microalloyed steel. The semi-quantitative statistic work of the packet size was carried out by the aid of optical microscope. TEM, EBSD and SEM were applied to investigate the microstructure refinement, precipitation, the evolution of crystal defects configuration and their interaction during the relaxation. The results demonstrate that the steel is composed of ultra-fine bainite/martensite composite microstructure, and the microstructure could be refined markedly by RPC processing. The best thermo-simulation process for refinement in this experiment is deformation by 30% at 850°C, and then relaxing at this temperature for 60 to 200 s. Increasing the reduction ratio from 30 to 60% or decreasing the deformation temperature to 800°C would cause the optimized relaxation time to become shorter, and increasing the deformation temperature to 900°C would cause the refinement effect to be weaker. It is also indicated that the nucleation, growing and coarsening of precipitates, and the dislocations polygonizing occur during the relaxation. Both two processes could be helpful to refine the intermediate transformation microstructure, and when these two processes corporate and promote each other, the optimized processing is obtained.

(cf. *ISIJ Int.*, **42** (2002), 1553)

Delayed fracture properties of 1 500 MPa bainite/martensite dual-phase high strength steel and its hydrogen traps

J.L.Gu et al.

It is very imperative to improve delayed fracture properties of high strength steel, which may enlarge its usage. The published literature shows that the susceptibility to hydrogen embrittlement of a novel 1 500 MPa bainite/martensite dual-phase high strength steel is inferior to that of conventional quench-tempered high strength steel. The stress corrosion cracking (SCC) in a 3.5% NaCl solution for novel 1 500 MPa bainite/martensite dual-phase high strength steel was investigated in this paper by using modified wedge-opening-loading (WOL) specimens. The experimental results show that K_{ISCC} for novel 1 500 MPa bainite/martensite dual-phase high strength steel is larger than $50\,MPa \cdot m^{1/2}$, exceeding conventional high strength steel. Its crack growth rate $(da/dt)_{II}$ is about 1×10^{-5} mm/s, which is less than that of conventional high strength steel. Hydrogen trapping phenomena in the steel were investigated by electrochemical permeation technique. The lath boundaries and stable retained austenite are beneficial hydrogen trap, slowing down the segregation of hydrogen on the crack tip, hence K_{ISCC} increases and crack growth rate decreases.

(cf. *ISIJ Int.*, **42** (2002), 1560)

Thermal and mechanical stability of retained austenite in aluminum-containing multiphase TRIP steels

S. van der Zwaag et al.

Stability of retained austenite is the key issue to understand transformation-induced plasticity (TRIP) effect. In this work, both thermal stability and mechanical stability are investigated by thermo-magnetic as well as *in situ* conventional macro X-ray diffraction and micro synchrotron radiation diffraction measurements. The thermal stability in a 0.20C–1.52Mn–0.25Si–0.96Al (wt%) TRIP steel is studied in the temperature range between 5 and 300 K under a constant magnetic field of 5 T. It is found that almost all austenite transforms thermally to martensite upon cooling to 5 K and M_S and M_f temperatures are analyzed to be 355 and 115 K. Transformation kinetics on the fraction *versus* temperature relation are well described by a model based on thermodynamics. From the *in situ* conventional X-ray and synchrotron diffraction measurements in a 0.17C–1.46Mn–0.26Si–1.81Al (wt%) steel, the volume fraction of retained austenite is found to decrease as the strain increases according to Ludwigson and Berger relation. The diffraction measurements also show that the mechanical stability depends on the orientation of the grain with respect to the direction of the applied stress, and the austenite grains at an angle of 45° or 60° were found to be more stable than those at lower or higher angles. Both thermal and diffraction experiments show an increase in the average carbon concentration of the remaining austenite with lowering temperature or increasing stress. Thermal and mechanical stability of retained austenite is therefore attributed to the carbon distribution over different austenite grains.

(cf. *ISIJ Int.*, **42** (2002), 1565)

Effect of microstructure on the yield ratio and low temperature toughness of linepipe steels

Y.M.Kim et al.

The present study aims at elucidating the effects of microstructural features on the yield ratio and toughness of high strength linepipe steels. The main emphasis has been placed on understanding the effects of constituents on the properties. Several alloy systems with different constituents, *i.e.* ferrite–pearlite steels, ferrite steels with acicular ferrite as second phase, acicular ferrite steels with ferrite as second phase, and bainite steels, have been investigated. Experimental results show that while the refinement of ferrite grain size improves both yield strength and low temperature toughness of ferrite-base steels, it increases the yield ratio. Modification of matrix from ferrite to acicular ferrite or bainite results in improvements in both yield strength and yield ratio. However, bainite steels have worse low temperature toughness (*i.e.*, higher DBTT) than the other types of steels. It has been shown that the low temperature toughness of acicular ferrite steels can be improved by the introduction of polygonal ferrite as a second phase. This is mainly due to the refinement of effective grain size by the introduction of second phases. The relationship between the yield ratio and work hardening exponent has also been established using the Swift equation. Based on the results, the optimum microstructure for a better combination of strength, toughness and yield ratio is suggested to be the one having second phase of polygonal ferrite in an acicular ferrite or bainite matrix.

(cf. *ISIJ Int.*, **42** (2002), 1571)

Analysis of degradation of creep strength in heat-affected zone of weldment of high Cr heat-resisting steels based on void observation

K.Shinozaki et al.

The deterioration of creep rupture strength in welded joints of high Cr ferritic heat-resisting steels was investigated based on creep tests of internal pressure specimens and single pass welded specimens. Results showed that at high temperature and low stress cracks occurred in the fine-grained heat-affected zone (FGHAZ) and was identified to be Type IV cracking. It was found that the peak weld temperature between app. Ac_1 and app. Ac_3 led to the Type IV cracking and many creep voids were observed in the FGHAZ. Further, effects of creep time on specimen necking, void distribution and precipitate coarsening were investigated. It was found that the creep void occurrence and specimen diameter reduction increased at an accelerating rate during creep. Precipitate observation showed that after long time precipitate coarsening was more in the FGHAZ than in the base metal (BM) and in the coarse-grained HAZ (CGHAZ). Auger Electron Spectroscopy (AES) point analysis showed that many precipitates existed in creep voids. Based on this observation, it was suggested that large precipitates were preferential sites for void nucleation. Finally, simulations using a welded joint model and a matrix/precipitate model were performed to investigate creep void occurrence. Results showed that creep deterioration easily occurred in the FGHAZ and large precipitates present in this zone acted as nucleation sites for voids.

(cf. *ISIJ Int.*, **42** (2002), 1578)

Ultrafine grained ferrite formed by interrupted hot torsion deformation of plain carbon steel

G.L.Kelly et al.

A plain carbon steel was deformed using a hot torsion deformation simulator. A schedule known to produce strain-induced ferrite was used with the strain interrupted for increasing intervals of time to determine the effect of an isothermal hold on the final microstructure. Microscopy and electron backscattered diffraction (EBSD) were used to analyse the changes that occurred in the partially transformed microstructure during the hold and the subsequent applied strain. The strain-induced ferrite coarsened during the hold and this coarsened ferrite was refined during the second deformation. These results were compared to those obtained for a different plain carbon steel deformed in single pass rolling close to the Ar_3 temperature.

(cf. *ISIJ Int.*, **42** (2002), 1585)