

Thermodynamic Analysis of Inclusions of Low Melting Point Area in Spring Steel

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Abstract: The activity data of each component of a CaO–SiO₂–Al₂O₃ system were calculated by thermodynamic software Factsage. The composition of low melting point inclusions in a CaO–SiO₂–Al₂O₃–MgO system was analyzed by thermodynamic calculation. The results show that the area of low melting point inclusions first increases then decreases with accumulating the alumina and magnesium oxide contents, respectively; the low melting area of CaO–SiO₂–Al₂O₃–MgO inclusion is the biggest when the content of MgO and Al₂O₃ is 15%. To obtain low melting point inclusions, the alumina and magnesium contents should be approximately controlled to be 15%, and the CaO should be 40%.

Key words: spring steel; low melting point area; thermodynamic computation

For spring steel, under periodic alternating stress such as the load of tensile, bending, compression, torsion and impact, fatigue fracture is the main failure form^[1]. The spring break resulted from fatigue crack propagation which is caused by big brittle inclusion in steel becomes one of the main reason of spring failure^[2]. Aluminum deoxidation reaction speed is faster than the aluminum melt and diffusion speed at steelmaking temperature, so the form of larger particles deoxidation product is inevitable in the local of rich aluminum area^[3]. Hard and non-deformable inclusions such as Al₂O₃ play the most important role in drawing, bending, shortening the spring steel fatigue life and reducing the fatigue strength^[4]. Previous result shows that^[5, 6]: there is almost no deformation crack produced on interface between steel and inclusions when deformation index $V > 0.5$; on the contrary, fishtail type crack with tapered gap usually will be produced, and tapered gap and hot tear become the most common defects especially when $V < 0.03$. Therefore, the low melting point plastic inclusion, produced by controlling the composition of brittle inclusion and changing its shape, has great significance for improving the fatigue life of spring steel. In the process of smelting high carbon spring steel, silicon manganese instead of the original aluminum is adopted as deoxidizer currently. Moreover, CaO–SiO₂–Al₂O₃ system inclusion became the main deoxidation product in steel and refining slag^[7]. The activity data of CaO–SiO₂–Al₂O₃ system at 1800 K were calculated by thermodynamic software Factsage^[8], and then the area of low melting point inclusions in CaO–SiO₂–Al₂O₃–MgO phase diagram is

obtained. To get great deformability inclusion in spring steel, the range of composition control is discussed.

1 Thermodynamic Calculation and Analysis of Inclusion

Thermodynamic calculation software Factsage based on minimum Gibbs free energy not only has strong calculating function on slag phase diagram but also can calculate the activity of each component of slag directly. According to the given elemental composition, temperature, pressure and the activity of one element, selecting the possible product and appropriate database, then each component of slag can be calculated by Factsage, correspondingly. This software has been applied to thermodynamic prediction and the study of phase balance and thermodynamic properties. It is pointed out that the thermodynamic calculation software has provided a powerful and reliable method for better researching and controlling the properties of inclusions in steel^[9, 10].

1.1 Discussion and iso-activity diagram for CaO–SiO₂–Al₂O₃ system

The iso-activity diagram for balanced component Al₂O₃ and SiO₂ in CaO–SiO₂–Al₂O₃ ternary system at 1823 K is calculated by using the Equilib module of Factsage, as shown in Fig. 1.

The result is obtained through the analysis and comparison. (1) Factors affecting the activity of Al₂O₃: with the increase of $R(\text{CaO}/\text{SiO}_2)$, the $a(\text{Al}_2\text{O}_3)$ value is increased. The value of $a(\text{Al}_2\text{O}_3)$ decreases with increasing SiO₂ content. The $a(\text{Al}_2\text{O}_3)$ value decreases with increasing CaO content. And the value

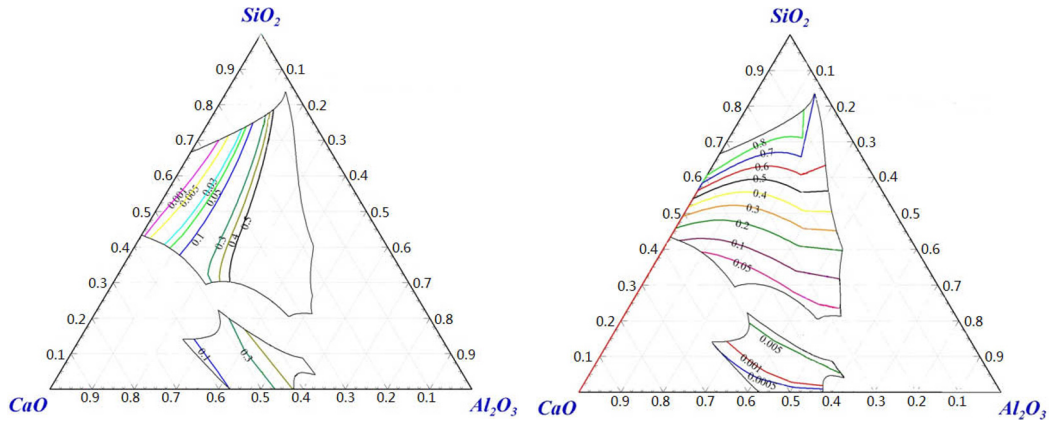


Fig. 1 Iso- $a(\text{Al}_2\text{O}_3)$ and iso- $a(\text{SiO}_2)$ in a $\text{CaO-SiO}_2\text{-Al}_2\text{O}_3$ ternary diagram (1823 K)

of $a(\text{Al}_2\text{O}_3)$ ranges from 0 to 0.5 in liquid region. (2) Factors affecting the activity of SiO_2 : with the increase of $R(\text{CaO}/\text{SiO}_2)$, the value of $a(\text{SiO}_2)$ decreases. The $a(\text{SiO}_2)$ value increases with increasing the content of CaO. And the value of $a(\text{SiO}_2)$ decreases with increasing the Al_2O_3 content. In liquid region, the value of $a(\text{SiO}_2)$ ranges from 0 to 0.8.

1.2 Control range of plasticity of inclusions in $\text{CaO-SiO}_2\text{-Al}_2\text{O}_3\text{-MgO}$ system

1.2.1 Effect of MgO content on the low melting point area of $\text{CaO-SiO}_2\text{-Al}_2\text{O}_3\text{-MgO}$ inclusion

Because of the erosion of ladle refractory by molten steel and slag in actual industrial production process, a certain amount of MgO is contained in non-metallic inclusions unavoidably. It is necessary to research the influence of MgO content on the phase diagram of the low melting point area. Low melting point area of melting point less than 1400 °C in a $\text{CaO-SiO}_2\text{-Al}_2\text{O}_3\text{-MgO}$ system is shown in Fig. 2 with different fractions of MgO which is 0%, 5%, 10%, 15%, and 20%, respectively. Fig. 3 shows the relationship of low melting area percent to MgO content. It can be seen in Fig. 3 that the low melting point area is dramatically increased when the content of MgO ranges from 0 to 15%. As the content of MgO continuously increases, low melting point area is slightly reduced. Until the MgO content is more than 25%, the low melting point area is decreased rapidly. To obtain the most favorable low melting point inclusions, the MgO content should be controlled to be 15%.

1.2.2 Effect of Al_2O_3 content on the low melting point area of $\text{CaO-SiO}_2\text{-Al}_2\text{O}_3\text{-MgO}$ inclusion

To get the influence of Al_2O_3 content on low melting point area in $\text{CaO-SiO}_2\text{-MgO}$ pseudo-phase

diagram, the low melting point area with different fractions of Al_2O_3 which is 5%, 10%, 15%, and 20%, respectively, has been compared. The low melting point area in $\text{CaO-SiO}_2\text{-MgO}$ diagram is given in Fig. 4. Fig. 5 shows the relationship of low melting area percent to Al_2O_3 content.

It can be seen from Fig. 5 that the area of low melting point percent is dramatically increased when the content of Al_2O_3 varies from 0 to 15%. However when Al_2O_3 content is more than 15%, the percent of low melting point area decreased rapidly. Therefore, to obtain the most favorable low melting point inclusions, the Al_2O_3 content should be controlled to be 15%.

1.2.3 Effect of SiO_2 content on the low melting point area of $\text{CaO-SiO}_2\text{-Al}_2\text{O}_3\text{-MgO}$ inclusion

To get the influence of SiO_2 content on low melting point area in $\text{CaO-SiO}_2\text{-MgO}$ pseudo-phase diagram, the low melting point area with different fractions of SiO_2 which is 35%, 40%, 50%, and 60%, respectively, has been compared. Relationship of low melting area percent to SiO_2 content is shown in Fig. 6. As can be seen in Fig. 6, the effect on the low melting point area is not remarkable when the content of SiO_2 is less than 35%. The area of low melting point is increased significantly when the content of SiO_2 is more than 40%. And the percent of low melting point area declines when the content of SiO_2 is over 50%. By comprehensive analysis, the most favorable low melting point inclusion can be obtained by controlling the SiO_2 content to 50% of $\text{CaO-SiO}_2\text{-Al}_2\text{O}_3\text{-MgO}$ system.

1.2.4 Effect of CaO content on the low melting point area of $\text{CaO-SiO}_2\text{-Al}_2\text{O}_3\text{-MgO}$ inclusion

To get the influence of CaO content on low melting point area in $\text{CaO-SiO}_2\text{-MgO}$ pseudo-phase diagram,

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