

INFLUENCE EVALUATION OF NON-METALLIC INCLUSIONS ON ACICULAR FERRITE FORMATION

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ABSTRACT

The beneficial effect of grain refinement consisting in facilitating the nucleation of intragranular acicular ferrite (AF) is influenced by evenly dispersed fine inclusions in steel. In particular fine inclusions (oxides, sulphides, nitrides) are especially effective in AF nucleation. The preferential AF nucleation is realized at intragranular sites (inclusions) in austenite (A) matrix. In present work an attempt has been performed to contribute to the elucidation of physical metallurgy mechanism of AF formation based on the existence of the Mn-depleted zone acting as the AF nucleation site in the austenite matrix. This zone is formed around MnO.SiO₂ inclusions by the MnS nucleation on it and the subsequent Mn diffusion in the steel matrix into the MnS nucleus.

Keywords: acicular ferrite, non-metallic inclusions, Mn-depleted zone, grain size, microstructure refinement

1. INTRODUCTION

Owing to beneficial effect on grain boundary refinement resulting from the intragranular AF nucleation, the utilization of inclusions in steel has attracted much attention at present. Fine inclusions comprised e.g. of Ti₂O₃, TiN, CuS and MnS are known as the most effective nucleation sites for AF. In this connection great number of mechanisms has been suggested to elucidate the role of fine above mentioned inclusions as effective AF nucleants. The very frequent and promising suggestion is based on the existence of the Mn-depleted zones formations in A-matrix acting as preferential sites for A-decomposition into AF. This zone can be detected in the vicinity of the manganese-silicate (MnO-SiO₂) inclusions in dependence on MnS nucleation at the considered primary non-metallic inclusions. Simultaneously, it is necessary to take into consideration the subsequent Mn-diffusion realized in the steel matrix to MnS nucleated particles. In addition to this mechanism it has been observed the formation of Mn-depleted zone around cation-vacancy oxides-type, including e.g. Ti₂O₃ what contributes to the enhancement of AF nucleation process [1, 2].

In the present study an attempt has been devoted to the elucidation of the conditions leading to the formation of the Mn-depleted zone and based on the precipitation of MnS on manganese-silicate oxide inclusions in Si/Mn deoxidized low-carbon steels.

2. MORPHOLOGY CHARACTERISTICS OF NUCLEATING NON-METALLIC INCLUSIONS

The results of local chemical analysis lead to the conclusions, the MnS concentration gradient exists across the inclusions. The Mn-content becomes higher towards the surface of inclusion what results from the transfer of both Mn and S from the steel matrix. Further, the achieved data about the heterogeneity of inclusions chemical composition lead to the suggestion that the mass transfer is sluggish. It shows, the Mn- and S-contents are increased on the outer inclusions part. These findings have been achieved owing to the realized continuous transfer of Mn and of S. Therefore, the outer inclusions part is in liquid phase while the inclusions interior is in solid state. The prolonged Mn and

S diffusion to the inclusion results in the MnS precipitation at the rim of MnO-SiO₂ particles. Regarding the MnS-phase morphology, the existence of the liquid state at the outer part of inclusions contributes to the formation of special MnS-shape initiated on the surface of the MnO-SiO₂ (primary) inclusions. The detected morphology characteristics demonstrate the MnS formation on manganese-silicate inclusions that also influences the development of the Mn-depleted zone around the primary inclusions and in this way makes the transformation process of A-decomposition into AF more effective [3].

3. FORMATION STAGES OF NON-METALLIC INCLUSIONS

When steel deoxidized with Si/Mn is continually cooled, the matrix of this steel is not in thermodynamic equilibrium state with coexisting inclusions that have been nucleated during the cooling process. On the contrary, the matrix is supersaturated with Mn and S in comparison with the inclusions [3]. During slow continually realized cooling, the formation of the Mn-depleted zone (MDZ in Fig. 1) can be found in the vicinity of primary inclusion (MnO-SiO₂). At higher cooling rate, the limited Mn and S transfer is determined what results in the elimination of the Mn-depleted zone formation [3, 4]. The transfer within the inclusion is sluggish what leads to the formation of concentration gradient across inclusion (Fig. 1A). The outer part of the inclusion remains liquid during the applied subsequent isothermal holding (e.g. at 1200 °C) its inner part after solidification keeps the solid state even during the subsequent isothermal annealing at above given temperature.

The prolonged Mn and S transfer to the inclusions eventually leads to the precipitation and growth of MnS at the outer part of MnO-SiO₂ inclusion. This process is presented in Fig. 1B [3].

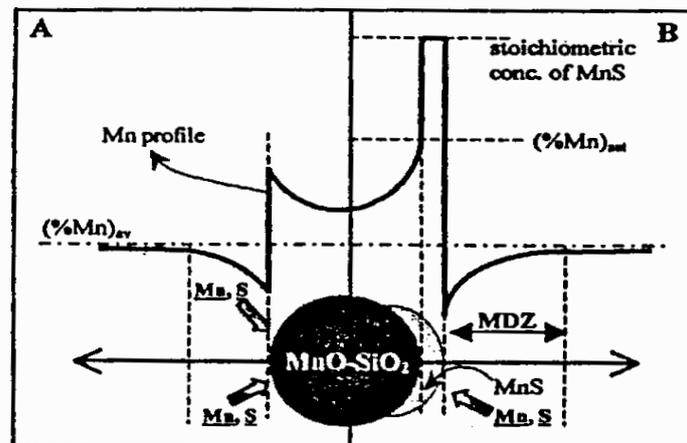


Figure 1. Transfer of Mn and S at the metal/inclusion interface;
 A) Concentration gradient across the inclusion
 B) Precipitation and growth of MnS particles at the outer part on the inclusions

The described results demonstrate, it is very useful to retain the Mn-depleted zone around the inclusions together with MnS particles precipitated on the surface of primary inclusions at temperature of A-decomposition into AF. The analysis of present results leads to conclusion the high sulphide capacity of primary inclusions represents favourable conditions contributing to the formation of both the Mn-depletion zone and MnS precipitation on MnO-SiO₂ inclusions what facilitates the AF nucleation.

4. EFFECT OF FURTHER ELEMENT

In addition to the evaluation of manganese-silicate inclusion in present work the attention is also devoted to study of the nucleation activity of inclusions containing Mg (Mg-oxides). The attempt has been made to explain the traits of Mg containing oxides which are known to have even dispersion in steel melt [4]. In order to investigate the influence of inclusion traits with Mg addition to Mn/Si/Ti

deoxidized steel with graduated Mg content (up to 52ppm). The Fig. 2 shows the variation of the size and the number density in dependence on Mg-content in investigated specimen. The inclusion size reflects the response of special behaviour of these particles containing Mg because after the addition of

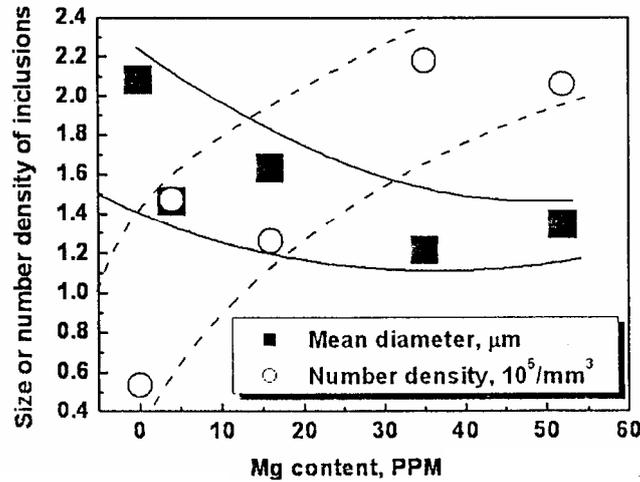


Figure 2. Variation on the size and the density number of selected inclusions with Mg addition in steel of each

this element the formed inclusions are not susceptible to growth by collision and agglomeration due to their beneficial wettability for even dispersion in steel. It is known that so dispersed fine Mg-containing inclusions facilitate the intragranular AF nucleation from them what results in the finer microstructure in Mg-containing steels [5]. The inclusion size decreases and the density number of inclusion is increasing with Mg-content in the steel matrix.

The typical morphology of the analysed inclusions found in steel is of complex type comprising central oxide and periphery of MnS. Figure 3 demonstrates that there is none significant change in the

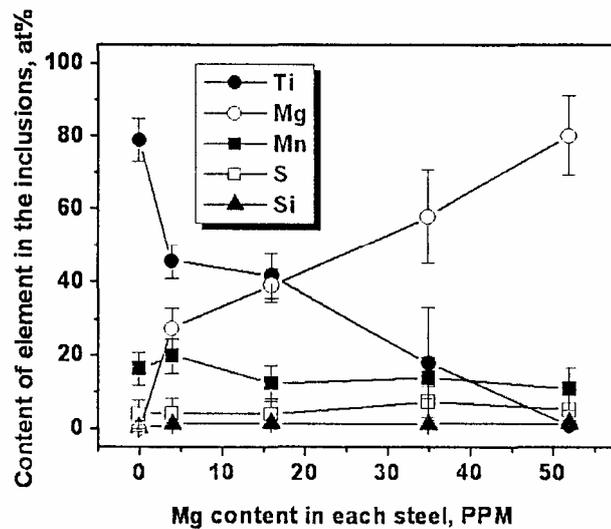


Figure 3. Variations in the average composition of selected inclusions with Mg addition in steel of each

susceptibility of oxide phase for MnS formation in the investigated steel type. The S content does not show any ascertainable variation in inclusions. It is interesting to state a surplus Mn-coexists in oxide phase in some other state than MnS. This state can be interpreted as a result of partial Mn dissolution in the cation vacancy site of the iron lattice.

The presented results and their analysis show the mechanism based on the Mn-depleted zone formation around fine intragranular non-metallic inclusions is real. This mechanism successfully elucidates the influence of physical metallurgy parameters responsible for the AF intragranular nucleation.

5. CONCLUDING REMARKS CONCERNING MAGNESIUM ADDITION AND GENERALIZATION OF ACHIEVED RESULTS

After addition of Mg in Mn/Si/Ti deoxidized steel typical inclusions morphology has been found. The found inclusions have complex chemical constitution [4, 5]. In their central part the oxide particles occurrence is found in majority examples. The MnS particles precipitate on the surface of the primary inclusions. In relation to the Mg increased content in steel the central oxide inclusions change the chemical composition of this phase. This process accompanied with a gradual Mg addition in steel leads to their continual modification in the inclusion chemistry e.g. from (Ti-Mg-O) to MgTiO₃ [4]. The average size of the formed inclusions containing Mg is decreasing with increasing content of this element in steel matrix. These changes are thought to result from the optimum wettability of Mg containing oxides. It leads to achievement of their even distribution in matrix. The Mg containing inclusions are not susceptible to their growth as it results from the beneficial wettability behaviour expressed with the wetting angle about 90° of MgO with steel melt [4].

The found microstructure of steel modified with Mg addition is refined. Dispersed fine Mg-containing inclusions facilitate the heterogeneous AF nucleation. The main size of the inclusions decreases, e.g. from 2.1µm (without Mg-addition) to 1.2µm (in case of 35ppm Mg addition in steel). On the contrary, the number density has been increasing, namely from $0.54 \cdot 10^5 \text{mm}^{-3}$ to $2.2 \cdot 10^5 \text{mm}^{-3}$ for the same change in Mg-content as in above mentioned example of grain size refinement [4].

6. CONCLUSIONS

The nucleation potency of some complex inclusions represents a decisive initiation parameter in A/AF transformation. It has been established the higher density numbers of evenly dispersed fine intragranular particles (0.5÷2.0µm) are very effective in the refinement of ferrite by AF nucleation. The type of non-metallic inclusions participating in the considered nucleation process is determined by steel deoxidization while special distribution of inclusions is influenced by their wettability with steel melt. The mechanism of AF nucleation based on the existence of Mn-depleted zone around the primary steel inclusions in connection with MnS formation is analysed in detail.

7. REFERENCES

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