Distribution and Detriment of Bubbles in Continuous Casting Interstitial Free Steel Slab

Min WANG,1,2)* Yan-ping BAO,1,3) Li-hua ZHAO,2,3) Quan YANG2) and Lu LIN1,2)

1) State Key Laboratory of Advanced Metallurgy, University of Science and Technology Beijing, Haidian District, Xueyuan Road 30#, Beijing, 10083 China.  2) National Engineering Research Center of Flat Rolling Equipment, University of Science and Technology Beijing, Haidian District, Xueyuan Road 30#, Beijing, 10083 China.  3) School of Metallurgical and Ecological Engineering, University of Science and Technology Beijing, Haidian District, Xueyuan Road 30#, Beijing, 10083 China.

(Received on September 18, 2014; accepted on December 24, 2014)

The distribution and detriment of bubbles in ultra low carbon interstitial free steel were studied by X-ray radiographic and cold-rolled experiment; a total of 24 pieces samples with size 230 mm × 65 mm × 2 mm were detection and 150 bubbles were counted; the results showed that: (1) Two bubbles bands formed in continuous casing slab; bubbles distributed asymmetry in thickness direction of the slab; small bubbles mainly concentrated in inner art side 1/8 to 1/4 in thickness direction; large bubbles were main in center of the slab in thickness direction; (2) Hundreds of inclusions with sizes 2 μm to 10 μm accumulated in cone-shape region after bubbles. Inclusions or Fe and FeO particles often attached or mixed with the bubbles. (3) Small bubbles entered into down-flow easily and rushed out the mould, bubbles and inclusions accumulative band formed in inner art side of the slab. (4) The bubbles, inclusions around the bubbles or large Fe and FeO particles mixing with bubbles became source of the sliver defect.

KEY WORDS: bubbles distribution; interstitial free steel; X-ray radiographic; silver defect.

1. Introduction

In order to avoid nozzle clogging, argon gas was blown into submerged nozzle from stopper during slab continuous casting process. But blowing argon gas also affected flow characteristic of liquid steel in mold especially when a asymmetric unbalanced flow happened.1,2) Argon bubble captured by solidified shell were key sources of defects after rolling, such as pencil blister and sliver; inclusions often accompanied with the bubbles during the continuous casting process and also some inclusions attached on the bubbles can remove by bubble floatation.3–5) Abbel et al. reported that large argon bubbles (diameter >0.5 mm) had a non-homogeneous distribution in slab in respect width and depth based on radiographic method.6) Miyake et al. believed that the distribution of bubbles in slab depends on the steel grade, especially on the sulfur content based on study on Kakogawa Work; and the authors pointed that electromagnetic stirring in the mold (M-EMS) was effective for removing bubbles and reduce sliver defect.7) In cold rolled IF steel, slivers and blow-holes were two main types of visual surface defects; generally, the defects were caused by argon bubbles or argon bubbles in combination with entrapped mould powder; the sliver defects had relationship with the argon bubbles containing the alumina clusters or mould slag.8) So it is important to evaluate the detriment and evolution of bubbles’ distribution in steel slab.

2. Experimental Method

This paper focused on the study on the bubbles’ distribution in ultra low carbon interstitial free steel whose chemical composition was listed in Table 1; and the bubbles were detected by X-ray radiographic and cold-rolled experiment; the X-ray detection parameter was listed in Table 2. A large slab specimen with size 400 mm (width direction) × 230 mm (slab thickness direction) × 65 mm (casting direction) was cut from the continuous casting slab in SHOU GANG Qian’an steel work in China. The slab section was 1 600 mm (width) × 230 mm (thickness) and the continuous casting conditions for this steel were listed Table 3. During the con-

Table 1. Chemical composition of IF steel/wt%.

| Elements [C] | S | Si | [Mn] | [P] | [S] | [Al]T | [Ti] | [N] |
|-------------|---|----|------|-----|-----|-------|-----|-----|
| Range       | 0.002 | 0.06–0.15 | 0.06–0.15 | 0.09 | 0.010 | 0.02–0.045 | 0.05–0.09 | 0.004 |
| target      | 0.003 | 0.06–0.15 | 0.06–0.15 | 0.09 | 0.010 | 0.02–0.045 | 0.05–0.09 | 0.004 |

* [Al]T represent the total aluminum content in liquid steel.

Table 2. Test parameters of X-ray radiographic machine.

| Testing standard |JB/T4730.2-2005|
|------------------|--------------|
| voltage          | 160 kV       |
| exposure time    | 2.5 min      |
| focal distance   | 900 mm       |
| current          | 5 mA         |
| Film type        | AGFA C7      |

* Corresponding author: E-mail: worldmind@163.com
DOI: http://dx.doi.org/10.2355/isijinternational.55.799
tinuous casting process, argon gas pipeline was connected with the tube situated in the center of stopper body with diameter 40 mm; the other hand of tube connected with stopper crown. In the center of stopper crown, there was a hole with diameter 5 mm; the argon gas injected into the submerged entry nozzle by the hole of stopper crown with flow rate 4 L·min⁻¹ and pressure >0.10 Mpa. So, bubbles often accumulated in the slab. Here, we mainly studied the bubbles’ distribution in quarter of the slab width; because in this steel work, most of sliver defects on cold-rolled sheet appeared in this area; as shown in Fig. 1(a), under the surface of defect, many FeO particles existed, which may be relevant with the bubbles’ accumulation (see Fig. 1(b)). It was important to judge the relationship between bubbles’ distribution and defects’ formation on surface of cold-rolled sheet. In this study, a total of 24 pieces samples were chose to do X-ray detection. Samples preparations for bubble detection were shown in Fig. 2; the samples were machined into slices with size 230 mm × 65 mm × 2 mm, and smooth surfaces on both sides.

The detection mechanism of X-ray radiographic was described in Fig. 3. The X-ray beamed on the surface of sample; after the ray penetrating through the sample, image formed on the film. The defect existed in the sample were shown in the film. When there was no defect in the sample, intensity change of X-ray accorded with Eq. (1). When defects existed in the sample, intensity of X-ray radiation attenuated according to Eq. (2). The light of optical density in film image depended on the difference between defects and steel matrix. Due to apparent difference between bubbles and steel matrix, the bubbles could be distinguished from film image easily.

\begin{equation}
J_a = J_o \cdot e^{-\mu S} \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \ quad
X-ray in the defect.

3. Results and Discussion

After X-ray radiation detection, bubbles in steel samples were gotten from the film image. Figure 4 was a diagram of bubbles’ distribution on the film. Figure 4(a) was 30 mm from the narrow side; Fig. 4(b) was 266 mm from the narrow side. Different sizes of bubbles were displayed on the image. A total of 24 pieces samples were detected and the numbers of bubbles in different location of the slab were summarized in Table 4. There were 150 bubbles totally. Bubbles’ three-dimensional distribution showed in Fig. 5. In the thickness direction, bubbles showed an asymmetrical distribution. Small size bubbles (<0.5 mm) were more in the inner arc side of the slab than that in the outer arc side, and mainly accumulated in a quarter region of the inner side. Big size bubbles (>0.5 mm) mainly distributed in center region of the slab at thickness direction.

3.1. Distribution of Bubbles in Slab

As described in Figs. 6 and 7, bubbles’ distribution in thickness direction presented following characteristics. (1) About 35% bubbles existed in region of the inner art side 1/8 to 1/4; in this region, bubbles with sizes 0.1 mm to 0.5 mm were much more than that with size >0.5 mm. (2) 20% bubbles existed in slab center of the thickness direction; in this region, large bubbles were more than small bubbles; above

---

Table 4. Numbers of bubbles in different location of the slab.

| x/mm | 0.05 | 0.08 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.7 | 0.8 | 1 | 2 | 3 | total |
|------|------|------|-----|-----|-----|-----|-----|-----|-----|---|---|---|-------|
| 2    | –    | –    | –   | –   | –   | –   | –   | –   | –   | – | – | – | –     |
| 12   | –    | –    | 1   | –   | –   | –   | –   | –   | –   | – | – | – | 1     |
| 14   | –    | –    | 1   | 1   | 1   | –   | –   | 1   | –   | – | – | – | 4     |
| 16   | –    | –    | 8   | 3   | 4   | –   | –   | 4   | –   | 1 | – | – | 20    |
| 18   | 1    | –    | –   | –   | –   | –   | –   | –   | –   | – | – | – | 2     |
| 20   | –    | –    | 8   | 6   | 1   | 1   | –   | 1   | –   | – | – | – | 17    |
| 22   | –    | –    | –   | –   | –   | –   | –   | –   | –   | – | – | – | 0     |
| 24   | –    | –    | –   | –   | –   | –   | –   | –   | –   | – | – | – | 0     |
| 26   | –    | –    | –   | –   | 1   | –   | –   | –   | –   | – | – | – | 1     |
| 28   | –    | –    | –   | –   | –   | –   | –   | –   | –   | – | – | – | 0     |
| 30   | –    | 10   | 1   | –   | –   | –   | –   | 1   | –   | – | – | – | 11    |
| 32   | –    | 7    | 1   | –   | –   | –   | –   | –   | –   | – | – | – | 8     |
| 34   | –    | 4    | –   | –   | –   | –   | –   | –   | –   | – | – | – | 4     |
| 36   | –    | 2    | 1   | 1   | –   | –   | –   | 1   | –   | – | – | – | 4     |
| 38   | –    | –    | –   | –   | –   | –   | –   | –   | –   | – | – | – | 0     |
| 40   | –    | –    | –   | –   | –   | –   | –   | –   | –   | – | – | – | 0     |
| 42   | –    | –    | –   | –   | –   | –   | –   | –   | –   | – | – | – | 0     |
| 44   | –    | –    | –   | –   | –   | –   | –   | –   | –   | – | – | – | 0     |

*x represented the distance from the narrow face sided of slab to the sample location with unit mm.
80% bubbles with sizes >0.5 mm were in this region. (3) The number of bubbles in 1/4 of inner art side occupied 51% of the total number, but just 9% bubbles existed in 1/4 of outer art side.

Different sizes of bubbles’ distribution in thickness direction were shown in Fig. 7, results showed that: 70% small bubbles with sizes <0.5 mm existed in the region of inner art side 1/8 to 1/4, which distance from inner art side 30 mm to 60 mm; 10% of these kinds of bubbles accumulated within the 10 mm of the inner art surface and outer art surface respectively. During the argon blowing process, small bubbles were tend to move to the solidification front with steel flow due to its good following performance, so small were easily captured by the solidification shell.

Figure 8 showed the number distribution of bubbles in width direction of the slab. There were almost no bubbles within 15 mm of the narrow face side of the slab; 50% bubbles with size 0.1 mm to 0.5 mm located in the area of distance from narrow side 30 mm to 60 mm; 10% of these kinds of bubbles accumulated within the 10 mm of the inner art surface and outer art surface respectively. During the argon blowing process, small bubbles tended to move to the solidification front with steel flow due to its good following performance, so small were easily captured by the solidification shell.

There were two bubbles bands (defined as band I and band II) in slab. Band I was mainly small bubbles with size 0.1 mm to 0.5 mm and located in the region of inner art side 1/8 to 1/4 in thickness direction, which was distance from narrow side 20 mm to 60 mm in width direction. Band II mainly consisted of large bubbles with size >0.5 mm and located in center of the slab in thickness direction, which was distance from narrow side 200 mm to 300 mm in width direction. The results indicated that small bubbles moved further than large bubbles; it meant that bubbles with small size <0.5 mm had good following performance, as the bubble’s size grew, the following performance weaken.

3.2. Morphologies and Detriment of Bubbles in Slab

In order to judge the bubbles shapes, we chose a sample slice which contained 11 bubbles (see Fig. 4(a)) and marked bubbles gathering location in the sample; metallographic sample were machined and observed on the longitudinal section in bubbles’ gathering location. Two different types’ bubbles were observed as shown in Fig. 9. First type of bubble was spherical with size 0.1 mm to 0.5 mm (see Figs. 9(a) and 9(b)) and mainly distributed in the band I; second type was irregular with size above 0.5 mm (see Fig. 9(c)) and mainly distributed in band II.

Argon bubble was considered as carrying media for nonmetallic inclusions in the liquid steel. The interaction between bubbles and inclusions had been studied for long time and many references.9–11) Two main ways of interaction between bubbles and inclusions were acceptable, which also were supported by our present study. (1) Small inclusions followed the bubbles’ moving track in their wake; as shown in Fig. 9(a), hundreds of inclusions with size 2–10 μm accumulated in cone-shape region around a bubble; (2) Inclusions attached to the bubbles; as shown in Fig. 9(b), many different sizes of inclusions attached on the surface of a bubble; it seemed to relate with the slag entrapment due to argon blowing; the typical inclusion composition shown in Fig. 9(b) was complex oxide with elements Ca, Si, Al, Mg and K. So the detriment of bubbles remained in slab was not just due to the bubble itself, but also due to large of inclusions around the bubbles.
Further to study the detriment of bubbles and inclusions for the cold sheet, a slab sample with size 140 mm (casting direction) *80 mm (thickness direction from inner art side) *7 mm (width direction distance from the 15 mm to 22 mm of the narrow side) was machined from left part of the slab in Fig. 1. The sample was rolled in an experimental scale machine by three passes; and the rolling reductions of each passes were 60%, 50% and 50% respectively. After first pass, the thickness reduced to be 2.8 mm from 7 mm; and second pass the thickness changed to be 1.4 mm; and the final thickness was 0.7 mm after third pass finished. After rolling, some defects appeared on the surface of cold-rolling sheet, as recording in Table 5. The sample was rolled in an experimental scale machine by three passes; and the rolling reductions of each passes were 60%, 50% and 50% respectively. After first pass, the thickness reduced to be 2.8 mm from 7 mm; and second pass the thickness changed to be 1.4 mm; and the final thickness was 0.7 mm after third pass finished. After rolling, some defects appeared on the surface of cold-rolling sheet, as recording in Table 5. The macro-defects on the surface after cold-rolling were shown in Fig. 10. Because bubbles gathered in this location based on the X-ray detection, these defects were relevant with bubbles and inclusions around the bubbles existed in the slab. A typical big blowhole defect after cold rolling was shown in Fig. 11(a); unfold the surface, many inclusions and slag entrainment were found as shown in Fig. 11(b), which was similar with that found in the industrial production in Fig. 1; under the defect, many inclusions including Al₂O₃ particles (see Fig. 11(c)), slag entrainment particles, Fe particles (see Fig. 11(d)) gathered under the surface. So, it was obviously that this kind of defect on the surface of cold-rolling sheet was due to the accumulation of bubbles and inclusions around the bubbles. Bubbles gathering area in slab always accompanied with the inclusions band; during the rolling process,

| Defect number | Location of defects (rolling direction by vertical to rolling direction) | Defects size (rolling direction by vertical to rolling direction) |
|---------------|------------------------------------------------------------------------|------------------------------------------------------------------|
| 1             | 55 mm×43 mm                                                             | 0.5 mm×5 mm                                                        |
| 2             | 15 mm×15 mm                                                             | 5 mm×2.5 mm                                                        |
| 3             | 90 mm×65 mm                                                             | 9 mm×1 mm                                                          |
| 4             | 185 mm×10 mm                                                            | 5 mm×20 mm                                                         |
| 5             | 690 mm×20 mm                                                            | 10 mm×10 mm                                                        |

Fig. 10. Typical macro-defects on the surface after cold-rolling.

Fig. 11. Silver defects on cold-rolling sheet at bubbles gathering area: (a) Morphology of the defect on cold-rolled sheet; (b) inclusions accumulation under defect; (c) Al₂O₃ inclusions and EDS under the defect; (d) Fe particles and EDS under the defect.
bubbles and inclusions band mixed together easily, the steel cavities filling with inclusions were formed in steel matrix; when the cavities were closed to the surface enough, peeling defect formed on the surface of the cold-rolled sheet.

3.3. Formation Mechanism of Sliver in IF Slab

Based on the experimental results, a formation mechanism of sliver was described in Fig. 12. The formation process was summarized following:

(1) Argon bubbles with different sizes flow out with the liquid steel from the outlet of the submersed nozzle;

(2) Small bubbles moved along the streamline and separated two parts; due to the difference of the density among liquid steel, bubbles and inclusions, lots of small inclusions often followed in the bubbles’ wake or some attached on the surface of the bubbles; a part of small bubbles entered into up-flow, as the velocity decreasing, these bubbles and inclusions around the bubbles floated into the mould slag. Another part of small bubbles entered into down-flow, most of bubbles and inclusions around bubbles also could float up into mould slag due to the difference between bubbles or inclusions and liquid steel after growing up; some small bubbles could rush out the mould and captured by the solidification shell, bubbles and inclusions accumulative band formed in inner art side of the slab.

(3) Most large size bubbles float up after flow out the submersed nozzle, some Fe particles around the bubbles were oxidized and changed to be FeO particles due to spilling of the bubbles; large Fe and FeO particles mixed with bubbles also could be captured by the solidification shell.

(4) During rolling process, the bubbles, inclusions around the bubbles or large Fe and FeO particles mixing with bubbles became the source of the sliver defect.

4. Conclusion

The distribution and detriment of bubbles in ultra low carbon interstitial free steel were studied by X-ray radiographic and cold-rolled experiment; the results were summarized as following:

(1) Two bubbles bands formed in continuous casing slab. Band I located in the region of inner art side 1/8 to 1/4 in thickness direction, and distanced from narrow side 20 mm to 60 mm in width direction; in this band, small bubbles were in the majority. Band II mainly consisted of large bubbles with size >0.5 mm and located in center of the slab in thickness direction, which was distance from narrow side 200 mm to 300 mm in width direction.

(2) Bubbles and inclusions were interaction; small inclusions followed the bubbles’ wake and hundreds of inclusions with size 2 μm to 10 μm accumulated in cone-shape region after bubbles. Inclusions or Fe and FeO particles can attach or mixed with the bubbles.

(3) Small bubbles entered into down-flow easily; after rushing out the mould, bubbles and inclusions accumulative band formed in inner art side of the slab.

(4) The bubbles, inclusions around the bubbles or large Fe and FeO particles mixing with bubbles became the source of the sliver defect.

Acknowledgements

This work was supported by State Key Laboratory of Advanced Metallurgy Foundation in China (KF13-09), Doctoral Fund of Ministry of Education of China (2013006110023) and National Natural Science Foundation of China (51404018). The authors express their appreciation to the foundation for providing financial support that guarantees the study successfully to be carried out.

REFERENCES

1) Y. Miki and S. Takeuchi: ISIJ Int., 43 (2003), 1548.
2) B. G. Thomas, X. Huang and R. C. Sussman: Metall. Mater. Trans. B, 25B (1994), 527.
3) L. F. Zhang, J. Aoki and B. G. Thomas: Metall. Mater. Trans. B, 37B (2006), 361.
4) W. Damen, G. Abbel and G. D. Gendt: Rev. Métall., 94 (1997), 745.
5) M. Cross, T. N. Croft, G. Djambazov and K. Pericleous: Appl. Math. Model., 30 (2006), 1445.
6) G. Abbel, W. Damen, G. D. Gendt and W. Tieckink: ISIJ Int., 36 (1996), S219.
7) T. Miyake, M. Morishita, H. Nakata and M. Kokita: ISIJ Int., 46 (2006), 1817.
8) H. Kimura: Nippon Steel Tech. Rep., (1994), No. 61, 65.
9) M. Iguchi, T. Chihara, N. Takanashi, Y. Ogawa, N. Tokumitsu and Z. Morita: ISIJ Int., 35 (1995), 1354.
10) T. Bonometti, J. Magnaudet and P. Gardin: Metall. Mater. Trans. B, 38B (2007), 739.
11) J. W. Haverkort and T. W. J. Peeters: Metall. Mater. Trans. B, 41B (2010), 1240.