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Jingwei Zhao

University of Wollongong, jzhao@uow.edu.au

Zhengyi Jiang

University of Wollongong, jiang@uow.edu.au

Dongbin Wei

University of Wollongong, dwei@uow.edu.au

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Abstract

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Keywords

steel, cast, microalloyed, segregation, elemental, analysis

Disciplines

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Analysis of elemental segregation in a microalloyed cast steel

Jingwei Zhao^a, Zhengyi Jiang^b and Dongbin Wei^c

School of Mechanical, Materials and Mechatronic Engineering, University of Wollongong, NSW
2522, Australia

^ajzhao@uow.edu.au, ^bjiang@uow.edu.au, ^cdwei@uow.edu.au

Keywords: Microalloyed cast steel, Segregation, Energy dispersive X-ray spectroscopy

Abstract. Quantitative investigation is made on the elemental segregation in different zones of a heavy microalloyed cast steel by energy dispersive X-ray spectroscopy. It is demonstrated that C shows serious segregation tendency than that of Mn and Si, and the degree of C segregation in the surface zone is higher than that in the central zone. C enrichment is generally observed at both dendrite arm and grain boundaries, and more C segregation at dendrite arm boundary in contrast to that at grain boundary is found in this steel. The distribution of C concentration shows a decreased trend from root to tip along the dendrite arm boundary. The C concentration at trigeminal boundary intersection shows higher level than that at other position of the grain boundaries.

Introduction

Microalloyed cast steels are basically C-Mn steels with additions of conventional microalloying elements such as titanium (Ti), niobium (Nb) and vanadium (V). The idea to develop these steels originated from the successful wrought grades which a combination of excellent strength and toughness can be acquired by introducing an appropriate amount of alloying elements into these steels. Although wrought grades of microalloyed steels have been available for years, demands for producing low-cost, high-strength steel castings with good toughness and weldability have encouraged researchers to focus on cast grades of microalloyed steels. Nowadays, microalloyed cast steels have been found many applications in the manufacturing industrial parts such as offshore platform nodes, machinery supports, natural gas compressor housing, ingot moulds and buckets [1].

Cast steel products are produced by a solidification process. The microstructure can be finely tuned, such as the grain structure, phase transformations and precipitation. However, elemental segregation defect is also intimately linked to solidification. Elemental segregation (e.g. carbon) is detrimental to casting quality, and defective final product may be produced. During the production of cast steel products, this is of serious concern to foundries, and often results in scrapped casting or expensive repairs. Therefore, it becomes valuable to investigate the elemental segregation behaviour in order to find a way to eliminate such defects in cast steel products. Despite lots of work has been carried out to investigate the elemental segregation in microalloyed cast steels [2-4], quantitative analysis on the elemental, especially C, segregation in different zones of a heavy steel casting with large cross section, and as well as the segregation mechanism have not been well reported.

In this paper, the elemental segregation in different zones of a heavy microalloyed cast steel is quantitatively analysed. The formation mechanism of carbon segregation in this steel is discussed.

Experimental procedures

The material used in this study was a microalloyed steel. The chemical compositions were as follows: (wt.%): 0.17 C, 1.2 Mn, 0.47 Si, 0.1 Cr, 0.02 Ni, 0.02 Cu, 0.02 Al, 0.02 Ti, 0.02 Nb, 0.01 V, 0.01 P, 0.01 S, 0.006 N and the balance Fe. The material was supplied as a casting ingot with cross section size of 200 mm × 200 mm and height of 400 mm, which was manufactured by vacuum induction melting method. Ingot was cut into two equal parts along the height direction, one of which was employed to prepare experimental specimens from both the surface (specimen 'CS') and central (specimen 'CC') zones of the transverse section.

Specimens were metallographically polished and etched with 2% nital solution for microstructural observation by optical microscope (OM). Slightly overetched specimens were examined under scanning electron microscope (SEM). Compositional measurements were performed using energy dispersive X-ray spectroscopy (EDS) on SEM. Line scanning was used to qualitatively study the elemental segregation. A series of spot measurements were taken from both the dendrite arm and grain boundaries to quantitatively analyse the elemental segregation. Only those elements having concentrations above 0.1 wt.% (C, Mn and Si) were included in the analysis. The remaining elements were excluded since their concentrations were too low to be accurately quantified.

Results and discussion

Elemental segregation. Fig. 1a and b show the OM structures of specimens CC and CS, respectively. As demonstrated, dendrite has been caused during casting process. Moreover, specimen CC shows larger grain size than that in specimen CS, which is thought to be caused by the slow cooling rate in the central zone in contrast to that in the surface zone during the cooling process after casting.

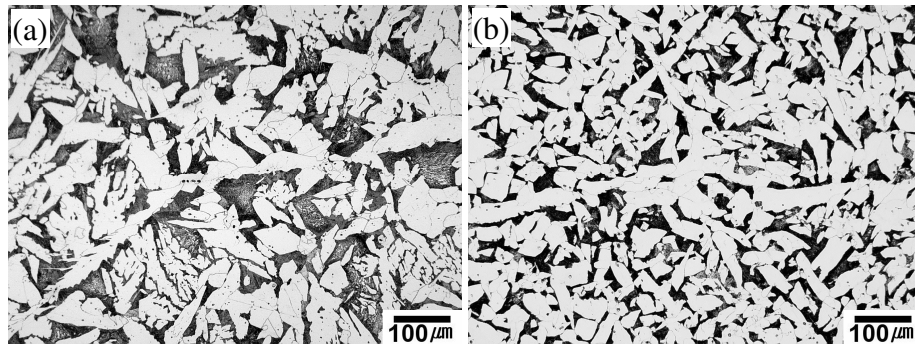


Fig.1 OM structures of the cast steel: (a) specimen CC and (b) specimen CS.

The result of EDS line-scanning across a dendrite arm boundary for the CS specimen is presented in Fig. 2. High C peak is found at dendrite arm boundary, indicating C segregation was caused during solidification. In order to investigate the distribution of elements in the cast steel, spot analysis, where the electron beam is focused into a fine spot on the site of interest, was performed to quantitatively measure the compositions of C, Mn and Si along dendrite arm and grain boundaries for both the CC and CS specimens.

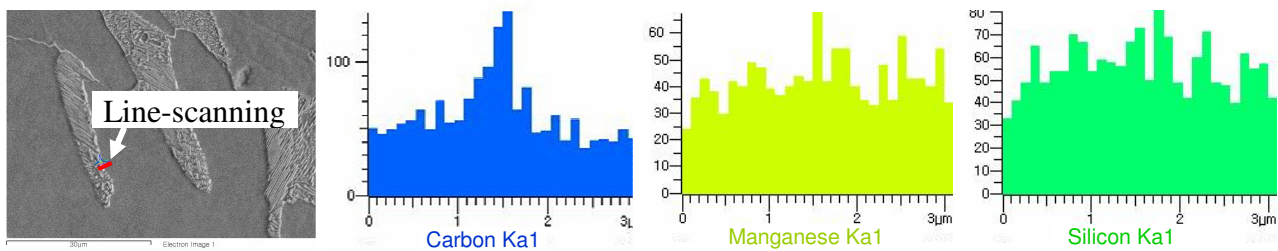


Fig. 2 Line-scanning shows C segregation along dendrite boundary for the CS specimen.

Fig. 3 shows the SEM images of the studied cast steel and the measured position for EDS analysis. Ten measurements were taken from root to tip along the dendrite arm boundaries (Fig. 3a and c), and seven measurements were conducted at trigeminal boundaries (Fig. 3b and d). All the measured points were equidistant. The measured compositions for C, Mn and Si are presented in Fig. 4. It can be seen that the concentrations of Mn and Si are much lower than that of C. Also, both Mn and Si distribute uniformly along grain and dendrite arm boundaries. Differently, a decreased C concentration trend from root to tip along the dendrite arm boundary is found (Fig. 4a and c). The C concentration at trigeminal boundary intersection shows higher level than that at other position (Fig. 4b and d).

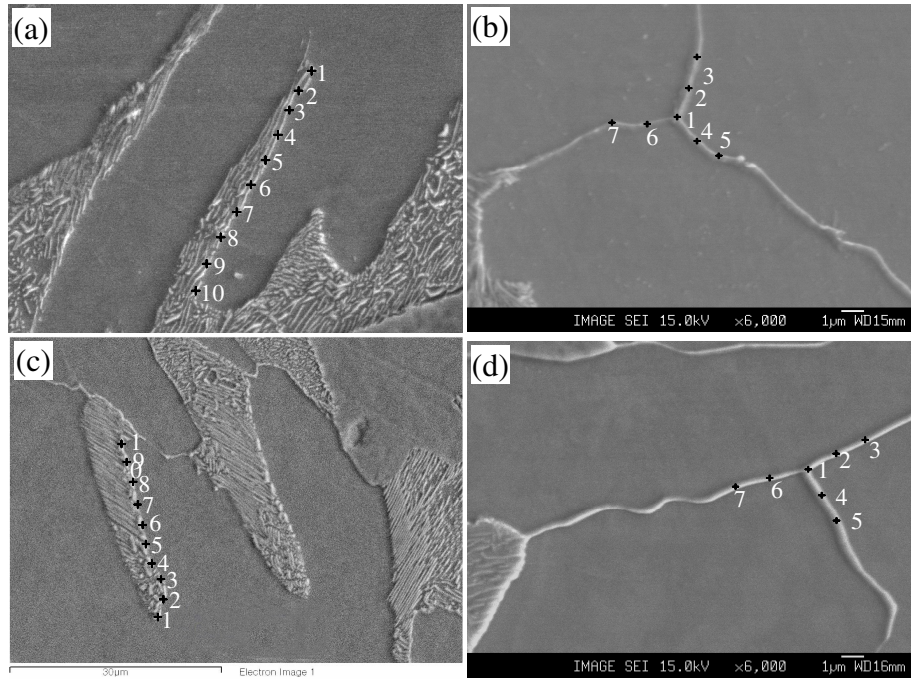


Fig. 3 SEM images of the studied cast steel and the measured position for EDS analysis: (a,b) specimen CC and (c,d) specimen CS.

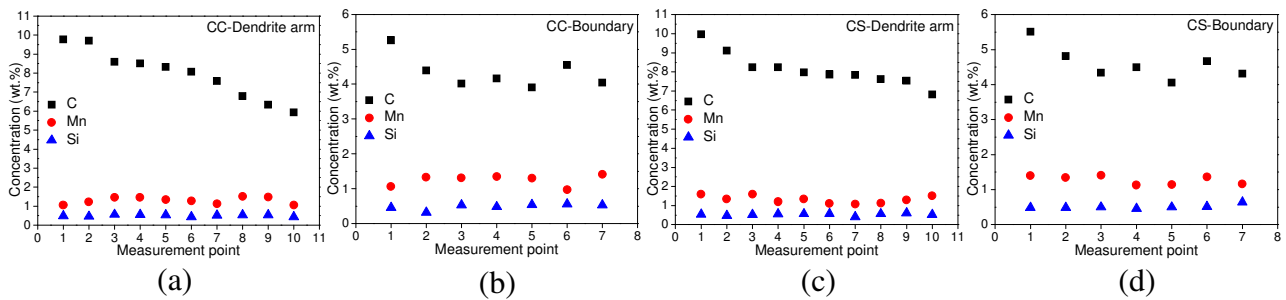


Fig. 4 Measured compositions for C, Mn and Si at (a,c) dendrite arm and (b,d) grain boundaries: (a,b) specimen CC and (c,d) specimen CS.

The average measured compositions for C, Mn and Si at grain and dendrite arm boundaries are listed in Table 1. It can be found that the C concentration at dendrite arm boundary is much higher than that at grain boundary. Moreover, specimen CS shows higher C concentration level in contrast to specimen CC at either grain or dendrite arm boundary. Based on the chemical compositions given in the section “Experimental procedures” and the results given in Table 1, it is clear that serious C segregation at grain and dendrite arm boundaries has been occurred during solidification. Also, the degree of C segregation in the surface zone is higher than that in the central zone of the cast steel, which is caused by the lower C diffusion velocity in the surface zone than that in the central zone during solidification.

Table 1 Average compositions (wt.%) for C, Mn and Si at grain and dendrite arm boundaries

Specimen	CC			CS		
Element	C	Mn	Si	C	Mn	Si
Grain boundary	4.33	1.25	0.49	4.60	1.28	0.51
Dendrite arm boundary	7.96	1.30	0.50	8.12	1.32	0.53

Mechanism of C segregation. The basic cause of segregation is that the liquid rejects solutes during freezing because the solid has less solubility for them as compared to the liquid. If an impure liquid is kept in contact with its solid at the freezing temperature for an appreciable time, equilibrium partitioning of the solutes would be attained between the liquid and the solid. It may then be written as $K=C_S/C_L$, where K is the equilibrium partition ratio, C_S and C_L are the solute concentrations in the solid and liquid, respectively [5]. In carbon steels, the equilibrium partition ratio of C is much lower than that of Mn and Si [6]. Since the solute elements with the lowest K values have the highest tendency to segregate during solidification [5], C shows serious segregation in contrast to Mn and Si.

Under equilibrium solidification conditions where diffusion in solid and liquid is complete, the composition of both solid and liquid adjusts during cooling in accordance with the phase diagram so that the final solid has the composition of the original melt, and no C segregation occurs. Under real conditions, however, C diffusion in the solid is restricted, and the steel after solidification is inhomogeneous in composition. When grains grow parallel to the grains boundaries, grooves form at the contact of solid and liquid during grains growth process. C tends to be enriched in the grooves, especially at the frontier of solid-liquid interfaces, and then C segregation along dendrite arm boundaries will be occurred. Under opposite growth condition, highly-enriched C exists at the binding-site of grains after solidification, leading to C segregation at grain boundaries. The mechanism of C segregation at dendrite arm and grain boundaries is schematically illustrated in Fig. 5a and b, respectively.

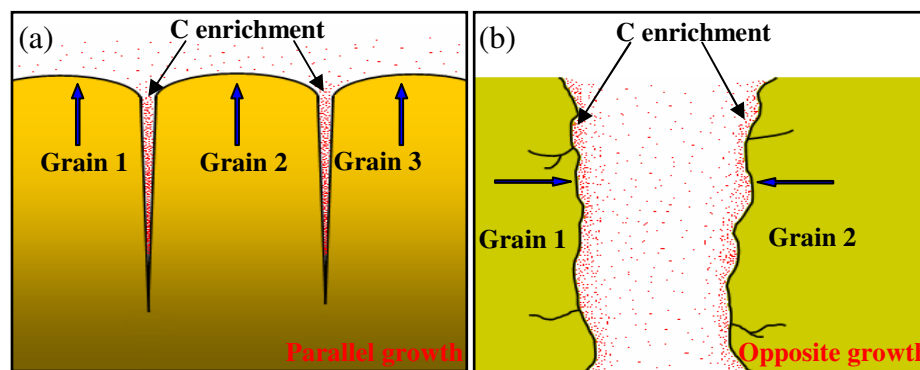


Fig. 5 Mechanism of C segregation at (a) dendrite arm and (b) grain boundaries during solidification.

Conclusions

The extent of elemental segregation in a microalloyed cast steel was quantitatively analysed using EDS techniques. The results indicate that C shows serious segregation tendency in contrast to Mn and Si. Enriched C exists at dendrite arm and grain boundaries, and the C concentration at dendrite arm boundary shows much higher level than that at grain boundary. The C concentration shows a decreased trend from root to tip along the dendrite arm boundary. More C segregation takes place at the trigeminal boundary intersection in contrast to other position of the grain boundaries. The degree of C segregation in the surface zone is higher than that in the central zone of the cast steel.

References

- [1] H. Najafi, J. Rassizadehghani, S. Asgari: Mater. Sci. Eng. A Vol. 486 (2008), p. 1.
- [2] M. Pudar, S. Zamberger, K. Spiradek-Hahn, R. Radis, E. Kozeschnik: Steel Res. Int. Vol. 81 (2010) p. 372.
- [3] E. Lopez-Chipres, I. Mejia, C. Maldonado, A. Bedolla-Jacuinde, M. El-Wahabi, J.M. Cabrera: Mater. Sci. Eng. A Vol 480 (2008), p. 49.
- [4] P. Hasek, K. Macek: Metallic Mater. Vol. 41 (2003), p. 335.
- [5] G. Krauss: *Steels-Processing, Structure, and Performance* (ASM International, Ohio 2005).
- [6] P.M.N. Ocansey, D.R. Pourier: Mater. Sci. Eng. A Vol. 211 (1996), p. 10.