論 文 の 内 容 の 要 旨

論文題目　Phase Transformation Behaviors of Steels Containing Ti-Compounds
(鋼中のチタン化合物による相変態挙動に関する研究)

氏　名　李昶準 (イチャンジュン)

Intragranular ferrites formation from non-metallic in steels is considered as one of the key concepts for steel microstructure refinement. Among various non-metallic compounds, Ti-compounds have attracted many researchers' attention owing to their good ferrite formation capability. However, many controversies about intragranular ferrite formation behaviors in steels still remained in spite of numerous studies by many researchers so far. Thus, in this study, intragranular ferrites formation behaviors in steels containing Ti-compounds were investigated.

In chapter 1, the meaning of research about intragranular ferrite formation behavior was stated, related to steel microstructure control. Also, the factors possibly affecting intragranular ferrite formations were explained, with background knowledge to understand intragranular ferrite formation from non-metallic compounds in steels. Lastly, previous studies related to several Ti-compounds which are known as effective intragranular ferrite formers were introduced.

In chapter 2, difference between TiO and TiN in intragranular ferrite formation behaviors was investigated. While B1 compounds such as TiN and TiO have been known to nucleate intragranular ferrites owing to the low misfit between B1 compounds and ferrite, many studies have reported that TiO and TiN show different ferrite formation behaviors in spite of their similar lattice parameter. It means there are more factors affecting intragranular ferrite formation behaviors of B1 compounds besides lattice matching between ferrite and B1 compounds. As the results of the experiments with specimens manufactured by hot-press

method, it was confirmed that ferrite formation behaviors were different according to the chemical composition of the compounds. Whereas the orientation relationship called the Baker-Nutting orientation relationship played the dominant role in ferrite crystal orientation determining at relatively high temperatures over 600°C for both compounds, at lower temperatures around 500°C, other low-index orientation relationships between ferrite and B1 compounds were also observed. At that time, the bigger misorientation from the exact low index orientation relationship was allowed between ferrite and TiO than ferrite and TiN. As the result, at 500°C, ferrite from TiO had the tendency to satisfy the Kurdjumov-Sachs orientation relationship with prior austenite as well, being misrorientated from the exact low index orientation relationships with TiO, which may lead to reduction of total interface energy. On the other hand, TiN still tended to have the relatively exact low index orientation relationships including the Baker-Nutting orientation relationship. This could be explained by computational calculation, which shows that the interface energy difference between the Baker-Nutting orientation relationship and other was bigger for TiN than that for TiO. Also, calculation showed that displacement till 10 degrees from the Baker-Nutting orientation relationship between ferrite and TiO, differently from TiN, did not increase the interfacial energy significantly.

In chapter 3, formation of ferrite holding a specific orientation relationship with prior austenite was observed and investigated. Several studies reported that acicular ferrites formed from TiN holding the orientation relationship with prior austenite, which means randomly orientated to TiN, after welding process. Considered that many researchers have reported that TiN forms polygonal ferrites which hold low-index orientation relationships with TiN, it is required to look into the factor determining ferrite crystal orientations when forming from TiN. Two steels containing 1 vol. % TiN, which were made by power metallurgy, were austenitized at different temperatures; 1400°C and 1200°C. As the results of the continuous cooling at 5°C/s after austenitizing, steels showed very different final microstructure according to the austenitizing temperature. That is, when austenitized at 1400°C, mainly ferrite holding the orientation relationship with prior austenite were formed while polygonal ferrites holding the orientation relationship with TiN were formed when austenitized at 1200°C. Some of the ferrites held the orientation relationship which is misorientated from the Kurdjumov-Sachs orientation relationship by around 8°. Analysis with EPMA indicated that Ti was released from the TiN

compounds to 1 wt% in both cases, and Calculated Fe-C-Ti phase diagram suggested that most of Ti forms carbide at 1200°C while it remains solved in the steel matrix till 0.2 wt% at 1400°C. This result may imply that the solved Ti in the steel matrix is playing an important role in ferrite crystal orientation. It was confirmed through the model experiments with Ti-containing alloy which was pre-deformed that grain refinement is achievement by drag effect of solute Ti and formation of ferrite holding the orientation relationship misorientated from the Kurdjumov-Sachs orientation relationship.

In chapter 4, formation and growth of ferrites according to the orientation relationship with prior austenite were also investigated. Factors affecting formation of ferrites holding the specific orientation relationship were also studied. The ferrites holding the specific orientation relationship other than the Nishiyama-Wasserman orientation relationship (the near K-S orientation relationship), which is misorientated from the Kurdjumov-Sachs orientation relationship so that $\{110\}\alpha$ is parallel to $\{112\}\gamma$, were observed in steels containing Ti-compounds such as TiN and TI_2O_3, while it was not in steels containing MgO, Al_2O_3 and TiO_2. The ferrites holding the near K-S orientation relationship were also observed in steels of different compositions. Formation temperature of the ferrites holding the near K-S orientation relationship was affected by the compounds and the composition of the steels. In steels containing TiN, ferrites holding the near K-S orientation relationship formed at higher temperature by approximately 50°C than ferrite holding no orientation relationship with prior austenite while they formed at the almost same temperature in steels containing Ti_2O_3. In both cases, ferrites holding the near K-S orientation relationship were observed to grow at lower growth late lower than the ferrites holding no orientation relationship with prior austenite. The effect of TiC formation at relatively lower temperatures was also suggested through the experiments with different cooling rate in austenite region which showed that the ferrites holding the near K-S orientation relationship did not form when the cooling rate is low. This hypothesis was also supported by the experiment with steels without carbon.

In Chapter 5, several nucleation models which can explain the results of Chapter 4 have been suggested. Classical nucleation models could not explain the ferrite formation behavior holding the orientation relationships with prior austenite (not with TiN) at higher temperatures than ferrite formation along the grain boundary. Thus, based on the results of previous chapters,

a new model for ferrites nucleation around the partial dislocation junctions was suggested. The validity of the model was confirmed by comparison with pillbox model on the grain boundary.

In summary, further understandings about intragranular ferrite formation behaviors in steels containing Ti-compounds were achieved in this study. Especially, crystal orientation relationship between intragranular ferrite / compound / prior austenite on intragranular ferrite formation was mainly investigated. Various factors affecting the ferrite formation between ferrite and prior austenite such as phase transformation temperature, austenitizing temperature and type of compounds were examined and their roles in intragranular ferrite formation were understood. A specific orientation relationship which is misorientated from the Kurdjumov-Sachs orientation relationship was observed and analyzed. The specific condition for ferrites to form with the specific orientation relationship was found and several nucleation models to explain the mechanism were suggested.