Application and Verification of Free Nitrogen Theory

in Gray Iron Melting using Electric Arc Furnace

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ABSTRACT

A 30 ton electric arc furnace with magnesia linings is used for melting spheroidal graphite iron in commercial operation. Although the electric arc furnace is considered the furnace most prone to inducing chill formation in commercial processes, this problem can be addressed by controlling the free nitrogen during operation. It was found that there is a strong correlation between the amount of free nitrogen in the chilled sample and the chill depth in wedge samples. If denitrification is suitably conducted, chill formation can be prevented. It is concluded that denitrification is the most effective anti-chill mechanism and the best graphitization process, apart from controlling the cooling rate. In this study, the examples in practice are introduced.

Keywords: free nitrogen, denitrification, chill, spheroidal graphite iron, electric arc furnace

1. INTRODUCTION

The electric arc furnace (EAF) has many benefits for the utilization of undefined and random raw materials, for the preparation of a large amount of molten iron by heating, and for desulfurization using basic linings, slag making, etc. The EAF is generally used for steel melting, but can also be used for gray iron melting. However, the use of the EAF for grey iron melting is quite rare in commercial practice because molten iron has a strong tendency to form a chill structure. Formation of the chill structure is thought to be induced by heating above 3000°C by the electric arc. The EAF exhibits the strongest propensity to induce chilling among the utilized furnaces, such as induction, cupola, and rotary furnaces. Spheroidal graphite iron (SGI) castings are particularly prone to chill formation. Therefore, such castings have reduced ductility and fatigue strength, and the quality of the castings is generally not guaranteed. In former practice, factors such as the temperature, raw materials, alloy elements, impurities, kind of linings, etc., were understood, whereas melting engineers were unable to elucidate the key factor inducing formation of the chill structure. This is the main reason why EAFs have not been put into general use.

As examples of kryptol furnace melting on the laboratory scale, Inoyama¹⁾ and Lee²⁾ reported that pretreatments like argon gas bubbling and the addition of aluminum and calcium to the base molten iron of SGI were effective for reducing the acid soluble nitrogen (N_s), thereby preventing chill formation. They analyzed the N_s and acid insoluble nitrogen (N_l). However, because N_s includes aluminum nitride (AIN) and magnesium nitride (Mg₃N₂) in conjunction with free nitrogen (N_F), some unspecified factors remained. At that time, N_s from AIN and Mg₃N₂ could not be separated as the analytical technology was not yet available. A schematic illustration of the analyzable nitrogen constituents is shown in Fig. 1. Lee³⁾ also evaluated the N_s effects and concluded that melting flake graphite iron under vacuum atmosphere was effective for obtaining a full graphite structure, even in a permanent mold. Unfortunately, similar experiments were not carried out for spheroidal graphite iron.

Some researchers^{4–6)} reported that the magnesium treatment temperature influences chill formation for spheroidal graphite iron. According to Kurai⁴⁾, magnesium treatment after superheating above 1,500°C was effective for reducing inverse chill in sand molds. Kitsudou^{5,6)} similarly reported that magnesium treatment at ~1,400°C after superheating over 1,600°C was effective for chill prevention in a permanent mold. Horie⁷⁾ succeeded in forming chill-free thin-wall sand casting samples by pretreatment with sulfur and mischmetal. Horie concluded that Ce sulfide promoted graphitization by acting as nuclei.

As described above, chill-free conditions have been achieved in the laboratory. However, the mechanism has not been clarified. Thus far, the experimental results have not been unified into a single theory. This is one of the reasons why the theories have not been adopted in foundry practice.

Based on the ferro (Fe)–carbon system equilibrium phase diagram⁸), the chill structure is only observed as cementite (Fe₃C). Even if silicon is added to this system and the Fe-C-Si system equilibrium phase diagram⁹) is considered, the result is the same. When these diagrams were drawn, the influence of the atmosphere would not have been taken into account. However, it is considered that nitrogen gas in the atmosphere contributes to the formation of Fe₃C. Nishi¹⁰) reported that ledeburite cementite in white iron and perlite cementite in grey iron formed solid solutions with molecular nitrogen. The authors postulated that atomic N may replace carbon in the Fe₃C lattice and promote chill formation.

The objectives of this study are two-fold, one is to prove the relation of N_F to chill formation in practice and the other is to establish the melting process with less possibility of chill formation in 30 ton EAF operation. The theory should be applicable in practice, and stable results should be obtained in processing a large amount of molten iron. Experiments are conducted on both SGI and flake graphite iron (FGI).

2. EXPERIMENTAL PROCEDURE

The raw materials shown in Table 1 were charged into a 30 ton EAF with magnesia linings and the base iron was melted. After melting down, dicalcium silicate, which has a basicity of about 2, was added to protect the surface of the base molten iron. When the temperature exceeded 1,500°C, the base molten iron was tapped into the ladle and returned to the

furnace. During this operation, the chemical composition was roughly adjusted using a stirring stream. The base molten iron (38.6 ton) was tapped into the ladle with an argon bubbling apparatus after again heating above 1,500°C. By stirring molten iron by Ar gas bubbling, the carbon and silicon content was precisely adjusted with a carburizer and Fe-75Si to obtain the final base molten iron. At the same time, the temperature was adjusted for pouring. Denitrification treatment was conducted with this process by Ar gas bubbling up to the CO/SiO₂ critical equilibrium temperature¹¹. The base molten iron was moved to a nearby mold in a foundry shop. The base molten iron was transferred from ladle to ladle, and during the transfer, Mg and inoculation treatments were conducted at \sim 1,400°C by the sandwich method. These treatments were scheduled for execution near the furnace because the time required for moving the molten iron from the melting shop to the foundry was more than 20 min. The time was considered too long to influence fading after the melt treatments. The chemical compositions of the samples are shown in Table 2. Small pieces of thin-wall steel plate were used as a cover material. The treated molten iron was poured into a furan sand mold at ~1,320°C. The product was used as a part of an injection machine with a rough weight of 36 ton (Fig. 2). The standard 50 mm Y-block (JIS G 5502, C type) test samples were cast on the product. The material grade was FCD450 (JIS G 5502). The mechanical properties of the cast-on FCD450 sample are specified in the Japanese Industrial Standards (JIS) as well as other standards. In this study, a separately cast sample was attached to the casting product because it was difficult to achieve safe pouring from big the ladle to the small mold. The time-temperature schedule for minimizing N_F is shown in Fig. 3^{12,13}. The schedule was previously applied to the heavy section casting products in the property and performance qualification test^{14,15}. To evaluate the influence of N_F on chill formation, the schedule was planned by considering deoxidation, nitrification, and denitrification. The wedge sample and metal mold chill sample for chemical analysis were taken at the turning points from melting to pouring, and the free oxygen (O_F) was measured at each point by using zirconia solid electrolyte. The shape of the wedge sample and the procedure for measuring the chill depth are shown in Fig. 4. The metal mold is shown in Fig. 5. The chemical composition of the chill samples was analyzed by using a spectrometer. They total oxygen (O_T) and total nitrogen (N_T) were also analyzed using a gas analyzer. Furthermore, the free nitrogen (N_F) was also analyzed by the procedure shown in Fig. 6. Analysis of the acid-soluble matter in ALN and Mg₃N₂ was not carried out in conventional studies^{1,2)}.

A similar operation was conducted for FGI. The product is part of a marine engine, material grade FC250 (JIS G5501), and the rough weight is 31 ton (Fig. 7). Φ 30 standard samples were cast on the product. Molten iron was poured into a furan sand mold at 1,320°C.

3. RESULTS

Each material was subjected to five temperatures using the same procedure. A similar trend was obtained for each material at the given temperatures. The representative results are shown below.

3-1. SGI castings

The chemical composition of the base and melt-treated molten iron at all sampling points are shown in Table 3. The desired final chemical composition was heavy section spheroidal graphite iron casting, and the carbon equivalent (CE) was set to the slightly hyper-eutectic composition. The gas composition and chill depth at each sampling point is shown in Table 4. N_F was calculated by deducting the quantity of all inclusion nitrides (N_I) from N_T . The values shown in Table 3 and 4 are illustrated in Fig. 8. The fracture surfaces of the wedge samples are shown in Fig. 9(a). There appeared to be a strong correlation between the C and Si content and the chill depth during preparation of the base molten iron; however, after inoculation, the chill depth was greater than that of the base molten metal. The chill depth was synchronous with higher temperature, but was not synchronous at lower temperature. Among the gaseous components, only N_F showed a correlation with the chill depth at all stages, whereas the other components did not. Overall, N_F is the only factor that was strongly correlated to the chill depth. Ar gas bubbling treatment in the ladle was effective for denitrification, but excessive treatment caused reabsorption of nitrogen. Nitrogen absorption occurred during the process of melt treatment. This

chilling tendency was also observed for the wedge sample. The microstructure and mechanical properties of the cast-on test sample are shown in Fig. 10(a) and Table 5, respectively. Figure 10(b) presents an example of the chill microstructure of the cast-on test sample from conventional practice. The N_F is the only factor that was strongly correlated with the chill depth of the wedge samples, whist no such relationship was observed for any of the chilling factors such as the chemical composition, temperature, and other gaseous components (O_T , O_F , and N_T). The chill depth generally increases after Mg and inoculation treatment, as also observed in this study, indicated by an increase in N_F . The chill depth and N_F also increased when the sample was poured from the ladle to the basin. There may also be some increase in the chilling tendency during filling of the mold with the melt-treated sample.

Despite concerns about the formation of ledeburite cementite and/or inverse chill because of the tendency towards chilling in wedge samples as described above, the microstructure and mechanical properties of the cast-on samples and product casting was unaltered, similar to the results of the previous qualification test^{14,15}. This is attributed to the large size of the product casting and slow cooling rate utilized herein.

3-2. FGI castings

The chemical composition of molten iron in the furnace and ladle is shown in Table 6. The gas composition and chill depth at each sampling point is shown in Table 7. The values shown in Table 6 and 7 are illustrated in Fig. 11. The fracture surfaces of the wedge samples are shown in Fig. 9(b). Here, the phenomena were similar to those of the SGI, wherein a strong correlation to the chill depth was only observed for N_F . The FC250 material contains no Mg, but contains much more sulfur; therefore, the chill depth is shorter than that of FCD. The microstructure and mechanical properties of the Φ 30 standard sample are shown in Fig. 12 and Table 8 respectively. The issues encountered with the FC250 material were not observed, the microstructure did change (as occurred with SGI), and the product casting did not affect the quality.

4. CONSIDERATIONS

4-1. Possibility of Fe₃(CN) formation

As described above, N_F showed a strong correlation to the chill depth, and even promoted chill formation. This correlation with N_F was necessary for the formation of ledeburite Fe₃C. It is proposed that the actual morphology will comprise carbonitride [Fe₃(CN)] because the amount of free N is much less than that of C. N_F may replace a part of the C atoms in the ledeburite crystal lattice (Fig. 13)²). If the N_F content is several mass %, Fe_xN_y¹⁶ species may be formed. The formation of Fe₃(CN) is supported by the bonding properties of Fe and N from the viewpoint of the electronegativity¹⁷⁾. This is because the difference in the electronegativity of Fe and N is larger than that of Fe and C (Fig. 14). Based on the atomic size, it is more probable for N atoms to infiltrate the Fe₃C crystal structure because the diameter of the N atom (1.06Å) is smaller than that of the C atom (1.42Å)¹⁸⁾. The existence of carbonitride in the solid state has already been reported by Liedtke et al.¹⁰ However, $Fe_3(CN)$ is not stable in the liquid state because nitrogen (here N_F) is a gas-phase element. If the solidification is slow enough, nitrogen (N_F) may adopt the gas state. In contrast, if solidification is fast enough, N_F may take the Fe₃(CN) form. A part of the Fe-C system equilibrium phase diagram illustrating the possibility of Fe₃(CN) formation is shown in Fig. 15. Here, the authors propose N_F theory for chill formation and graphitization. If N_F is controlled and there is sufficient denitrification, chill formation can be prevented. In other words, full graphitization will be guaranteed. In fact, even permanent mold castings in spheroidal graphite iron with a wall thickness of 5.4 mm can be successfully prepared chill-free $^{12,13)}$ when N_F is controlled based on the concept described above. The N content in cementite can be analyzed, as performed in steel research¹⁹. At the same time, the formation of Fe₃(CN) was clear.

After ensuring that the conditions are conducive to anti-chilling and/or full graphitization, site theory²⁰⁻²²) is helpful for achieving the spheroidal graphite morphology in practice. This theory is based on extensive laboratory data and practical applications.

4-2. N_F controls

The factors that control N_F and thus contribute to chill formation during the overall process of SGI and FGI manufacture are described and the reasons are explained below.

4-2-1 Chemical composition of base molten iron

This description is common to both SGI and FGI. Although C and Si are introduced to minimize defects such as shrinkage and to guarantee the mechanical properties, they are expected to minimize nitrogen (N_F) adsorption²³⁾ and the risk of chill formation²⁴. The content of C and Si should be adjusted to around the CO/SiO₂ equilibrium critical temperature¹¹⁾ to minimize the N_F absorption due to super-heating. Oxidative loss of the additive is also minimized by this operation. The temperature is calculated by applying Eqs. 1 and 2. When the general chemical composition of the base molten iron is 3.50 C and 1.50 Si (mass%), the calculated T_{EC} is ~1,405°C.

Where T_K is the absolute temperature. A lower sulfur content in the base molten iron is advantageous for graphite spheroidization, but accelerates nitrogen (N_F) adsorption when the content too low²⁵). This means that a low S content increases the risk of chill formation. Because basic slag is formed and a basic lining is used in the electric arc furnace, desulfurization is expected during melting. Therefore, Fe-48S is added if needed. Based on experimental analysis, 0.010~0.013 mass% S is considered suitable for the base molten metal of SGI. For FGI, Fe-48S was added to the base molten iron to avoid heat cracking. The suitable content is around 0.060 mass% S.

4-2-2. Superheating

This discussion pertains to both SGI and FGI. Superheating is mainly applied for deoxidation of base molten iron utilizing CO (Eq. 3) above 1,500°C. The reaction begins when the CO/SiO₂ equilibrium critical temperature (T_{EC}) is exceeded.

 $SiO_2 + 2C \Rightarrow Si + 2CO\uparrow \cdots (3)$

Here, SiO_2 refers to the materials called slime in the base molten iron and lining material of the furnace; C is the carbon in the base molten iron; CO is carbon monoxide gas. However, in practice, the sensible and visible reaction begins at ~1,450°C. Moreover, the beneficial reaction for speedy melting occurs above 1,500°C. This is called superheating. Superheating should be ended when the CO reaction in the base molten iron is complete, otherwise, the CO reaction is initiated at the interface between the furnace lining wall and the molten iron. This results in the loss of C from the base molten iron and extraction of Si from the furnace lining. In other words, the chemical composition is readjusted and the wear life of the furnace lining is shortened.

Kitsudo⁶⁾ reported experimental evidence that a temperature of 1,600°C is needed to decrease the oxygen content of the metal. However, such a high temperature is not utilized in practice because of the problems described above. In electric arc furnace melting, the molten metal has a shallow depth and wide surface area; therefore, artificial slag is usually formed for the two following reasons: (1) to minimize heat loss and (2) to prevent or minimize oxidation and nitrification. **4-2-3. Mg treatment**

After superheating, the Mg treatment temperature for SGI should be lowered as much as possible for natural denitrification. When the temperature is reduced from the superheating temperature, the N_F solubility is also naturally reduced. However, the temperature should not be in the range of oxide formation. In this study, the actual CO/SiO₂ critical temperature^{12,13} was selected for Mg treatment. This is the temperature when SiO₂ slag begins to form on the surface of the base molten iron, which is approximately 15°C below the equilibrium temperature¹³. Mg vaporizes at ~1,100°C. When the temperature is much higher than this, the vapor pressure become higher and the molten surface forms severe waves as seen in boiling water. Nitrogen (N_F) is thought to be absorbed from the atmosphere close to the molten surface during the waving process. The severe waving increases the surface area of the molten iron. Although molecular N₂ is known as an inert gas and is stable, dissociation of the gaseous form and persistence of atomic N are

possible. For example, nitrogen oxide (NOx) is generated by lightning²⁶ or when air is heated beyond $1,000^{\circ}C^{27}$. These phenomena indicate the possibility of the generation of atomic N through reaction processes. These situations are comparable to the electrical discharge in the electric arc furnace and the molten surface.

Spheroidizing agents with the lowest possible Mg content should be selected to achieve gentle Mg vaporization. The reason is the same as described above. The severe Mg reaction causes severe waves and nitrogen (N_F) absorption. Furthermore, the N_T of the spheroidizing agents should be as low as possible, otherwise the molten iron becomes contaminated by N_F from the alloys.

4-2-4. Inoculation

This description pertains mainly to SGI. Inoculation imparts two effects (Fig. 16). One is the offset of N_F to avoid the risk of chill formation. In fact, in practice, powerful inoculants contain elements such as aluminum, calcium, strontium, zirconium, etc., that have strong infinity for N_F . This is not a general theory, but we developed our own theory through experimentation. Alloy makers empirically determined the elemental compositions with almost no theory, based on trial and error. The other effect is to introduce micro-concentration spots of Si into the molten iron. This causes the nodule number to increase. These inoculation effects are gradually lost with time. This fading phenomenon leads to newly absorbed N_F after inoculation. The micro-concentration spots are homogenized, and the number of graphite nucleation sites decreases. Therefore, inoculation should be conducted at the latest stage possible before solidification starts.

4-2-5 Pouring

Pouring must to be conducted as fast as possible after inoculation and the stream must be laminar flow. The lower the amount of combustion gas, including N, the better. The ignition loss in the sand mold must be low enough. Molten flow in the sand mold is desired to be as calm and fast as possible.

4-3 Difference in chilling tendency of SGI and FGI

The chilling tendency of SGI after melt treatment is generally higher than that of FGI. One reason why the N_F absorption of SGI is greater than that of FGI is because the final molten iron of SGI is strongly refined on deoxidation, denitrification, and desulfurization by Mg treatment. Additionally, the S content of the base molten iron in SGI changes to a lesser degree than that in FGI. According to Choh²⁵, the nitrification of molten iron becomes easier when the S content is low enough.

5. CONCLUSIONS

The following points were found through EAF melting of gray iron:

- (1) There is a strong correlation between N_F and the chill depth. When N_F is higher, the chill depth is deeper.
- (2) Chill formation can be avoided by denitrification.
- $(3) N_F$ has a high propensity to replace C atoms in the Fe₃C lattice and promote chill formation.
- (4) If sufficient denitrification occurs throughout the process from melting to pouring, only stable solidification will be possible based on the Fe-C-Si equilibrium phase diagram, i.e., graphite solidification will be guaranteed.

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Table 6 Chemical composition of base and treated molten iron in flake graphite iron casting

Table 7 Gas composition and chill depth of base and treated molten iron in flake graphite iron casting

Table 8 Mechanical properties of cast-on test sample in flake graphite iron melted in electric arc furnace

Total nitrogen									
	(a) General study								
Acid solub (Free N, A	le nitrogen IN, Mg ₃ N ₂)	Acid insoluble nitrogen = Nitride'							
(b) Studie	s by Y. $Lee^{1,3)}$, N	N. Inoyama ²⁾ , K. Kurai ⁴⁾							
Free N	AlN, Mg ₃ N ₂	Acid insoluble nitrogen = Nitride'							
Free N	All nitride								

(c) This study

Fig. 1 Forms of analyzable nitrogen in chilled iron samples.







Fig. 3 Temperature-time schedule from arc furnace melting to pouring^{12,13}).





Fig. 4 Illustration of wedge samples taken at all sampling points.



Fig. 5 Permanent mold made of steel (SS400) for sample analysis.



Fig. 6 Procedure for free nitrogen analysis.



Rough dimension ; W3,700 x L2,600 x H2,600 mm

Fig. 7 Three-dimensional illustration of a part of marine engine as FC250 casting product prepared in 30 ton electric arc furnace.



Fig. 8 Relationship of chill depth to melt conditions for spheroidal graphite iron.



(a) Spheroidal graphite iron



(b) Gray iron

Fig. 9 Fracture surfaces of wedge samples showing molten state.



Fig. 10 Microstructure of cast-on sample in SGI melted in electric arc furnace.



Fig. 11 Relationship of chill depth to melt conditions for flake graphite iron.



Fig.12 Microstructure of cast-on sample in FGI melted in electric arc furnace.



Fig. 13 Crystal structure of cementite $(Fe_3C)^{2}$.



Fig. 14 Electronegativity scale developed by L. Pauling¹⁷⁾.



Fig. 15 Iron range of Fe-C system equilibrium phase diagram⁸⁾ and N_F in cementite structure.



Fig. 16 Potential and expected effects of inoculation.

Material		Ratio					
Wateria	С	Si	Mn	Р	S	Mg	(wt%)
Pig iron	4.17	0.26	0.03	0.027	0.015		21.7
Return	3.52	0.25	0.22	0.055	0.008	0.053	41.8
Steel scrap	0.01	1.11	0.19	0.011	0.008		35.1
Fe-75Si	0.05	75.70	tr.	0.015	0.005	—	1.1

Table 1 Raw materials for Arc furnace melting

Table 2 Chemical composition of spheroidizer and inoculant

Agent	(Addition				
	Si	Mg	Ca	RE	Al	(wt%)
Spheroidizer	49.88	6.07	1.82	≦0.01	0.63	1.1
Inoculant	74.45		1.72		1.90	0.4

Process		Time after	Temp.	. Chemical composition (mass %)								
		(min.)	(°C)	С	Si	Mn	Р	S	Ce	Mg	CE	
		0	1430	3.16	0.95	0.20	0.051	0.014	0.000	0.002	3.48	
		11	1482	3.12	0.92	0.21	0.051	0.014	0.000	0.001	3.43	
Melting		17	1508	3.11	0.90	0.21	0.050	0.014	0.000	0.002	3.41	
in furnace		37	1420	3.32	1.27	0.21	0.051	0.013	0.000	0.001	3.74	
		50	1477	3.25	1.21	0.22	0.051	0.012	0.000	0.001	3.65	
		58	1509	3.24	1.18	0.22	0.050	0.012	0.000	0.001	3.63	
		65	1445	3.51	1.29	0.22	0.051	0.012	0.000	0.001	3.94	
Argon bubbling		71	1430	3.50	1.31	0.22	0.051	0.012	0.001	0.001	3.94	
in ladole		77	1415	3.55	1.42	0.22	0.051	0.012	0.001	0.001	4.02	
		80	1409	3.54	1.42	0.22	0.050	0.012	0.001	0.001	4.01	
Before treatment	Ladle	93	1397	3.59	1.43	0.23	0.050	0.012	0.001	0.000	4.07	
After treatment	Ladle	101	1339	3.55	2.27	0.23	0.057	0.010	0.002	0.057	4.31	
	Basin	106	1311	3.57	2.26	0.23	0.057	0.010	0.003	0.052	4.32	
										CE=C+	-1/3Si	

Table 3 Chemical composition of base and treated molten iron in spheroidal graphite iron casting

Table 4 Gas composition and chill depth of base and treated molten iron in spheroidal graphite casting

Deserves		Time after	C	Chill				
Process		(min.)	O _T	O _F	N _T	N _F	NI	(mm)
		0	51	2	68	34	34	55
		11	50	1	71	33	39	55
Melting		17	36	5	68	33	36	55
in furnace		37	33	2	69	12	57	10
		50	37	4	75	46	30	36
		58	24	2	67	43	49	55
		65	32	1	76	22	30	9
Argon bubbling		71	41	1	68	1	70	10
in ladole		77	29	1	74	3	70	6
		80	32	1	76	3	71	7
Before treatment	Ladle	93	23	1	74	7	67	6
A ftor treatment	Ladle	101	8	0	62	10	53	15
After treatment	Basin	106	11	0	61	17	44	19

		Hardness			
Sample*	Proof	Tensile	Elongation	Reduction	
Sumple	stress	stress strength		of area	HB
	(Mps)	(Mpa)	(%)	(%)	
FCD450-10	>280	>450	>10		140~210
50Y-block	337	484	17	19	170

Table 5 Mechanical properties of cast-on test sample in spheroidal graphite iron melted in electric arc furnace

* JIS G 5502-2001

Process	Time after	Temp.	p. Chemical composition (mass %)							
	(min.)	(°C)	С	Si	Mn	Р	S	CE		
	0	1499	2.89	1.56	0.46	0.050	0.046	3.41		
Melting in furnace	22	1555	3.52	1.82	0.66	0.050	0.059	4.13		
(Bottom bubbling)	45	1477	3.28	1.36	0.29	0.050	0.011	3.77		
	59	1476	3.32	1.35	0.66	0.049	0.011	3.77		
	65	1418	3.70	1.72	0.67	0.051	0.063	4.27		
Argon bubbling	69	1406	3.70	1.81	0.67	0.051	0.062	4.30		
in ladole	79	1384	3.62	1.81	0.66	0.050	0.060	4.22		
	82	1375	3.57	2.00	0.66	0.050	0.061	4.24		
Ladle	94	1360	3.56	2.03	0.66	0.050	0.057	4.24		
Basin	109	1328	3.61	2.02	0.67	0.051	0.059	4.28		

Table 6 Chemical composition of base and treated molten iron in flake graphite iron casting

D	Time after	C	Chill				
Process	(min.)	Т•О	F•O	T•N	F•N	P•N	(mm)
	0	42	2	95	21	74	55
Melting in furnace	22	20	3	88	28	60	55
(Bottom bubbling)	45	32	2	93	4	89	35
	59	27	1	95	21	74	55
	65	29	1	93	2	91	5
Argon bubbling	69	24	1	94	7	87	6
in ladole	79	32	1	90	6	84	4
	82	28	1	90	2	89	6
Ladle	94	32	1	89	1	89	6
Basin	109	39	1	91	5	86	8

Table 7 Gas composition and chill depth of base and treated molten iron in flake graphite iron casting

MD; Melt down, $O_T\,$; Total Oxigen, $O_F\,$; Free Oxigen $N_T\,$; Total nitrogen, $N_F\,$; Free nitrogen, $N_I\,$; Inclusions as nitride

Table 8 Mechanical properties of cast-on test sample in flake graphite iron melted in electric arc furnace

Sample * (mm)		Tensile	Transverse	Hardness	
		strength (Mpa)	Road (N)	Defrection (mm)	HB (10/3000)
FC250	Separately cast	>250	-	_	< 241
	Cast-on t80~150	>170	-	_	
Φ30 x L500 cast-on t120		282	11425	6.0	217

* JIS G 5501-1995