論文の内容の要旨

論文題目

Evolution Mechanisms of Non-metallic Inclusions in Fe-Al-Ti-N Alloy

(Fe-Al-Ti-N 合金中非金属介在物の生成機構)

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In steelmaking process, various non-metallic inclusions are formed. These inclusions have been perceived as harmful and removed by using slag. However, removal of micro size of all inclusions or inclusions formed in solid steel is impossible. Therefore, utilization of inclusions is required and researches on this topic have been studied. The main objective of current study is to investigate the positive influence of inclusions on the steel properties. For this aim, effects of formed and evolved inclusions in the six different compositions of fundamental Fe-Al-Ti-O-N alloy system on the grain refining have been studied.

In Chapter 1, formation and change behaviors of inclusion in not only liquid state but also solid state of various grades of steel have been introduced, especially, Fe-Al-Ti-O alloy system. Furthermore, oxide metallurgy which is to utilize positive effects of the formed inclusions at various processes has been introduced. Most researches have reported the effects of Ti based inclusions on the austenite grain size. However, all researches have investigated the influence of inclusions not in the fundamental system but in the complex compositions of steel. Therefore, the current research has been initiated to clarify the effect of generable all inclusions including Ti based inclusions in Fe-Al-Ti-O-N alloy on the basis of clarification of formation and evolution procedure of inclusions in not only liquid state at steelmaking temperature as 1873 K but also solid state at general heat treatment temperature as 1473 K.

In Chapter 2, characteristics of the various types of inclusions formed in Fe-Al-Ti-O-N alloy at 1873 K have been studied. In order to obtain various types of inclusions, production method of alloy has been changed. The observation area has been distinguished as “Outer layer” and “Inner layer” by different inclusions morphology in all samples due to stirring force. Even “Outer layer” of alloys has been different by crucible type. In the “Outer layer”, oxide based inclusions almost have been observed. On the other hand, TiN and TiS based inclusions have been consisted in the “Inner layer”. The definite formation processes of all inclusions not only oxide inclusions but also nitride and sulfide inclusions have been discussed based on calculation of thermodynamic data and measurement of inclusion characteristics such as size, morphology and composition. It has been found that oxide inclusions except small Al_2O_3-TiO_x inclusions basically form at deoxidation step and TiN, TiS and small Al_2O_3-TiO_x inclusions precipitate by solidification. The increase of number and size of TiN particles has occurred with increasing nitrogen content.

In Chapter 3, in order to clarify the formation and evolution behaviors of inclusions in solid Fe-Al-Ti-O-N alloy, heating experiments have been carried out at 1473 K. By comparing Fe content of inclusions near surface of specimen and total oxygen content between as cast and heated samples, no existence of oxidation during heating has been proved. Furthermore, in order to protect alloy from oxidation, ampoule has been applied for some samples.

Based on the results obtained in Chapter 2, formation and change behaviors of inclusions by heating at 1473 K have been clarified in Chapter 3. The effects of not only bulk alloy composition but also partial morphology change of primarily existing inclusions on the formation and evolution of inclusions have been observed as follows. The oxygen provided by dissolution of small Al_2O_3-TiO_x inclusions have become the base of formation of TiO_x based inclusions in the “Outer layer” by heating. On the other hand, TiN or TiS formation have occurred rather than Ti oxide formation due to relatively insufficient oxygen source in the “Inner layer”. Therefore, it has been considered that TiN or TiS was more stable than Ti oxide in the bulk alloy, however Ti oxide could form when enough amount of oxygen is provided.

The close correlation between nitrogen content and precipitations of TiS and TiN has been indicated. The size of TiN phase on the oxide phase has increased by the increase of nitrogen content.

Besides, from the type and compositional changes of oxide inclusions, stable oxides in each Fe-Al-Ti-O-N alloy at 1473 K have been estimated. Comparing between computed stable oxide at 1873 K and estimated stable oxide at 1473 K, it has been clarified that influence of temperature on the oxide stability was limited.

In Chapter 4, effects of inclusions on grain size have been estimated by measurement of ASTM grain size number. Positive influence of Ti based inclusion, i.e. TiN, on the reduction of grain size has been identified during solidification, as introduced in Chapter 1. By heating, the number of TiN inclusions increased and the grain size decreased. On the other hand, significant effect of TiS or oxide based inclusions on the grain refining has not been observed.

In Chapter 5, parameters which have a beneficially influence for grain refining have been discussed. It has been found that the size of grain formed during solidification considerably depends on Ti and N contents. On the other hand, the change of grain size is correlated to the variations of products of Ti and N activities and Ti and S activities during heating. The grain size decreased with increasing the degree of increase of product of Ti and N activities. On the contrary, the grain size increased with increasing the degree of increase of product of activities of Ti and S.

In the as cast and heated samples, it has been indicated that the ASTM grain size number increased with increasing the average size of TiN particles.

Relationship between the number of polyhedral type of oxide(Al_2O_3 or Al_2O_3-MgO)+TiN or TiN+TiS inclusions and grain size has been investigated. The polyhedral type of oxide+TiN or TiN+TiS inclusions has similar morphology with spinel inclusion ($MgAl_2O_4$) covered by TiN, which have been reported as the beneficial inclusion for grain refining.

By summarizing the results shown in Chapter 4 and Chapter 5, it is concluded that the control of number density of TiN based inclusions, size of TiN particles and product of Ti and S activities is significant to accelerate grain refining during heating at 1473 K.