear oxide inclusions and cold shuts during examining this effect.

There were found out also considerable differences in the quantity content of Aluminum between the center and the surface of castings. In Tab 1, there are shown the results of Al content on samples (40x40x40 mm) from the test sticks. The Al contents were determined from the top, bottom surface of the molten sample and form the center of the cut surface. Measurements were performed on a spectrometer Hilger Polyvac . The surfaces of samples were ground. For samples with a high Aluminum content > 1800 ppm were found to increase the quantity content of aluminum, corresponding to the increased amount of oxides. These dense oxide inclusions limit the formation of pinholes. ‘By contrast, lower contents of Al about 200-400 ppm, which were determined for the samples with the highest distribution of spins, the quantity content of Aluminum in the middle of sample is higher than at the surface. This can be explained by the Aluminum consumption for the reaction with water vapor during form hydrogen and pinholes. It was interesting to see the difference in the Al quantity contents in samples, which were cast from the ladle to chill mould and after passing through a sand mold, on samples cut from a casting. The results of melts of compacted graphite cast iron with higher Al content showed that in the casting there is a decline of quantity content of Aluminum. In Tab 2, there are twelve measurements, it is the arithmetic average of x = 11 %, with a standard deviation of 6% (after rounding). However, we have to allow for that the influence of the change of chemical composition of iron in the ladle by inoculation adjustment of 0.8 % FeSi75 and 0.6 % of modifications BJOMET 3. This "dilution" of cast iron was a mere 0.6 %. Here we can see a certain analogy with steel castings, in which statistically significant changes in the content of Aluminum in samples taken from ingot moulds and casting in sand moulds were found. These changes are caused by reoxidation of the metal and a decrease in the content of Aluminum in samples taken from ingot moulds and casting in sand moulds. These changes are caused by deoxidation of metal and the decrease of quantity contents of aluminum was in the range of 23.5 to 28.7 % [4]. In these experiments with vermicular graphite iron, we also examined the shape of the formation graphite. We have stated perfect formation of vermicular graphite with a sporadic occurrence of spheroidal graphite.

Table 1 Contents of Al in dependence on position.

No.	Absolute and relative contents of Al					
	Top		Middle		bottom	
	[ppm]	%	[ppm]	%	[ppm]	%
48	405	89,6	452	100	420	92,9
50	415	94,3	440	100	422	95,9
64A1	2505	95,9	2610	100	2550	97,7
64A2	2740	103	2660	100	2780	104,5
65	2160	100,5	2150	100	2175	101,1
66	2280	112,9	2020	100	2120	105

Table 2 Content of Al in a ladle and in a casting

No.	Samples	Quantity of Al [ppm]	diference %
66/1	Ladle 1	2180	100
66 1A	casting A	2040	93,6
66 1B	casting B	1950	89,5
66/2	ladle 2	2180	100
66 2B	casting B	1920	88
64/1	ladle 1	2500	100
64 A1	casting A	2250	90
64/2	ladle 2	2500	100
64 A2	casting B	2400	96
66/1	Ladle 1	2100	100
66 B1	casting B	1950	92,8q
70	ladle	770	100
70 A	casting	670	87
67	Ledle	1930	100
67 A	casting A	1900	98,4
67 B	casting B	1880	97,4
68/1	ladle 1	640	100
68 A1	casting A	540	84,3
68/2	ladle 2	770	100
68 A2	casting 2	670	87
69/2	ledle 2	580	100
69 A2	casting A	510	88

According to the work of Hrušovský and Wallace [5], this can be attributed to the very high content of aluminum and titanium, which were in our collection of melts [6]. These authors come with formula for the calculation of excess sulfur and determined the relationship between the shape of the graphite, sulfur, magnesium and rare earth metals (REM). The formula (1) for the calculation of excess sulfur content DS includes magnesium and REM too.

$\Delta S = \%S_{final} - 0.34\ (\%REM) - 1.33\ (\%Mg)$ (1)

Where % S_{final} is the final sulfur content in iron, % Mg, % REM are the residual contents of these elements in cast iron.

A positive value ΔS pointed to that a sulphur is in excess and a negative values pointed to that magnesium or REM are in excess. We calculated the final residual sulphur and magnesium (REM not used) by ours melts of vermicular graphite iron. The calculated values occurred in the negative area with limit values from 0.0083 % till 0.035 %. The arithmetic average of 26 analyses was S = -0.0225 %. Irons with values DS between 0.02 till 0.025 % have in the structure of vermicular graphite 80-100 % [5]. Aluminum and titanium according to Hrušovský [5] significantly broaden the range of ΔS and facilitate the production of vermicular graphite iron. This is fully confirmed in our experiments. Aluminum is weak nucleant, but it strongly deoxidates the melt (as a Mg and Ti). As mentioned above, the casting surface can form the oxide inclusion. Al simultaneously neutralizes nitrogen and improves feridization. This is used in the manufacture of thin-walled castings of spheroidal graphite cast iron by using inoculants with 4% Al. Mampey [1] has proved that Al in spheroidal graphite causes mushy solidification morphology compared with grey cast iron. This comes from a significant inverse segregation during the solidification of Aluminum. The remaining melt (10-20%) contains a much lower quantity of Al as a consequence of a lower temperature of solidification. In In the casting remain for a long time associated “islands” of melt in the surface layers during substituting metal. Absence of continuous solid peel leads to higher demands on the external feeding, which is reflected in the formation of surface shrinkage that we actually noted by higher Al contents.

3. COMPLEX INOCULANT ON BASED OF ALUMINUM

This inoculant has been developed for inoculation of thin-walled castings with thickness of grey cast iron. The thickness of walls is about 2-3 mm, where there is required low temperature of dissolution 1320-1360 ° C. Al is a basic component. Initial base FeSi75 is in Aluminum’s inoculant replaced by Al in the range 36.4% till 51.5% and the supporting elements Fe, Si, REM, Mg and Bi. Quantisation is recommended from 0.05 to 0.1%. The value higher than 0.15% leads to the formation of a viscous slag and surface defects during casting into bentonite sand with higher humidity [7]. The effectivity of inoculant on the basis of Aluminum in the grey cast iron inoculation was observed in the test castings, which are evaluated on the structural, mechanical and casting properties of cast iron with lamellar graphite. There were processed in different proportions based inoculant Al, composition are shown in **Table 3**.

Table 3 Chemical composition of inoculant (%)

Al	KVZ	Ca	Cu	Fe	Si	Mg	Bi
36-52	9-11	2-3	0,3-1	8-13	13-17	0,6 - 1	3,5-5,5

Table 4 Chemical composition (%), (MPa)

č.tav.	C	Si	Mn	Al	Sc	Rm	HB
1/1	3,4	2,32	0,57	0,018	0,97	218	195
1/2	2,8	1,77	0,49	0,021	0,76	382	267
2/1	2,7	1,43	0,38	0,004	0,74	315	265
2/2	2,6	1,33	0,37	0,067	0,69	319	270

The experimental melts were made in 40 kg induction furnace of neutral lining. There were compared the effectivity of inoculant FeSi75 with Al by processing quality cast iron EN- GJL -150 (SC = 0.97) and EN- GJL -250 (SC = 0.76). At first, it was evaluated the effectiveness of the inoculant AlSi the same quantity 0.05 % for both types of cast iron 1/1 and 1/2. The resulting chemical composition of the melts, the strength Rm (MPa) and hardness (HB) are shown in the **Table 4**. The casting properties of cast iron were an important part of the evaluation of the properties of the inoculants. The common inlet in the form of bentonite mould were cast kits 2 times 5 pieces of slabs with wall thickness 5,10,20,30 and 40 mm for analysis of influence of the inoculant effect on wall thickness. There were cast chill test and cone for evaluate tendency of shrinking, there were cast test sticks for Rm, fluidity test and the cooling curves were recorded.

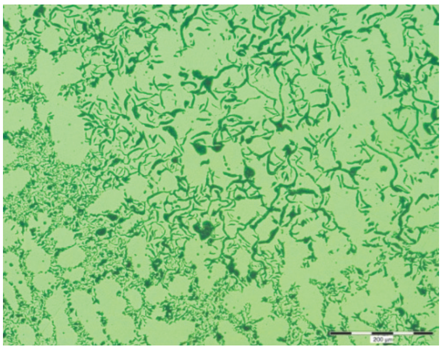

Fig. 1 LGI 1/1 Sc 0,97;AlSi 0,05%,ID 8, 100x

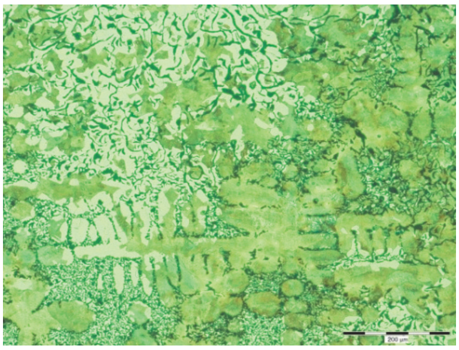

Fig. 2 LGI 1/1Sc 0,97;AlSi 0,05%, F15, etched, 100x

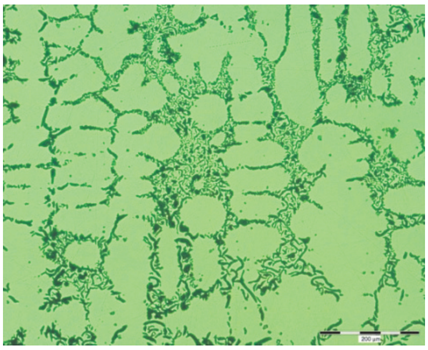

Fig. 3 LGI 1/2,Sc=0,76;AlSi 0.05%, ID 9, 100x

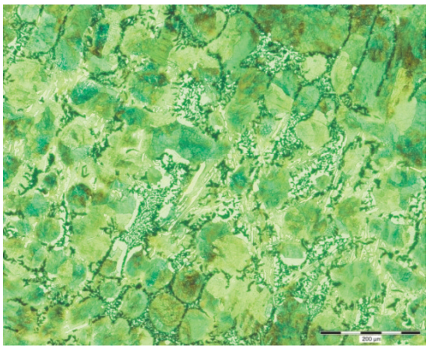

Fig. 4 LGI 1/2,Sc=0,76;AlSi 0.05%,P, etched, 100x.

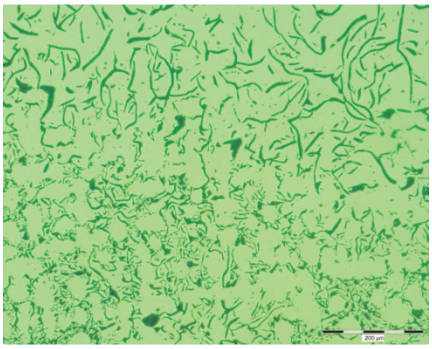

Fig. 5 LGI 2/1,Sc 0,74, FeSi 0,15%, ID 6.8, 100x

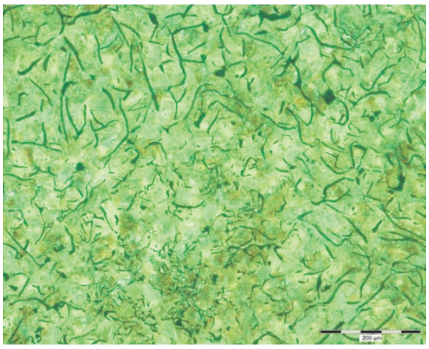

Fig. 6 LGI 2/1,Sc0,74FeSi 0,15%, etched,100x.

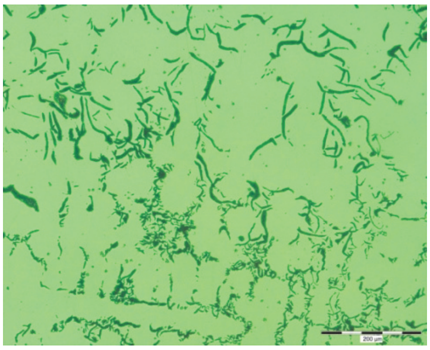

Fig. 7 LGI 2/2,Sc 0,74,AlSi 0,15%, ID 4.7,100x

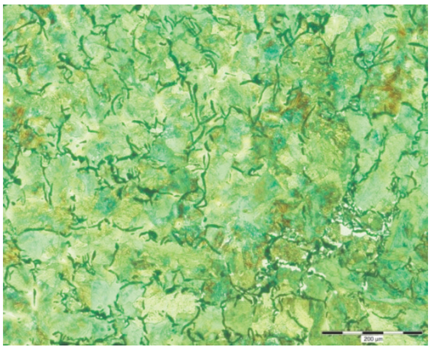

Fig. 8 LGI 2/2, Sc 0,74+0,15% AlSi, etched,100x.

The technological tests showed a standard values corresponding to the quality of cast irons. Among all tested cast irons there were not significant differences in height of chill, fluidity and tendency to the formation of concentric shrinkage. Only slabs with 0.15 % AlSi (melt 2/2) showed surface shrinkage and a significant degree of internal inhomogeneities. From by an eye visible shrink holes and shrinkage porosity in thick slabs 5,10,20 mm to large gas shrinkage in slabs of thickness 30, 40 mm. But gas shrinkage or shrinkage porosity were not in the same melt (2/2) in cones for the test of create concentric shrinkage poured into an open mould. Here is optimal outlet of gases. This fact suggests that the gas shrinkage were preferentially induced by reaction of aluminum melt inoculant and humidity of mould, by others castings of melt 2/2.

Metallographic analyses of the microstructure of lamellar graphite iron (LGI) 1/1, it was treated with an optimal amount of 0.05% AlSi (in **Fig. 1**, **2**) showed mainly interdendritic graphite form with areas of ferrite in pearlitic matrix. LGI 1/2 (in **Fig. 3**, **4**) with a lower degree of saturation (Sc = 0.76),it was inoculated the same amount of AlSi was formed also interdendritic graphite form. Melt LGI 2/1 was inoculated 0.15% FeSi75 (in **Fig. 5**, **6**) and LGI 2/2 0.15% of AlSi (in **Fig. 7**, **8**) had undercooling structure forms of graphite in matrix, but uniform distribution was by inoculated iron of FeSi75.

4. INOCULATION OF ICDP IRON WITH ALUMINUM AND CERIUM

Utility properties of cast iron ICPD (Indefinite Child Double Pour) are dependent on the morphology and shape of graphite in ledeburitic matrix. ICDP iron is a progressive material designed for the working layer of centrifugally cast rolls. They were made tests using Aluminum and cerium as an inoculant in the laboratory. They were cast two sets of test samples with a variable quantity proportion of Aluminum and cerium. The first set was inoculation by pure Aluminum. The final Aluminum contents were 0.017 % , 0.083 % and 0.110 % in the sample. The second set was inoculation with a combination of Al and Ce. The final contents were Al 0.035 % Ce 0.010 %, Al 0.100 % Ce 0.055 % and Al 0.0140 % Ce 0.007 %. The samples were carried out by metallographic analysis and measurement of hardness HV 50. By the metallographic analyses of the first set of samples were found lamellar graphite in matrix of iron. Distributions of graphite were uneven and mostly interdendrite. The highest surface quantity of graphite was determined on the sample with 0.110 %Al Fig 9. The hardness of the samples were in the range of values from 637 to 732 HV 50. The lowest hardness was measured on a sample with a low Al content 0.017 % **Fig. 10**. In the second set of samples, there was interdendrite lamellar graphite. In the case of the sample with Al Ce 0.100 % 0.055 % there were locally detected clusters of non-metallic particles **Fig. 11**. The microstructure consists of eutectic carbides skeleton and martensite. Among martensite needles we can observe residual austenite **Fig. 12**. The hardness of the sample were the range of values from 539 to 624 HV 50.

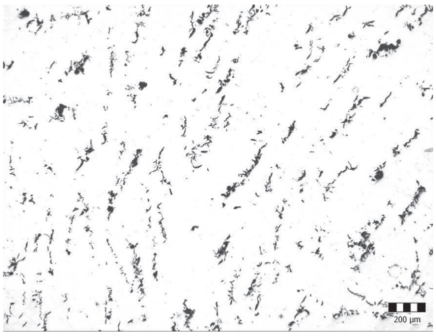

Fig 9 High surface quantity of graphite, 50x

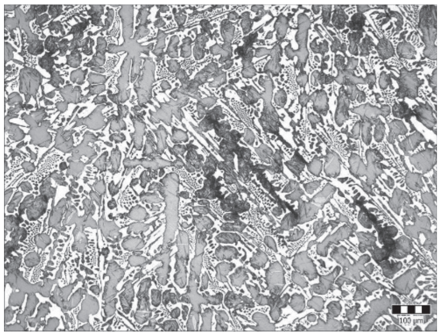

Fig. 10 Sample with low value HV 50,100x

Fig. 11 Clusters of non-metallic particles, 1000x

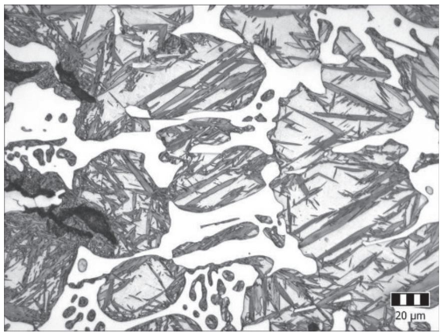

Fig. 12 The occurrence of retained austenite,1000x**.**

CONCLUSION

On the basis of the experiments it can be concluded that Aluminum in normal quality cast iron is an element whose activity involves risks with regard to the possible occurrence of internal and surface defects. In particular, the castings may randomly occur inside the type of shrinkage defects. Predicting the occurrence of this type of defect is difficult by respecting the principles of directional solidification and elimination of thermal points. Surface defects of type pinholes, oxide inclusions and cold shuts are probably dependent on the local concentration of Aluminum in the casting and humidity of mould. It is likely that the addition of Al to the iron in the form of an inoculant in the final time of casting may increase the risk of shrinkage of gas in castings, during the melt immediately reacts with humidity of mould. Some authors [8] recommend deoxidation of the melt in the furnace by adding pure Aluminum according to the detected oxygen content of iron in the form of oxides for elimination of endogenous bubbles in castings.

Inoculation Aluminum was tested on a progressive material ICDP. Aluminum was combined with cerium. In case of using pure Aluminum, the effect of the precipitated graphite was positive. Graphite in the structure was close-grained. Quantities of graphite were increasing in dependence on increasing quantity of Al. The effect of Al was observed also on the hardness. The hardness of the sample was the lowest with the lowest amount of Al. Low hardness corresponds with the content of residual austenite, which was the highest in this sample. The results of combination Al and Ce were inconsistent. The use of cerium was inefficient in terms of quantity and shape of graphite, in these cases. On the scratch patterns were detected clusters of non-metallic inclusions. For this set of samples were observed a higher amount of retained austenite. The residual austenite most likely evokes significantly lower hardness of the test material.

ACKNOWLEDGEMENTS

This work was undertaken with the financial support of the Grant Agency of the Czech Republic within the project Reg. No. 106/08/0789.

REFERENCES

[1] MAMPAEY,F: Aluminium cast irons. AFS Transactions, vol. 113, 2005, paper 05-149.

[2] STRAUSS,K.: Applied science in the casting of metals. PERGAMON PRESS, Oxford, 1970, 532 paper.

[3] ELBEL,T. et al.: Influence of aluminium on the formation of pinholes in cast irons. Archives of Foundry Engineering, vol. 8, 2008, issue 2, pp. 27-32.

[4] KOCIÁN,L.- ELBEL,T.: Analysis of change of chemical composition of steel due to reoxidation of metal. Acta Metallurgica Slovaca, vol. 11, 2005, N. 3, pp. 8-12.

[5] HRUSOVSKY,J.V.- WALLACE, J.F.: " Effect of composition on solidification of compacted graphite iron. AFS Transactions vol. 93, 1985, pp. 55-86,

[6] ELBEL,T. et al. : Vliv chemického složené litiny s červíkovitým grafitem na výskyt bodlin v odlitcích. Technological Engineering, vol 5, 2008

[7] Murgaš,M.-Pokusová,M.: Grafitizačné očkovadlo pre syntetickŭ liatinu; personal statement .

[8] VONDRÁK, V. - DUBOVÁ, M.: Slévárenská ročenka® 2003, Česká slévárenská společnost Brno, 2003, s. 112 - 123.(In Czech)