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学位論文題目　A basic study on the microstructure and mechanical properties of ultrahigh-strength TRIP-aided martensitic steel
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論 文 内 容 の 要 旨

In the present study, the microstructure, tensile properties, formabilities, impact toughness, and fatigue properties of transformation-induced plasticity (TRIP)-aided martensitic (TM) steel were investigated and are discussed in this thesis. The results obtained in this study are summarized below:

In Chapter 1, the background of advanced high-strength steels (AHSSs) and the aim of this study are introduced. AHSSs have been developed to improve the fuel efficiency and impact safety of automobiles. For the production of vehicles made primarily of steel in the future, light-weight automobile bodies can be fabricated by the application of newly developed AHSSs (e.g., TRIP steels). Focusing on the TRIP effect that improves the mechanical properties of steels, the mechanism of TRIP was introduced.

In Chapter 2, the effect of partitioning temperature after quenching on the microstructure and retained austenite characteristics of 0.2%C-1.5%Si-1.5%Mn (in mass%) TM steel are presented and discussed. The presence of a carbon-enrichment mechanism during partitioning is proposed in this chapter. TM steel consisting of wide and narrow lath-martensite structures contained about 3 vol% of retained austenite after quenching in oil, with 1.7–2.0 vol% of carbides only in wider lath-martensite structures. With partitioning at temperatures lower than 250°C for times shorter than 1000 s, the volume fractions of the retained austenite and carbide were maintained, although the carbon concentration of the retained austenite increased.

In Chapter 3, the effect of alloying elements on the microstructure and retained austenite characteristics of 0.2%C-1.5%Si-1.5%Mn TM steel are given and discussed. Addition of Cr and Mo to the base steel raised the upper limit of partitioning temperature to 400°C, although the carbon concentration in retained austenite decreased slightly. Further, Ni addition decreased the volume fraction of retained austenite and increased the carbon concentration.

In Chapter 4, the effects of quenching or isothermal transformation processes on the tensile properties and formability of 0.2%C-1.5%Si-1.5%Mn-0.05%Nb TM steels are presented and discussed. When isothermally transformed at temperatures below M_f, TM steel showed a tensile strength of 1.5 GPa and a total elongation of 8%. The hole-expanding ratio (λ = 30–50%) was higher than that in steel obtained after quench and partitioning

(QP). As a result, steel obtained after the IT process possessed a superior combination of tensile strength and stretch flangeability. It is considered that the excellent combination of IT process steel is mainly caused by a uniform and fine martensite lath structure matrix and a smaller amount of carbides that suppress the damage caused by punching and cracking on hole expanding, as well as by the presence of metastable retained austenite.

In Chapter 5, the effect of partitioning temperature after the IT process on the tensile properties and formabilities of 0.2%C-1.5%Si-1.5%Mn-0.05%Nb TM steel are presented and discussed. Partitioning after the IT process significantly enhanced the formability, especially stretch flangeability, of TM steel as compared to that obtained from partitioning after the quenching process. The excellent stretch flangeability was associated with softening of a mixed uniform wide and narrow lath martensitic structure matrix and an increase in the stability of the retained austenite, which suppressed the damage caused by punching and crack propagation on hole expansion through the partitioning process.

In Chapter 6, the effect of the addition of Cr, Mo, and/or Ni on the tensile properties and formabilities of 0.2%C-1.5%Si-1.5%Mn-0.05%Nb TM steel are given and discussed. The addition of 0.5%Cr and 1.0%Cr significantly improved the combination of tensile strength and stretch flangeability of TM steel. This was mainly caused by the refinement of the size of voids and cracks at the interface of an MA-like phase upon punching and suppression of void coalescence on hole expanding.

In Chapter 7, the effects of the addition of Cr, Mo, and/or Ni on the Charpy impact absorbed value and ductile-brittle fracture appearance transition temperature of 0.2%C-1.5%Si-1.5%Mn-0.05%Nb TM steel are presented and discussed, and are compared with those for TRIP-aided bainitic ferrite (TBF) steel and conventional martensitic steel. When Cr, Cr-Mo, or Cr-Mo-Ni was added to the base steel, TM steel exhibited a high upper-shelf Charpy impact absorbed value that ranged from 100 J/cm^2 to 120 J/cm^2 and a low fracture appearance transition temperature that ranged from −150°C to −130°C, while also exhibiting a tensile strength of about 1.5 GPa. This impact toughness of the alloyed steel was far superior to that of conventional martensitic steel and was caused by the presence of a softened wide lath-martensite matrix. This matrix contained only a small amount of carbide and hence had a lower carbon concentration, a large amount of finely dispersed martensite-retained austenite complex phase, and a metastable retained austenite phase of 2–4 vol% in the complex phase, which led to plastic relaxation via a strain-induced transformation and played an important role in the suppression of the initiation and propagation of voids and/or cleavage cracks.

In Chapter 8, notch-fatigue strengths and notch sensitivities of 0.1–0.6%C-1.5%Si-1.5%Mn TM steel are given and discussed. If TM steel containing 0.2%, 0.3% or 0.4%C were subjected to an ITP process, comprising isothermal transformation and partitioning processes, much higher notch-fatigue limits and lower notch sensitivities than those in the case of conventional martensitic steels (SCM steels) without retained austenite were achieved. It was expected that high notch-fatigue limits were principally associated with the plastic relaxation of localized stress concentration as a result of the strain-induced transformation of metastable retained austenite and a large amount of a finely dispersed MA-like phase along prior austenitic, packet, and block boundaries, as well as a small amount of carbide only in the wide lath-martensite structure, which contributed to difficult fatigue crack initiation and/or propagation.

In Chapter 9, the conclusions of this thesis are summarized. TM steel showed not only ultrahigh strength but also high formability, impact energy absorption capacity, and fatigue strength that are necessary to improve the fuel efficiency and impact safety of automobiles. It can be expected that the applications of TM steel would improve the global environment and our lives in the future.