3) Emphasizing on hydraulic test.
4) Emphasizing on relieving welding residual stress.
3. Economic comment system hasn't been established for application of high strength steel.

(cf. *ISIJ Int.*, **42** (2002), 1418)

Prediction of the laves phase morphology in Fe–Cr–W–C quaternary steels with the aid of system free energy concept

Y.Murata et al.

In order to elucidate the microstructure evolution in advanced high Cr heat resisting ferritic steels, a time–composition–temperature diagram of Fe–10mass%Cr–W–C quaternary steels is calculated on the basis of the system free energy theory proposed by Koyama and Miyazaki. Microstructures of the steels are predictable using such a system free energy consisting of chemical free energy, interface energy and strain energy between the matrix and precipitates in the steels. In this study, our attention is focused on the Laves phase as the precipitate, because this phase is formed in recently developed heat resisting ferritic steels and affects their creep strength largely. The calculations conducted in the Fe–Cr–W–C quaternary steels lead to the following findings: (i) The Laves phase is not formed in those steels containing less than 0.4 mol% W (about 1.4 mass% W) even after a long term aging at 923K; (ii) Only granular Laves phase precipitates in the steel containing 0.4 mol% W to 1.05 mol% W (about 3.5 mass% W) even in the early stage of aging at 923 K; (iii) The morphological change of the Laves phase from the fine coherent precipitate to the granular one occurs in a regular aging sequence in the steel if it contains more than 1.05 mol% W; (iv) Coherent precipitation line for the Laves phase is determined in the quasi-binary phase diagram as a function of the W content. These findings obtained theoretically are consistent with experimental results.

(cf. *ISIJ Int.*, **42** (2002), 1422)

Nanocrystallization in Fe–C alloys by ball milling and ball drop test

Y.Todaka et al.

Microstructural evolution and nanocrystallization in various carbon steels by ball milling and ball drop test has been studied. In ball milling, nanocrystallization was observed in all the carbon steels irrespective of the carbon content (up to 0.9 mass% C) or starting microstructure (ferrite, martensite, pearlite or spheroidite). In ball drop test, nanocrystallization was observed in high carbon steels or ultrafine grained low carbon steels. It is realized that high strength before ball drop test is required for the nanocrystallization. The nanocrystalline structure obtained by ball milling and ball drop test has similar microstructure with dark smooth contrast. The morphologies such as pearlite lamellar, spheroidite cementite, ferrite grain boundary disappeared by nanocrystallization. The boundary between the nanocrystalline and work-hardened regions is quite sharp. The hardness of the nanocrystalline region is about two times higher than that of work-hardened region. The annealing of nanocrystalline region shows substantially slow grain growth and re-precipitation of fine cementite. This annealing behavior is quite different from the work-hardened region which is characterized by recrystallization and fast grain growth.

From the present study, it was confirmed that the nanocrystalline structure produced by ball milling and ball drop test has quite similar in structure, hardness and annealing behavior although the number of deformation applied is substantially different.

(cf. *ISIJ Int.*, **42** (2002), 1429)

Fabrication of fine-grained high nitrogen austenitic steels through mechanical alloying treatment

T.Tsuchiyama et al.

Mechanical alloying (MA) treatment was applied for the fabrication of fine-grained high nitrogen stainless steels. Chromium nitride (Cr_2N) powder was mixed with Fe–Cr binary alloy powder to control its mean chemical composition to be Fe–23mass%Cr–1mass%N which is enough to stabilize stable austenitic structure at room temperature. The powder mixture was mechanically alloyed up to 360 ks in an argon gas atmosphere (MA powder). The MA powder was packed in a stainless steel tube in a vacuum and consolidated by warm rolling at 1 073 K. The consolidated materials were finally heated to various temperatures (1 173–1 473 K) for austenitizing and then quenched without holding at the temperatures. Although the materials heat-treated below 1 323 K had bcc (martensitic) matrix, those heat-treated above 1 373 K had stable austenitic structure with a small amount of Cr_2N. The grain size of matrix was maintained to be fine due to dispersed oxide particles within matrix in all steels. For example, the materials heat-treated at 1 473 K had fine austenitic structure in which the grain size was 2.2 μm and the solute nitrogen concentration was 0.86 mass%. The steel had very high yield strength of 1.1 GPa and moderate elongation of 30%. Such a high strength of the steel was explained by the combined strengthening mechanism of nitrogen solid solution strengthening and grain refining strengthening.

(cf. *ISIJ Int.*, **42** (2002), 1437)

Relation between creep rupture strength and substructure of heat resistant steel

M.Tamura et al.

Creep rupture tests were performed at around 650℃ on a low carbon steel, a W-bearing low carbon steel, a low carbon steel containing 0.1% of TaN and a 0.1%C–8%Cr–2%W–0.2%V–0.04%Ta steel (F-82H), structural material for fusion reactors. The equivalent obstacle spacing for mobile dislocations is calculated using only rupture data according to the creep theory developed by some of the authors. Thin films taken from the ruptured specimens were examined under a transmission electron microscope (TEM). The observed sub-grain size or the calculated inter-particle distance roughly coincides with the equivalent obstacle spacing. This indicates that the microscopic variable, *i.e.* the obstacle spacing for mobile dislocations, such as sub-grain size or inter-particle distance, can be directly calculated from only the macroscopic variable, *i.e.* time to rupture or creep rate.

(cf. *ISIJ Int.*, **42** (2002), 1444)

Effects of copper addition on mechanical properties of 0.15C–1.5Mn–1.5Si TRIP-aided multiphase cold-rolled steel sheets

S.-J.Kim et al.

The main emphasis of the present study was placed on understanding the effects of copper addition on the mechanical properties and microstructures of low-carbon TRIP-aided multiphase cold-rolled steel sheets. These steel sheets were intercritically annealed at 790–800°C, and isothermally treated at 430°C for various times. Tensile tests were conducted, and the changes of retained austenite volume fractions as a function of tensile strain were measured using X-ray diffraction. The copper addition increased the volume fraction of retained austenite, although it did not affect the stability. However, the hardness of ferrite in Cu containing steel was higher than that of Cu free steel. As a result, the strain-induced transformation of retained austenite was sustained up to the high strain region, thereby leading to the simultaneous enhancement of strength and ductility. These findings indicated that when copper, a representative tramp element, was positively utilized in cold-rolled steel sheets, excellent mechanical properties could be achieved.

(cf. *ISIJ Int.*, **42** (2002), 1452)

A new surface treatment by pulsed plasma nitriding for chromium plated austenitic stainless steel

P.Kuppusami et al.

The present paper deals with the methodology adopted for pulsed plasma nitriding of chromium plated type 316LN austenitic stainless steel. The influence of nitriding temperature, time and gas mixture ratio of nitrogen to hydrogen on the nitriding behaviour of chromium plated type 316 stainless steel has been investigated. The results indicated that the nitriding temperature plays a dominant role in obtaining hardness and case depth in this material. Plasma nitriding at a temperature of about 833 K produced a case depth of about 5 μm and surface hardness of about 550 HV. At temperatures more than 1 073 K, a large fraction of chromium has been found to be converted to chromium nitride with hardness exceeding 1 000 HV. Nitriding at an intermediate temperature of 913 K for 45 h has been found to produce nitrided layer of optimum properties. Calculation of diffusion co-efficients and activation energy for nitrogen diffusion are presented to demonstrate that the nitride layer growth in chromium plated stainless steel is a diffusion controlled process.

(cf. *ISIJ Int.*, **42** (2002), 1457)

Inhibition of abnormal grain growth during isothermal holding after heavy deformation in Nb steel

S.C.Hong et al.

The microstructural evolution during isothermal holding at 590–750°C after heavy deformation was