Proceedings of the 72nd World Foundry Congress
21-25th May 2016, Nagoya, Japan

Mechanism of the molten metal surface pattern generating in gray cast iron

Toshitake Kanno[1], Yuki Iwami[1], Taiji Fukuo[2], Natsuki Miyai[2], Yuichi Hiramoto[1], Hideo Nakae[1]
[1] Kimura Chuzosho Co., Ltd., 1157 Shimizu-cho, Shizuoka-ken, Japan
[2] Nagaoka unibersity of Technology, 1603-1 Kamitomioka Nagaoka, Niigata-ken, Japan

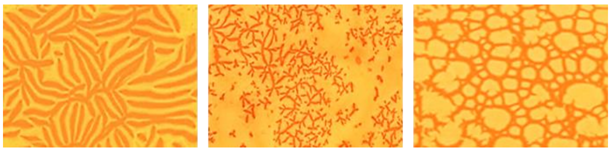
The surface patterns called Bamboo-leaf type, Pine needle type or Hexagonal type appear at around 1623 K on the molten iron. The origin of the surface patterns is a surface SiO_2 film which is formed by the oxidation of Si. The difference in radiation rate between SiO_2 and molten iron makes the patterns visible. The addition of 0.02% S reduces the surface tension remarkably. As a result, a complex Marangoni convection occurs beneath the surface and it generates the complex surface patterns. It has been said that the surface pattern can be shown only in a cupola. However, the reason is that Marangoni convection occurs due to sulfur coming from cokes in a cupola. Therefore, even in an electric induction furnace, if above conditions are satisfied, the surface pattern can be shown.

Keywords: *molten metal, surface pattern, gray cast iron, sulfur, silicon, surface tension. .*

1. Introduction

In a cupola molten metal, a surface pattern of Bamboo leaf type, Pine needle type, or Hexagonal type appears at around 1623 K, as shown in Fig.1. Sometimes the quality of molten gray iron metal was judged by those patterns.

As for the surface patterns, reported that it is an oxidation film of FeO-SiO_2 reported that it is not shown in an electric induction furnace [1-5]. However, the mechanism of the surface pattern is still unknown definitely. This research aims to reveal the formation mechanism of the patterns.



Bamboo-leaf Pine needle Hexagon

Fig. 1 Molten cast iron surface pattern in gray iron.

2. Experimental method

We observed the surface of molten metal during increasing temperature with heating(power on) and during decreasing temperature with cooling(power off) in a high-frequency induction furnace(output 50kW and 3000Hz, internal diameter of the furnace 200mm, melting capacity 50kg, refractory lining with 23mass%Al_2O_3 and 72mass%MgO (hereinafter referred to as %)). In this experiment, S and Si content were varied, based on the composition of FC300 (Fe-3.2%C-0.75%Mn-0.07%P). To investigate the effect of Si, Si content was varied form 0.05% to 3.5% while S content was set at 0.16%.

To identify the substance of the patterns, air was blown on the melt's surface at 1773 K where the surface pattern was not shown (we call it patternless surface) and Ar gas was blown on the melt's surface at 1623 K where the surface pattern was shown (We call it patterned surface).

3. Results of the experiments and discussion

3.1 Effect of S and Si

Fig.2 shows the relationship between S content and molten cast iron surface pattern. Molten iron with S content of over 0.02% starts to form a pattern, which develops in the order of bamboo-leaf, pine-needle, and hexagonal type as the S content increases.

Fig.3 shows the relationship between Si content and molten cast iron surface pattern. Molten iron with over 0.5%Si forms the pattern. As Si content increases, pattern develops in the order of bamboo leaves, large hexagons, and small hexagons. Also as Si content increases, the temperature rage at which the patterns appear widens.

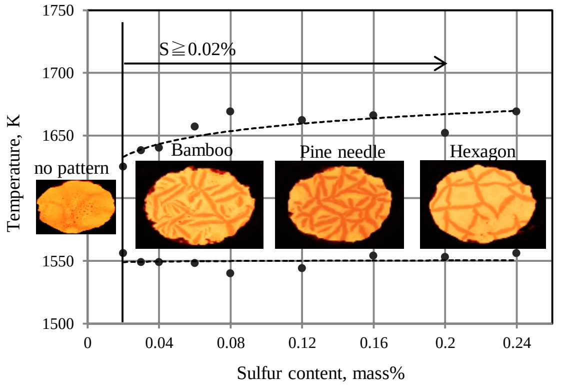


Fig. 2 Relationship between S content and surface pattern (Decreasing temperature).

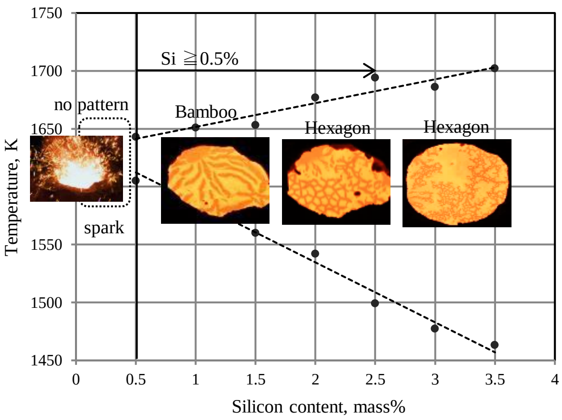


Fig. 3 Relationship between Si content and surface pattern (Decreasing temperature).

3.2 Effect of air or Ar on SiO_2 film

As shown in Fig.4, a pattern suddenly appears when air is blown on the patternless melt surface at 1773 K. On the other hand, the pattern disappears at the part where Ar gas is blown at 1623 K. This result shows that a surface pattern can be visualized, because SiO_2 film forms based on an reaction equation of $SiO_2+2C=Si+2CO$, happening in cast iron molten metal with much quanntity of C and Si. It is thought that a surface pattern appears in more than 0.5%Si, because Si is necessary for this reaction.

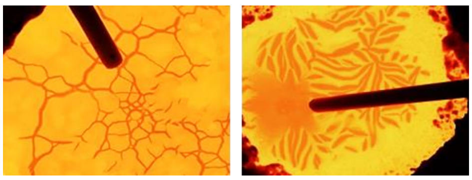


Fig. 4 a) Air flow. b) Argon flow.

3.3 Visualization due to difference in a radiation rate

As shown in Fig.5, because a radiation rate of the molten metal is different from SiO_2 film, the surface pattern is visualized. The molten metal's temperature becomes lower directly under the SiO_2 film. It is thought that the temperature difference causes the surface tension difference.

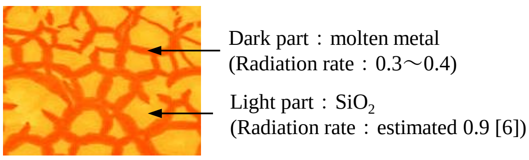


Fig. 5 Visualization due to radiation rate difference.

3.4 Effect of S on Marangoni convection

Surface tension is known to decrease when S is added in cast iron molten metal. Thus, it is thought that a surface pattern appears when S content becomes more than 0.02%. However, the complicated phenomenon such as the surface pattern does not occur only by the fallen surface tension.

Fig.6 shows the effect of surface tension of 18-8 stainless steel (Calculated results) [7]. There is a flexion point temperature in the relation between temperature and surface tension. The flexion point temperature and above mentioned radiation rate difference causes the surface tension difference It is thought that the complicated Marangoni convection appears due to the surface tension difference.

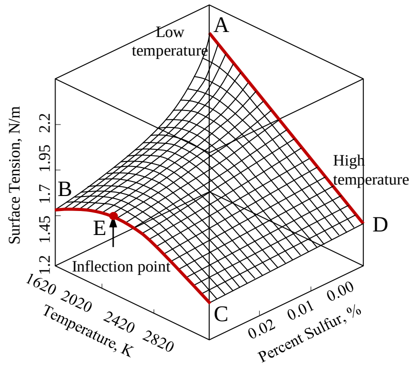


Fig. 6 Effect of concentration on the surface tension of molten 8Ni-18Cr-Fe Stainless steel (Calculation results) [7].

4. Summary

When SiO_2 film occurs based on the reaction of $SiO_2+2C=Si+2CO$, the surface pattern is visualized. S content of over 0.02% reduce surface tension . In addition to, there is a inflection point temperature in the relation between temperature and surface tension. As the result, the complicated Marangoni convection occurs and surface patterns appear. Therefore, the required conditions for pattern formation are as follows; (1) over 0.02%S, (2) over 0.5%Si, (3) appropriate amount of C, and (4) forming SiO_2 film.

References

[1] T. Kusakawa: *the Cupola Handbook* (Nihon Imono Kyokai) (Maruzen) (1957) 211

[2] T. Ishino: *the Handbook on Melting Cast Iron* (Nihon Imono Kyokai) (Maruzen) (1983) 185, 222

[3] Y. Saito: *Foundry Engineering* (Marauzen) (1965) 174

[4] O. Madono: Giessenei, 21 (1957) Nov. 5. 714

[5] E. Fuji: *Surface Patterns and Qualities of Molten Cast Iron* (Japan Foundry Forging Society) (2001) 104

[6] The Iron and Steel Institute of Japan: *the Handbook on Melting Welding Properties* (1972) 310

[7] W. Pitscheneder, T. DebRoy, K. Mundra and R. Ebner: 75Welding Journal March (1996) 71