bonitrides) and delay coarsening of microstructure, are the key to high creep strength of this type of steels. Therefore, different carbide, nitride and Laves phase forming elements (Cr, W, Nb, V, Ta, Ti) have been used to provide precipitation hardening. Furthermore, the aim is to produce a sequence of precipitates with different kinetics, *i.e.* with precipitation of a new phase during coarsening of the prior one. Co has been used for obtaining 100% martensite initially and for slowing down diffusion processes and particle coarsening. The partial replacement of Co by Cu is also investigated to reduce costs.

The first results of mechanical tests of the studied model alloys have shown positive effects of the addition of W and Ta as Laves phase and MX forming elements, respectively, as well as of the addition of B. Alloying with Co has also shown beneficial effects on the creep strength.

(cf. *ISIJ Int.*, **42** (2002), 1505)

The European efforts in material development for 650°C USC power plants—COST522

T.-U.Kern et al.

"Advanced Steam Power Plant" is one of three working groups within the frame of European COST 522 with the aim of developing and evaluating ferritic steels for steam conditions up to 650°C.

Today's state-of-the-art large fossil-fired steam turbines comprise live steam conditions of up to 610°C/300 bar and re-heat temperatures of up to 630°C. These ultra super critical steam parameters significantly increase plant efficiency and reduce fuel consumption and emissions of CO_2.

Ferritic materials should be used for thick-walled components to maintain high operational flexibility of such large plants. Rotors, casings, bolts, tubes/pipes and waterwalls are the critical components under current investigation. The class of the 9–12% Cr steels offers the highest potential to meet the required property level for critical components. Therefore a significant effort to increase the application temperature of these steels was the focus of study within the European COST 501 programme and has led to improved materials for 600°C application of forged and cast components and for pipework. These 600°C materials are already being successfully utilised in a number of advanced European power plants. Further potential for improvement in creep strength seems possible after taking into account the oxidation resistance for $T>600$°C.

A large number of new ferritic—martensitic compositions, which have been designed on the basis of the positive outcomes attained in previous studies as well as on the results obtained with advanced thermodynamic calculation tools are under investigation in the new COST 522 programme. Full-size cast and forged components have been manufactured from the most promising compositions and now are being evaluated by intensive mechanical testing.

(cf. *ISIJ Int.*, **42** (2002), 1515)

Effects of titanium addition on precipitate and microstructural control in C–Mn microalloyed steels

M.Vedani et al.

A study was carried out on the effects of Ti in a Ti-lean and a Ti-modified C–Mn microalloyed steels of otherwise comparable compositions. Analyses were carried out by SEM and TEM on steel microstructure, microalloying element precipitates and on non-metallic inclusions. A theoretical support to the experimental data was obtained by thermodynamic analyses aimed at stating phase stability and composition as a function of temperature for the steels investigated. Experimental results and theoretical predictions were combined to cast light on carbide, nitride and sulphide evolution during thermal cycles associated to fabrication route of the steels.

(cf. *ISIJ Int.*, **42** (2002), 1520)

Fine-grained structures developed along grain boundaries in a cold-rolled austenitic stainless steel

T.Morikawa et al.

Fine-grained structures developed by cold-rolling in a 310S austenitic stainless steel have been investigated by using transmission electron microscopy (TEM). Particular emphasis is laid on the role of initial grain boundaries in the transmutation process of twin-matrix (T-M) lamellae into fine-grained structures.

Microstructural evolution in a cold-rolled 310S steel is characterized by the development of dense T-M lamellae and their following collapse caused by shear band formation: shear bands destroy the T-M lamellae, and a fine-grained structure develops with increasing the area of shear bands. In the process of this grain refinement, such fine-grained structures have been found not only in shear bands but also in the area along initial grain boundaries. The fine-grained structure preferentially appeared around the intersections of grain boundaries with shear bands, and it expanded along the grain boundaries which were almost parallel to the rolling direction. In selected area diffraction patterns obtained from these fine-grained areas, large scatterings of crystal orientations were observed. On the basis of these results, the role of initial grain boundaries on the grain refinement is discussed.

(cf. *ISIJ Int.*, **42** (2002), 1527)

Characterization of nanostructure of rusts formed on weathering steel

M.Kimura et al.

Nano-scale structures of rusts formed on the weathering steel surface were investigated. It has been shown that the key structure is an $Fe(O, OH)_6$ network, which is different from crystalline FeOOH. Atomic structures were analyzed quantitatively by a combination of X-ray absorption fine structure (XAFS) analysis including *in situ* observation under wet conditions, X-ray diffraction (XRD), and transmission electron microscopy (TEM). It has been shown that the $Fe(O, OH)_6$ network structure evolves in the process of corrosion and a small amount of alloying elements such as chromium modifies the evolution process and the final morphology of rust.

(cf. *ISIJ Int.*, **42** (2002), 1534)

Interaction between dislocation and copper particles in Fe–Cu alloys

K.Nakashima et al.

The strengthening mechanism due to copper (Cu) particles was discussed in terms of the interaction between dislocation and Cu particles in aged Fe–Cu alloys. Since Cu particles are softer than the iron matrix, its interaction with dislocation is different from that with the Orowan mechanism. The moving dislocations can cut the soft Cu particles and pass through them when the bowing angle reaches some critical value (θ_c), and the precipitation strengthening due to Cu particles is expressed as a function of mean particle spacing (λ) and the θ_c ($\pi/2$ gives Orowan stress). The θ_c increased with increasing the size of Cu particles and reached $\pi/2$ when the Cu particle size became 70 nm. This means that the precipitation strengthening due to Cu particles is dependent on not only λ but also the Cu particle size, and 70 nm is the minimum Cu particle size for obtaining the Orowan stress.

(cf. *ISIJ Int.*, **42** (2002), 1541)

In-situ observation of dislocation motion and its mobility in Fe–Mo and Fe–W solid solutions at high temperatures

D.Terada et al.

The mobilities of the edge dislocations in Fe–W and Fe–Mo solid solution alloys at high temperatures were investigated with *in-situ* TEM observation in order to compare the effect of W and Mo on the solid solution hardening of ferrite. The dislocation behaviors were recorded continuously with VTR. TEM observations showed that the dislocations werfe moving viscously and that the dislocation velocites were constant in both Fe–W and Fe–Mo alloys. These results show that dislocations dragged solute atmosphere. The mobilities were determined to be $5.7\times10^{-15\ \mathrm{m/(Pa\cdot s)\ at\ 993\ K\ in\ the\ Fe–W\ alloy\ and}}$ $^{4.3\times10}-15$ m/(Pa·s) at 1011 K in the Fe–Mo alloy. It was found that the mobility in the Fe–W alloy is similar to that in the Fe–Mo alloy. Mobilities were estimated by simulation using the interaction between an edge dislocation and solute atoms. The results show that the simulated value was similar to the measured value in the Fe–Mo alloy while the simulated value is different from the measured in the Fe–W alloy. The simulated mobility of the dislocation in Fe–W is one-tenth as large as that in Fe–Mo. The simulated results for Fe–W did not agree with the experimental results. It is considered that the difference between the experimental values and simulated values chiefly came from the shape of the dislocations using for measurement and the diffusion constant which was used in the simulation. Experimental results showed that the mobility in Fe–W is as large as that in Fe–Mo. Therefore, it is suggested that the effect of W on the solid solution hardening of Fe is similar to that of Mo.

(cf. *ISIJ Int.*, **42** (2002), 1546)

Refining of intermediate transformation microstructure by relaxation processing

X.M.Wang et al.

The influence of RPC (relaxation-precipitation-controlling phase transformation) processing parameters on the microstructure was studied by thermo-simulation for a low carbon Nb and Ti containing