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Benefits of Residual Aluminum in Ductile Iron

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Two main chemistry systems of micro-inclusions can be identified in ductile iron: Ca-S-X and Mg-Si-O-X with the majority of the inclusions regardless of treatment type and location being of the second type, silicates. Laboratory investigations have shown that simple silicates were present in the matrix, while more complex silicates were present in conjunction with graphite, probably acting as graphite nucleation sites. In these more complex silicates, elevated levels of Al, Ca, Ce and La were typical. Comparing micro-particles embedded in iron matrix and graphite nodules of iron treated with pure Mg-metal and iron treated with MgFeSi alloy showed a higher amount of complex silicates with elevated Al-levels in the iron treated with MgFeSi. Further laboratory investigation was undertaken to explore which source of Al and which range of residual Al would have a favorable impact on the graphite nucleation in ductile iron. The work showed that a residual aluminum of 0.005 to 0.020 wt.% appears to be beneficial for improving ductile iron solidification characteristics without the incidence of pinholes. Greatest benefits were achieved when introducing the Al into the iron via an inoculant late during processing or via a pre-conditioner to the base iron. Al added via the MgFeSi provided less benefit. Some case studies illustrating the effect of Al in ductile iron are also presented, as Al-containing pre-conditioner or/and Al-bearing, FeSi inoculant application.

Keywords aluminum residual, ductile iron, inoculation, nodular graphite nuclei, preconditioning, structure, thermal analysis

1. Introduction

Aluminum is recognized for contributing to pinhole formation in iron castings. Typical critical ranges for Al are 0.05-0.2 wt.% in ductile and 0.01-0.2 wt.% in grey iron. The higher surface tension in ductile iron makes this iron less susceptible to form pinholes than grey iron (Ref 1). Aluminum will also add to the slag formation, resulting in poor furnace performance, more ladle and holder maintenance, and increased risk for slag inclusions in castings.

The majority of charge materials will contribute to residual aluminum presence in the iron melt as will in most cases also nodularisers and inoculants. Typical levels of Al in nodularisers are from less than 0.1 wt.% and up to 2-3 wt.% and in FeSi-based inoculants from 0.1 wt.% up to 4-5 wt.%. At higher aluminum levels, FeSi-based alloys will tend to improve solubility, but the increased slag formation and tendency for pinholes should call for caution.

Aluminum appears to play an important role in nodular graphite nucleation in ductile irons. Aluminum has been found in nodular graphite as a complex nitride, such as $AlMg_{2.5}Si_{2.5}N$ (Ref 2) and (Mg, Si, Al)N (Ref 3), as an oxy-nitride (Mg, Si, Al)ON at very low sulfur contents in the base iron (<0.01 wt.% S) (Ref 4), together with Mg and Ca as a constituent in sulfides and silicates in inclusions observed in induction and cupola melted iron (Ref 5), and in complex hexagonal silicate phases of $XO\text{-}SiO_2$ or $XO\text{-}Al_2O_3\text{-}2SiO_2$ on the surface of the previously formed Mg-silicates making more favorable sites for subsequent graphite nucleation (Ref 6).

Recent work has also shown that a specific low level of aluminum has a beneficial impact on the properties of hypoeutectic ductile iron. Generally, residual aluminum was found as an important, medium potency graphitizing influencing factor in both un-inoculated and inoculated ductile irons. Aluminum appears to have beneficial effects on decreasing the occurrence of free carbides, increasing nodule count, and improving casting soundness, without affecting graphite morphology. A residual aluminum of 0.005-0.02 wt.% appears to be beneficial for improving ductile iron solidification characteristics without the incidence of pinholes (Ref 7-11).

The main objective of the present paper is to explore the role of residual aluminum in nodular graphite formation for Mg versus MgFeSi treatments and which source and what range of residual Al would have a favorable impact on the graphite nucleation in ductile iron.

2. Laboratory Experiments

2.1 Aluminum Incidence in Nodular Graphite Nuclei

Micro-particles embedded in iron matrix and graphite nodules of treated iron have been analyzed. Scanning electron microscopy (SEM) analysis was performed by use of a Philips SEM-515 instrument equipped with WDS + EDS micro-analyzers. The base iron was premade from cupola melting in foundry conditions. Two variants of base iron Mg-treatment

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were considered, for the same ladle inoculation procedure: (1) cupola made iron with extensive desulfurization (0.005 wt.% S) followed by MgFeSiRE alloy treatment and ladle inoculation with Ca, Ba, Al-FeSi alloy; (2) cupola made iron used directly (0.10 wt.% S), treatment in Mg-converter and the same Ca, Ba, Al-FeSi alloy ladle inoculation, respectively (Table 1).

The two samples of foundry iron were characterized by chemistry (Table 2) and structure (Table 3) parameters. For the same position in the eutectic range (CE = 4.3-4.4 wt.%), the final ductile irons showed the same low level of manganese, phosphorus and residual elements (Ti, Cr, Ni, Cu etc.) and very low level of sulfur (despite very different initial sulfur contents). MgFeSiRE treated iron (sample 1) was mainly characterized by higher content of Mg, Ce and Al comparing to Mg-metallic treated iron (sample 2), for the same inoculation conditions.

Structure analysis showed relatively similar graphite and metal matrix features in both samples for both magnesium treatment variants. In the MgFeSiRE treated iron, a higher amount of nodules smaller than 10 μm was observed combined with better nodularity (86 vs. 78%) and shape factor (0.79 vs. 0.71), and the size distribution was more uniform. Prepared surface of each sample was in great detail searched for detection of micro-inclusions both in matrix and in connection with graphite nodules. Twenty micro-inclusions, 10 in matrix and 10 in connection with graphite nodules, were analyzed by EDS micro-analyzers in each sample. Chemical composition of micro-inclusions was determined in 1 to 3 different positions. The geometrical features of discovered micro-inclusions were obtained by Automate Image Analyzer (Buehler Omnimet V 5.0). Figure 1 shows the typical micro-inclusions embedded in iron matrix (a, b), and inside of graphite nodules (c, d) for both Mg-metallic (a, c) and MgFeSiRE (b, d) treatments.

Micro-inclusions were found in a large size range (0.8-8.0 μm). Typically, the same groups of elements were identified in the micro-inclusions distributed in both metal matrix and graphite nodules (Fig. 2):

- Common elements are typically for:
  - Base iron: Fe, Si, S
  - Treatments alloys: Mg, Ce, La, Ca, Al
  - Residual elements: O, Al
- Other elements occurring: Ti, K, Cr, Mn, P

Two main chemistry systems of micro-inclusions were identified: Ca-S-X and Mg-Si-O-X. The majority of the inclusions in both matrix and nodules regardless of treatment type where of the type Mg-Si-O-X. Simple silicates were typically seen in the

Table 1 Chemical composition of treatment alloys

Alloy	Chemical composition(a), wt.% Mg	Ca	Al	Ba	RE	Si
MgFeSiRE	5.5-6.5	0.5-1.0	max. 1.0	…	0.4-0.6	44-48
Ca,Ba,Al-FeSi	…	0.75-1.25	0.75-1.25	0.75-1.25	…	73-78

(a) RE, rare earth; Fe-balance

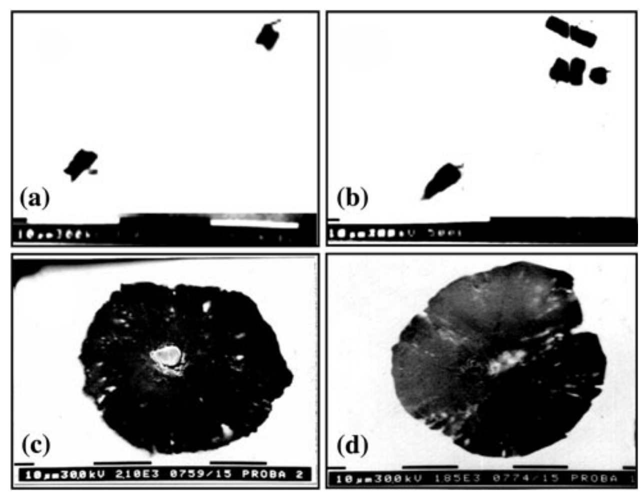

Fig. 1 Typical micro-inclusions embedded in iron matrix (a, b) and of graphite nodules (c, d)

Table 2 Chemical composition of ductile irons

Sample	Mg-treatment	Chemical composition, wt.% C	Si	Mn	P	S	Mg	Ce	La	Al	Ti	Cr	Ni	Cu	CE, wt.%
1	RE-MgFeSi	3.60	2.61	0.17	0.02	0.003	0.038	0.005	<0.005	0.030	0.019	0.026	0.015	0.22	4.39
2	Mg	3.55	2.48	0.16	0.02	0.002	0.031	<0.003	<0.005	0.014	0.020	0.029	0.014	0.20	4.30

Table 3 Structure analysis of ductile irons

Sample	Mg-treatment	Graphite analysis(a) Graphite, %	No. of nod. counted	Nodule count, mm^{-2}	Nodularity, %	$Diam_{ave}$, μm	$Shape_{ave}$, $4\pi A/p^2$	Ferrite/pearlite, %
1	RE-MgFeSi	9	653	133	86	26.1	0.79	63/37
2	Mg	9	774	158	78	25.4	0.71	67/33

(a) Total area: 4.9 mm^2; nodule class: $d_{av} \geq 5$ μm

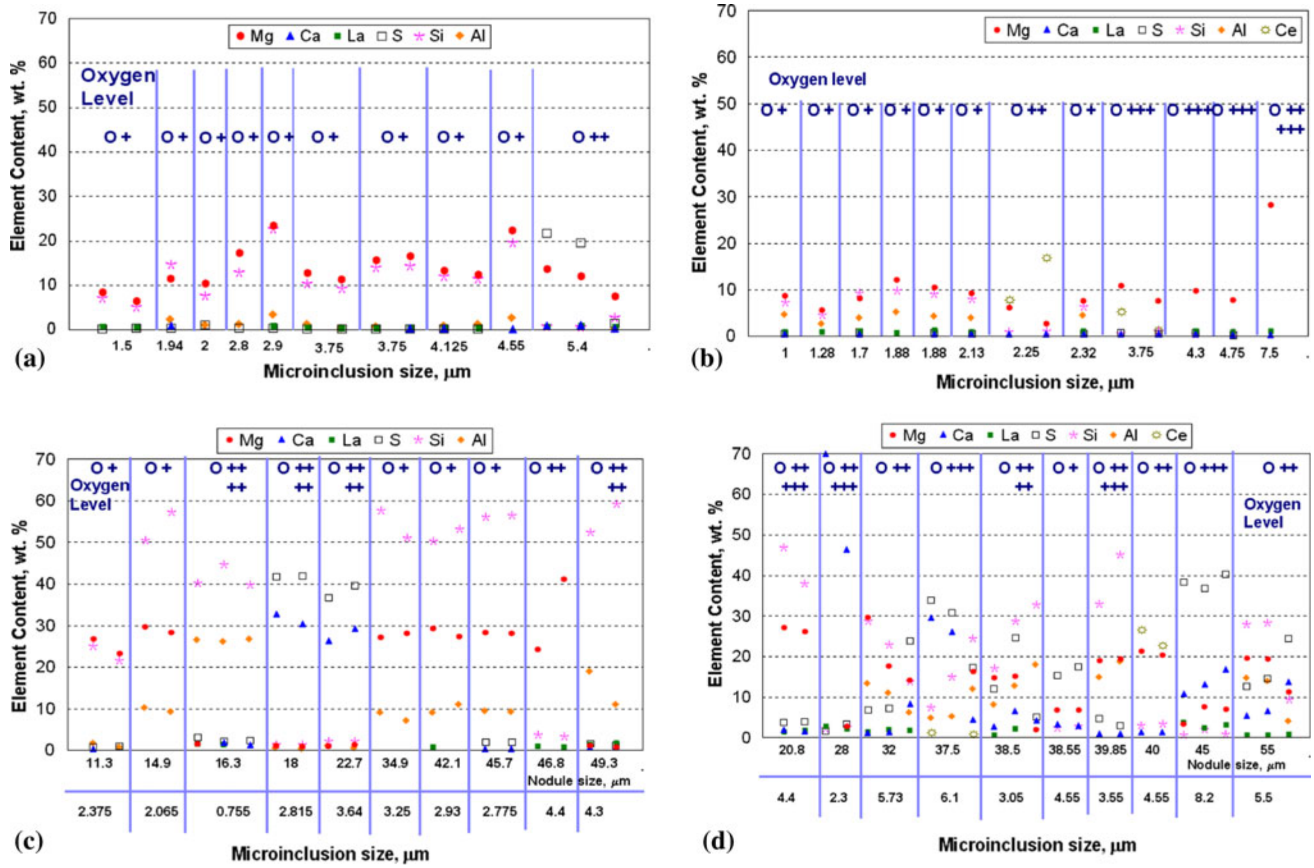

Fig. 2 Chemical composition (wt.%) of the micro-inclusions distributed in the matrix (a, b) and graphite nodules (c, d). [a, c = Mg; b, d = MgFeSiRE]; [+ as minimum up to +++++ as maximum oxygen level indicators]

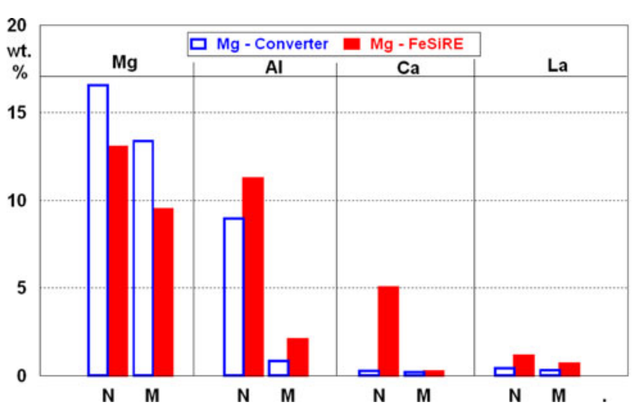

Fig. 3 Average content of Mg, Al, Ca and La in micro-inclusions distributed inside of graphite nodules (N) or metal matrix (M), of Mg and MgFeSiRE treated and Ca,Ba,Al-FeSi inoculated ductile irons

matrix, while complex silicates were found in conjunction with graphite and are probably acting as graphite nucleation sites. In these inclusions elevated levels of elements such as Al, Ca, Ce and La was found (Fig. 3). These complex silicates were mainly seen in the MgFeSiRE treated iron and often showed elevated Al-contents. The residual Al-content in the MgFeSiRE treated iron was higher and will normally be higher if no supplementary aluminum source, such as pre-conditioner or/and inoculant, is added to Mg metallic treated irons.

It was also found in most cases that the nucleus for nodular graphite was not a simple compound (silicate, sulfide, oxide etc.), but a complex compound made up of several phases. The different constituted phases had different positions, possibly governed by formation order, distribution zones and principal or secondary role in graphite nucleation. Under the present experimental conditions, Mg-silicates and Ca/Mg-sulfides were found as major compounds, with the sulfides as nucleation site or support compound for silicates of different complexity. The variation in complexity of these compounds, depending on the nodulariser type (such as Mg vs. MgFeSi) and chemical composition (Al, Ca, Ce, La etc. content) in conjunction with inoculation could be the key challenge to control graphite nucleation in ductile iron. In all of cases, Al appears to have a key role, as presence of this element is the main difference between Mg-micro-inclusions embedded in the matrix and graphite nodules (up to ten times higher Al content in graphite nuclei) (Fig. 3).

2.2 Influence of Residual Aluminum on Cast Iron Solidification Pattern

Having established that Al appears to have a key role in graphite nucleation in ductile iron laboratory investigations were undertaken to explore which source and what range of residual aluminum would have a favorable impact on the graphite nucleation of ductile iron. The experimental heats were obtained in acid lined coreless induction melting (100 kg, 2400 Hz) (Ref 7).

Three aluminum sources were used to vary the aluminum content in the final ductile iron (Table 4):

1. Al-FeSi alloy as pre-conditioner (0.4 wt.% in stream addition, before Mg-treatment);
2. MgFeSi alloys at different aluminum contents as nodularisers at 2.5 wt.% ladle addition with poring through Tundish lid;
3. Ca-FeSi alloys at different aluminum contents as inoculants with 0.5 wt.% stream addition into ladle.

The compositions of the final ductile irons were slightly hypo-eutectic (3.95-4.25 wt.% carbon equivalent), which was especially selected to increase the sensitivity of irons to chill and form shrinkage. The other main elements were those included in the normal range of ferritic/pearlitic ductile irons: 0.34-0.38 wt.% Mn, 0.019-0.02 wt.% P, 0.006-0.012 wt.% S and 0.04-0.06 wt.% residual Mg. Other residual elements (except Al) were achieved at low levels.

The aluminum contribution of the metallic charge was about 0.004 wt.% Al for all heats, giving 0.002-0.003 wt.% Al after melting. To obtain a very low final aluminum content (<0.003 wt.% Al) a high-purity base iron was treated with a low Al (0.02 wt.%) MgFeSi and an Ca-FeSi inoculant with low Al level (0.12 wt.%). For a medium Al (0.01-0.02 wt.% Al) and high Al (>0.04 wt.% Al) content the three above mentioned Al sources were combined to obtain the desired Al-level in the iron (Ref 7).

The solidification process was investigated by Quik-cup cooling curve analysis having a modulus of approximately 0.75 cm (equivalent to 30 mm diameter bar). The cooling curve and its first derivative (Fig. 4) were recorded, both for un-inoculated and inoculated irons, at different aluminum content and aluminum sources (Ref 7, 9).

The eutectic undercooling is measured as ΔT_m = Tst − TEU, where the stable (graphitic) eutectic temperature is defined as Tst = 1153 °C + 6.7 (%Si). ΔT_m exhibited a very large range (23-76 °C), while un-inoculated irons solidified with very high undercooling ΔT_m of 51-76 °C (Fig. 5). Other parameters were also introduced. ΔT_1 = TEU − Tmst relates the lower eutectic temperature (TEU) and the calculated metastable (white) eutectic temperature [Tmst = 1147 − 12(%Si)]. ΔT_3 = TES − Tmst relates the final eutectic solidification temperature TES, which corresponds to the lowest point on the first derivative of the cooling curve (FDES), and the metastable eutectic temperature (Tmst).

The ΔT_1 parameter illustrates the condition of irons at the start of eutectic reaction. If $\Delta T_1 < 0$ chill and white iron will appear. In these experiments, un-inoculated irons mainly presented white iron solidification ($\Delta T_1 < 0$), while inoculation moved the ductile irons to positive values for ΔT_1 in all cases (Fig. 6).

Increasing the residual aluminum levels resulted in a positive trend for the thermal parameters representative of eutectic undercooling: lower level of ΔT_m (Fig. 5) and higher level of ΔT_1 (Fig. 6), for both un-inoculated and inoculated irons. For inoculated irons medium Al appears to be an efficient range, while the Al-addition via inoculation appeared to give the greatest benefits. The next best solution is an Al-bearing

Table 4 Chemical composition of Al-bearing alloys

Al source	Role	Alloy	Chemical composition(a), wt.% Al	Ca	Mg	Si 78
FeSi	Pre-conditioner	1	5.0	0.05	…	78
Mg-FeSi	Nodulariser	2.1	0.02	1.0	5.5	46
		2.2	1.00	1.0	6.1	46
		2.3	2.60	1.0	6.5	46
Ca-FeSi	Inoculant	3.1	0.12	0.7	…	77
		3.2	1.30	0.7	…	76
		3.3	4.80	0.9	…	76

(a) Fe-balance

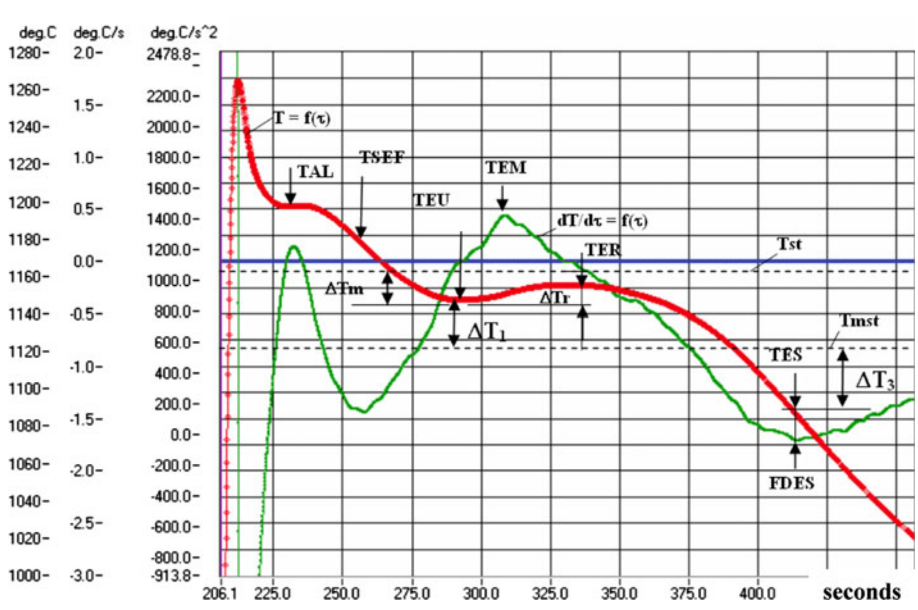

Fig. 4 Typical cooling curve and its first derivative of hypo-eutectic ductile iron

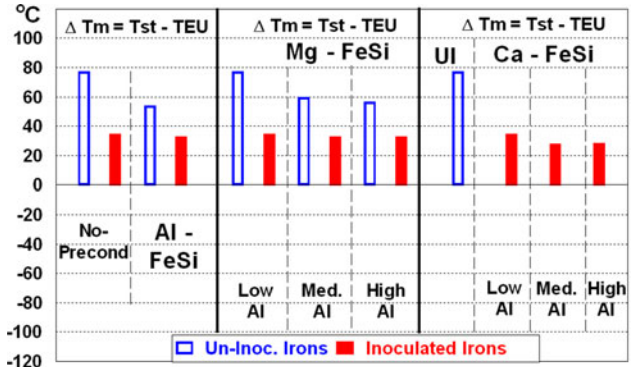

Fig. 5 Eutectic undercooling (ΔT_m) relative to stable (graphitic) eutectic temperature (Tst)

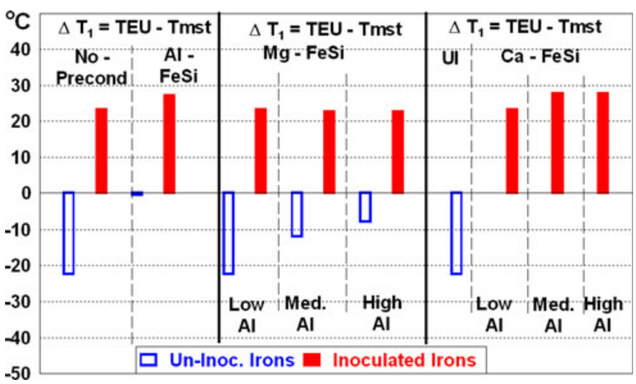

Fig. 6 Eutectic undercooling (ΔT_1) relative to metastable (carbidic) eutectic temperature (Tmst)

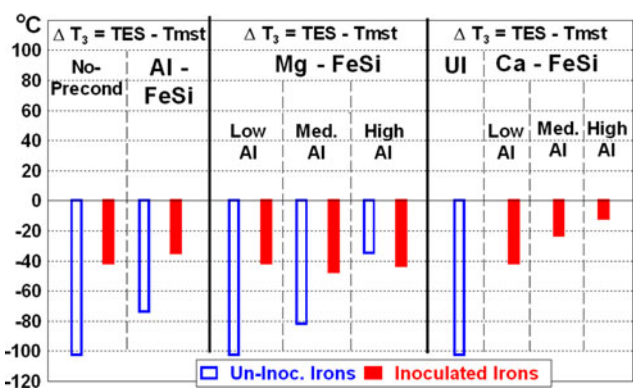

Fig. 7 Undercooling (ΔT_3) at the end of solidification (TES) relative to metastable (carbidic) eutectic temperature (Tmst)

pre-conditioner, while the Al-bearing MgFeSi treatment alloy is a less effective third option.

ΔT_3 = TES − Tmst is an important parameter for characterizing the behavior of the end of solidification. In these experiments, this parameter always showed negative values, but in a very large range ($\Delta T_3 = -9$ to -102 °C) (Fig. 7). The inoculation with Ca-FeSi had a positive effect, as ΔT_3 was never below −60 °C, compared to −60 to −102 °C for un-inoculated irons. The increase in aluminum was beneficial for reducing ΔT_3 in both un-inoculated and inoculated irons,

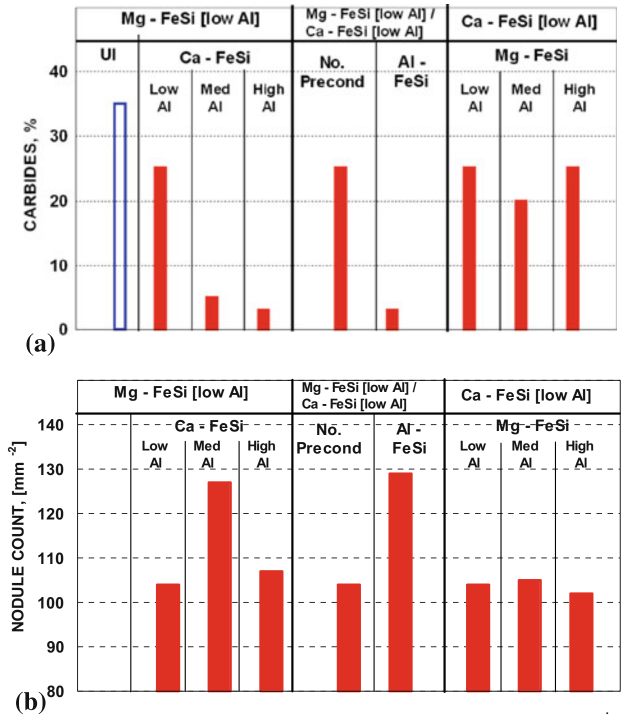

Fig. 8 Influence of aluminum source on the carbides amount (a) and graphite nodule count (b)

and the best source of Al appeared again to be the Al-bearing Ca-FeSi inoculant.

The round bar samples (25 mm diameter, 100 mm length, 0.59 cm cooling modulus, furan resin moulds, 1280-1330 °C pouring temperature) were also used for microstructure analysis, characterizing carbides, metal matrix and graphite morphology (Fig. 8).

The highest amount of carbides (35%) was found in the un-inoculated samples, without visible influence of residual aluminum present in the iron. Lower amount of carbides (20-25%) was typical for un-preconditioned and low Al, Ca-FeSi inoculated irons, independent of Al level in MgFeSi alloys. No more than 5% free carbides were observed in iron that were Al-preconditioned or inoculated with medium to high Al bearing Ca-FeSi alloys.

More than 80% nodularity was obtained, without detrimental influence of residual aluminum. Nodule count appears to be beneficially influenced by the residual aluminum, for Al-bearing Ca-FeSi inoculation or Al-FeSi preconditioning.

3. Case Studies

In the following section, some case studies to illustrate the efficiency of Al-bearing FeSi alloys in ductile iron production as inoculants or/and pre-conditioners of electrically melted irons are presented. Thermal analysis parameters, structure characteristics and chill test parameters have mainly been considered in the case studies presented.

3.1 Pilot Plant Case Study

More than 200 inoculants are commercially available in current market. A survey shows that more than 85% of these contain at least 0.8 wt.% aluminum, while none have more than 5 wt.%. Most of the alloys with very low level of aluminum are used for inoculation of gray iron. Almost all ductile irons are alloyed with aluminum-bearing inoculants, showing the empirical importance of this element. It is observed that many producers of heavy section ferrite ductile irons specially use inoculants with high level of aluminum, often combined with pre-inoculation with fade-resistant barium-bearing inoculants.

In a pilot plant slightly hypoeutectic (CEL 4.2 wt.%) 80%-ferritic ductile iron small size test parts were produced. The metal was melted in acid lining 1.5 metric ton medium frequency induction furnace, poured at 1520 °C, treated in 300 kg tundish ladle with 2 wt.% addition of 5.9wt.%Mg-0.5wt.%Ca-0.8wt.%Al-FeSi and inoculated at 0.25 wt.% with different alloys (0.2-0.7 mm size) added to filling stream of 50 kg pouring ladle 1 min before casting. The five different inoculants were:

i. 1wt.%Ca-1wt.%Al-1.8wt.%Ce-FeSi
ii. 2wt.%Ca-1wt.%Al-1.6wt.%Zr-FeSi
iii. 1wt.% Ca-4wt.%Al-FeSi
iv. 1wt.%Ca-1wt.%Al-FeSi
v. 1.5wt.%Ca-1wt.%Al-2.5wt.%Ba-FeSi.

Casting temperature was 1350 °C. Thermal behavior was recorded by use of ATAS (Adaptive Thermal Analysis System), graphite characteristics and wedge chill parameters were evaluated by microscopy. The relative performance of inoculant—i—is estimated as $RP_i = \Sigma_\kappa(X_{ik} - CL_k)/S_k$ where X_{ik} is measured value of property—k—using inoculant—i—CL_k is average value for property set—k—(column) and S_k is standard deviation form of the set. Thermal analysis performance is averaged and used as one parameter—k. Average performance has level 0% (Table 5).

The results showed that the high aluminum inoculant 1wt.%Ca-4wt.%Al-FeSi performed better than the other alloy bearing the same content of Ca and less Al, such as 1wt.%Ca-1wt.%Al-FeSi inoculant (Fig. 9). Overall, that the high Al-inoculant gave highest nodule count, but only mediocre nodularity. Iron inoculated with 1wt.%Ca-1wt.%Al-1.8wt.%Ce-FeSi alloy showed generally best performance in these tests, followed by 2wt.%Ca-1wt.%Al-1.6wt.%Zr-FeSi. The high barium bearing inoculant did not perform well during fast casting of small samples under the conditions in this trial.

3.2 Foundry Case Study

A foundry produced a range of ductile iron castings mainly for the automotive industry. Melting was via 8 metric ton medium frequency induction furnaces. Ductile iron of various grades are produced using charge consisting on 50 wt.% steel scrap, 50 wt.% cast scrap, FeSi fines, recarburiser. This is melted out to 1540 °C and tapping into 1800 kg converters containing Mg metal, Mischmetal and any alloying requirements. After treatment, the iron is transferred to a 7-ton autopour furnace prior to casting on a horizontal molding line. 0.05 wt.% of 3.5 wt.% Al, Ca-bearing FeSi was used, via in-stream inoculation unit (autopour). Occasional long period led to carbides and highlight shrinkage potential.

As trial procedure, 0.1 wt.% addition of Al and Zr bearing complex alloy [3-5 wt.% Al, 3-5 wt.% Zr, 0.6-1.9 wt.% Ca, 62-69 wt.% Si, Fe-balance] (Ref 10) made to the melting furnace. Iron was then tapped and Mg-metallic Fischer converter treated

Table 5 Test results for small size ferrite ductile iron using different inoculants with varying aluminum

Treatment	Property (k): inoculants	Thermal analysis parameters: TEU, °C	TER, °C	ΔT_r, °C	GRF1	GRF2	TES, °C	General thermal analysis performance	Nodule count, mm^{-2}	Nodularity, %	Clear chill, mm	Total chill, mm	Total Relative Performance
Mg5.9FeSi	Ca1-Al1-Ce1.8	1146	1152	6.26	78.9	25.0	1109		420.8	90.4	3.5	6.4	
	Ca2-Al1-Zr1.6	1147	1153	5.75	75.2	25.3	1109		433.5	89.3	4.0	6.7	
	Ca1-Al4	1147	1153	5.96	80.5	24.6	1108		443.1	84.4	3.9	6.7	
	Ca1-Al1	1146	1152	5.98	76.6	24.3	1108		423.6	84.5	4.4	7.8	
	Ca1.5-Al1-Ba2.5	1146	1153	6.68	80.3	35.3	1106		315.1	82.6	4.4	9.1	
Average	CL_j	1146	1152	6.13	78.3	26.9	1108		407.2	86.2	4.0	7.3	
St.dev.	S_j	0.50	0.32	0.36	2.32	4.71	1.42		52.23	3.38	0.36	1.13	
		Relative performance							$RP_{ik} = (X_{ik} - CL_k)/S_k$				$RP_i = \Sigma_k RP_{ik}$
Inoculant (i)	Ca1-Al1-Ce1.8	−26%	−1%	−36%	25%	40%	81%	14%	26%	123%	140%	87%	78%
	Ca2-Al1-Zr1.6	140%	−103%	105%	−132%	33%	41%	14%	50%	89%	22%	54%	46%
	Ca1-Al4	62%	−47%	45%	96%	49%	28%	39%	69%	−55%	32%	56%	28%
	Ca1-Al1	−74%	164%	41%	−75%	55%	25%	23%	31%	−51%	−88%	−39%	−25%
	Ca1.5-Al1-Ba2.5	−102%	−13%	−155%	85%	−178%	−174%	−90%	−176%	−106%	−106%	−158%	−127%

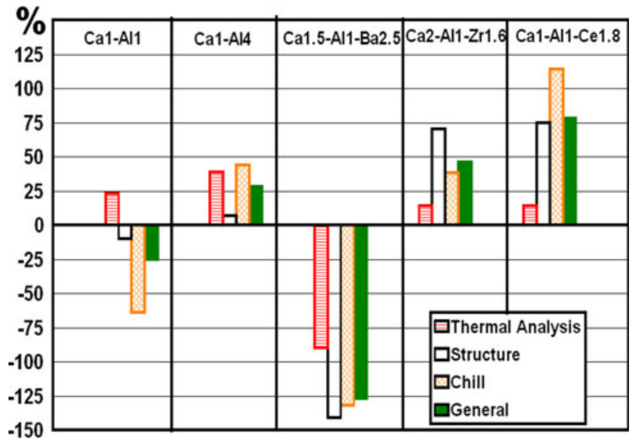

Fig. 9 Relative performance of Al-bearing FeSi-based inoculants

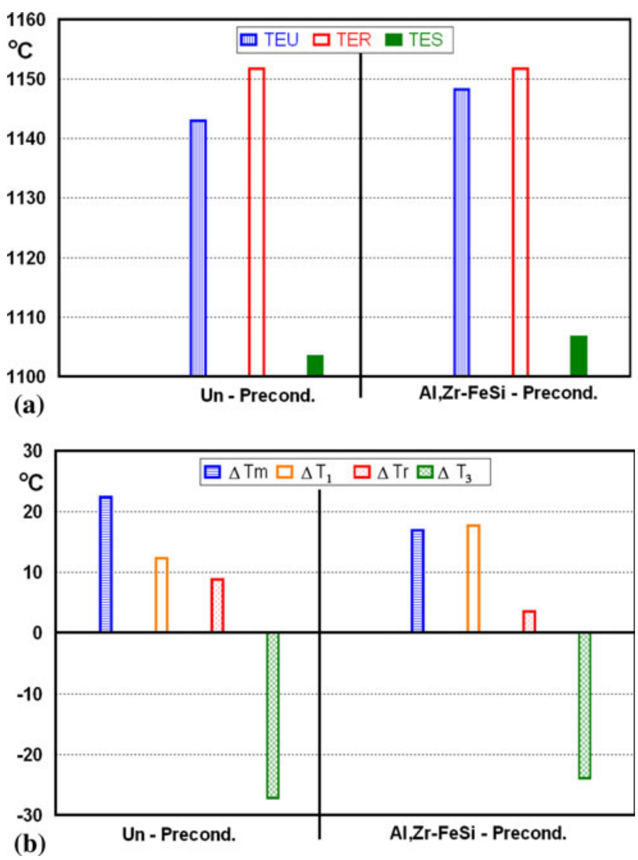

Fig. 10 Representative temperatures (a) and parameters (b) of cooling curves of un-preconditioned and 0.1 wt.% Al, Zr-FeSi preconditioned ductile irons [Mg-converter + 0.35 wt.% Al,Ca-FeSi inoculation]

and transferred to the autopour furnace. Inoculation was done in the stream using FeSi containing 1.0 wt.% Ca and 3.5 wt.% Al. Thermal analysis clearly shows the positive effect of preconditioning (Fig. 10).

The preconditioning raised the low eutectic temperature (TEU) with more than 5 °C, for the same level of the high eutectic temperature (TER). Consequently the eutectic undercooling, referring to the stable eutectic temperature (ΔT_m = Tst − TEU) decreased while the parameter referring to metastable eutectic temperature (ΔT_1 = TEU − Tmst) increased, respectively.

The reduction of recalescence (ΔT_r = TER − TEU) and combined with the increase in the temperature at the end of solidification (TES) and reduction in the metastable eutectic temperature (Tmst) as ΔT_3 = TES − Tmst indicate lower tendency to shrinkage formation.

Micro-specimen taken from castings with and without preconditioning illustrated the improved quality: nodule count increased by approximately 10%, carbides eliminated, improvements in thermal analysis characteristics maintained over 12 h, i.e. no "fade".

4. Conclusions

The presumptive role of residual aluminum proceeded from different sources, such as charge materials and FeSi-based preconditioner, Mg-master alloys and inoculants was investigated in laboratory experiments and plant trials. The conclusions drawn in the present paper based mainly on the scanning electron microscopy (SEM) analysis, thermal analysis, carbides sensitivity and graphite characteristics.

1. Two main chemistry systems of micro-inclusions (0.8-8.0 μm size) were identified in Mg-metallic (0.1 wt.% S initial) and MgFeSi treated irons (0.005 wt.% S initial), such as Ca-S-X and Mg-Si-O-X, with the majority of the inclusions in both matrix and nodules regardless of treatment type coming from second system.
2. Simple silicates were typically seen in the matrix, while more complex silicates, including Al, Ca, Ce, La, were found in conjunction with graphite and are probably acting as graphite nucleation sites. These complex silicates were mainly seen in the MgFeSi treated iron and often showed elevated Al-contents, according to higher residual aluminum content in this ductile iron.
3. Generally, Al-residual was found as an important, medium potency graphitizing influencing factor, in both un-inoculated and inoculated ductile irons: the most representative parameters of thermal analysis were improved, free carbides amount decreased, nodule count increased.
4. The greatest benefits were achieved when Al was introduced in to the iron via the inoculant late in the process or as pre-conditioner of the base iron early in the process. Al added via the MgFeSi provided the minimum benefit.
5. Some case studies illustrate the beneficial effects of an Al-containing pre-conditioner or/and Al-bearing, FeSi inoculant to eliminate previous problems with carbides and shrinkage porosity reduced in addition to improving nodule content over a wide range of components, mainly for automotive industry.

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