学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

Research on abnormal grain growth in reversely transformed austenite structure
(逆変態オーステナイトの異常粒成長に関する研究)

Control of austenite grain structure is of great importance in heat treatment process of carbon steel, because the prior austenite grain structure entirely affects the size and morphology of the final microstructure such as ferrite/pearlite structure, and thus to largely determines the final mechanical properties of steels. The present study mainly focuses on the abnormal grain growth (AGG) of reversely transformed austenite and the effects of cold deformation on it. The AGG of austenite which leads to extraordinary coarse austenite grains and bimodal grain size distributions degrades final mechanical properties of steels, because an initial variation in prior austenite grain size can result in a coarse and inhomogeneous final grain structures. Therefore, AGG in austenite grain structure during manufacturing processes is very harmful, which is quite worth to be investigated.

AGG has been extensively investigated because of both its technological relevance in the steel industry and scientific interest. In spite of the considerable research effort, there are still some issues that remain to be resolved. For example, it is unclear whether or not the initial microstructure of steel, such as ferrite/pearlite (F/P) banded and non-banded structure, affects the austenite abnormal grain coarsening. Since the banded structure is usually accompanied by a great inhomogeneity in alloy elements distribution, it may have a great effect on the austenite abnormal grain coarsening behavior. On the other hand, cold deformation prior to austenitizing, which strongly affects the precipitation of fine inclusions and reverse transformation kinetics during the reheating, may also have some effects on the austenite grain coarsening behavior. Therefore, the purpose of the present study is to investigate the abnormal grain coarsening behavior of reversely transformed austenite and the effect of cold deformation on it in both F/P banded and non-banded steels. Meanwhile, to investigate the effects of the cold deformation prior to the austenitizing on the austenite grain coarsening behavior, the local plastic strain distribution in the cold deformed work-piece is quantitatively evaluated first.

In this study, ball dropping and pressing experiments, which correspond to a model experiment for surface plastic deformation process, were conducted to investigate local plastic strain distribution in the vicinity of the deformed surface of pure iron. Evaluation of the local plastic strain was conducted by using the electron backscatter diffraction (EBSD) analysis. It was indicated that large macroscopic plastic strains with high strain rates lead to steep and narrow distribution profile of local plastic strain. The peak of the local plastic strain profile does not appear at the deformed surface but immediately beneath the surface. The deformation at high strain rates is favorable to localize the plastic strain in the vicinity of the surface. On the other hand, the deformation at lower strain rates makes plastically deformed zone wider. Furthermore, an easy and alternative way to qualitatively understand the misorientation and local plastic strain distributions in the microstructures by chemical etching is founded.

Cold plastic deformation produces misorientations inside the crystal grains, and the distribution of the misorientation is quite crucial to understand the deformation behavior of the metals or alloys. The misorientation manifestations in chemical etching contrast are investigated in the case of cold-deformed iron. The chemical etching is performed by using nital, while the crystal orientation is determined by EBSD. The correlation between the chemical etching contrast and crystal orientation have been studied in both cold-deformed and undeformed iron. The results clearly show that the chemical etching contrast strongly reflects the crystallographic orientation. The gradual change in chemical etching contrast inside the individual deformed grains gives information of both the misorientation and local plastic strain within the grains.

The grain growth behavior of austenite reversely-transformed from F/P banded and non-banded steels has been studied systematically. It was found that the grain-coarsening temperature, Tc, (the temperature at which abnormal grain growth occurs) of the initially banded F/P structure is quite low compared with that of the non-banded sample. In the F/P banded sample, the abnormal grains always originate from the former ferrite region. The occurrence of AGG is essentially attributable not to the austenite nucleation process during heating but to the grain growth process after the completion of austenizing. It was proposed that the lowered grain-coarsening temperature in the banded structure is due to the non-uniform pinning effect of AlN precipitates between former ferrite and pearlite regions. The lower Tc in the F/P banded steel can be greatly increased by applying cold deformation prior to austenitizing. The extent of abnormal grain coarsening above the Tc is also largely reduced by the cold deformation. This is attributed to the fine and uniformly distributed AlN precipitates caused by the cold deformation.

In the case of non-banded steel, the effect of cold deformation on the abnormal grain coarsening behavior of austenite depends on the initial state and distribution of AlN precipitates. For the non-banded steel with aluminum and nitrogen in solution, cold deformation reduces the AGG temperature-range of austenite. While the non-banded steels are subjected to a long time subcritical annealing treatment making the AlN fully precipitated and growth, the occurrence of AGG can be completely inhibited by the cold deformation. This can be explained by the size and spatial distributions of the precipitates affected by the cold deformation.