Promoting the Formation of Core-Shell Structured Carbides in High-Cr Cast Irons by Boron Addition

Jiaqi Li, D.Y. Li
Department of Chemical and Materials Engineering, University of Alberta, Edmonton, Alberta, Canada T6G 1H9

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INTRODUCTION: High chromium cast irons (HCCIs) are widely used in oil sand, mining and manufacturing industries due to their high resistance to wear, corrosion and corrosive wear [1]. HCCIs are composed of hard carbides and soft ferrous matrix. Although hard carbides withstand the wearing force, the lattice mismatch between the carbide and matrix introduces interfacial stress, increasing the risk of interfacial failure and thus decreasing the wear resistance [2]. Recent studies showed that core(M_7C_3)-shell($M_{23}C_6$) structured carbides (CSSCs) were present in Fe-45wt%Cr-4wt%C, helping minimize the interfacial stress. However, the core-shell structured carbides was not observed in samples with different carbon contents such as Fe-45wt%Cr-3wt%C and Fe-45wt%Cr-5wt%C. Such core-shell carbides are actually not often observed. Understanding the mechanism behind the phenomena would help develop approaches to produce core-shell structured carbides in HCCIs

In this study, we conducted thermodynamic analysis for the formation of core-shell structured carbides in HCCIs through alloying elements. With the guidance of thermodynamic analysis, we were successful to produce core-shell structured carbides in HCCIs with boron addition. We also conducted first-principles calculations to evaluate the effect of the core-shell structured carbides on its resistance to interfacial debonding.

METHODS: ThermoCalc software was used to conduct thermodynamics calculations with emphasis on the effect of boron on the formation of CSSCs. Fe-45wt%Cr-3wt%C-1.1wt%B and Fe-45wt%Cr-5wt%C-0.8wt%B were made and analyzed. Samples cut, polished, and characterized using SEM, XRD and EBSD. First-principles analysis was employed to demonstrate how the resistance to interfacial failure was enhanced by the core-shell structured carbides.

RESULTS AND DISCUSSION: Samples of Fe-45wt%Cr-3wt%C-1.1wt%B and Fe-45wt%Cr-5wt%C-0.8wt%B were characterized via SEM. As shown in Fig.1, both alloys contain primary carbides with core-shell structure. The dark core is M_7C_3, while the light grey shell and eutectic carbides are $M_{23}C_6$.

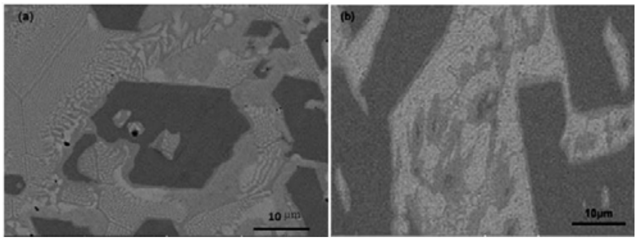

Fig. 1 a) As-cast Fe45Cr3C1.1B alloy, b) Fe45Cr5C0.8B alloy, annealed in 900℃ for 4h.

To understand why the added B induced the formation of the core-shell carbides, we calculated the phase diagram using ThermoCalc. Fig.2 depicts the phase diagram of Fe45Cr5C alloy with boron content in the range of 0~2wt%. The dashed line represents chosen chemical composition. At 900℃, the phase constituents of the alloy are ferrous matrix, M_7C_3 and $M_{23}C_6$ in equilibrium, which is consistent with the experimental results.

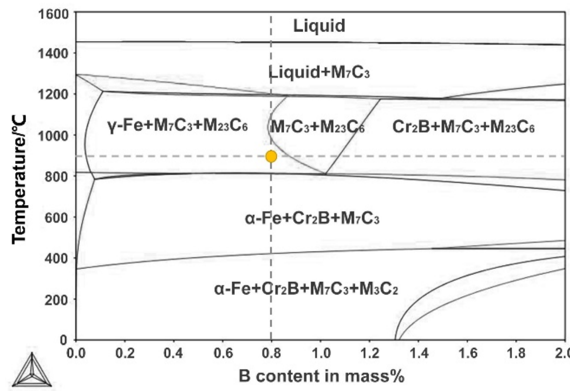

Fig. 2 Calculated quasi-binary phase diagram of Fe45Cr5CB alloy.

Gibbs free energy curve of M_7C_3 and $M_{23}C_6$ in Fe-45wt%Cr-5wt%C-0.8wt%B below 900℃ was computed and is shown in Fig.3. With increasing the boron content, Gibbs energy of $M_{23}C_6$ firstly decreases while that of M_7C_3 increases. When boron content reaches about 0.8wt%, the difference in Gibbs energy between $M_{23}C_6$ and M_7C_3 is maximized, corresponding to the largest driving force for driving early formed M_7C_3 transform to $M_{23}C_6$, forming the core-shell structure.

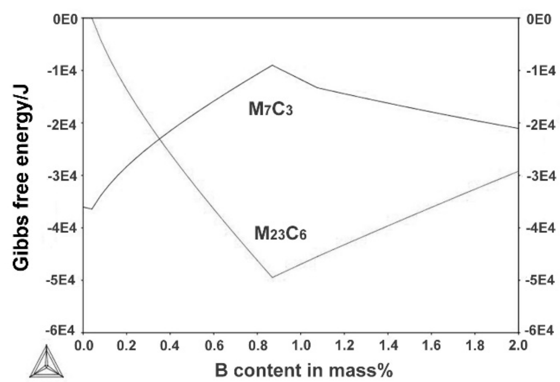

Fig. 3 Gibbs energies of M_7C_3 and $M_{23}C_6$ versus B content.

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