profile and area of exit cross section of workpiece in oval–round (or round–oval) pass rolling sequence has been improved. Afterward, the generality and robustness of the model was studied to assess the potential that finite element method generally used for predicting it might be replaced by the model. Since only the shape of the inlet cross-section of workpiece and geometry of the roll groove are considered in the model, the problem of obtaining the final rolled shape is greatly simplified and subsequently the computational time required for whole rolling process is a few seconds.

Extensive hot bar rolling experiments at different temperatures (800–1 100°C) was carried out to investigate the effect of the change of rolling conditions and material parameters, such as the ratio of the specimen diameter to roll diameter, roll gap (*i.e.*, pass height), roll groove design, steel grades and temperature of material on the model. This model has then been applied to a rod mill to extend its application coverage.

It was shown that the predicted surface profile and area of exit cross section are in good agreement with those experimentally measured for the variation of rolling conditions and material parameters. It was found that if we are interested in the capability for predicting the surface profile and area of exit cross section of workpiece for the entire rod (or bar) rolling line within a very short time, the proposed model might be an alternative which can replace the three-dimensional finite element method usually used in the analysis of rod (or bar) rolling analysis.

(cf. *ISIJ Int.*, **42** (2002), 726)

Effect of the number of work-roll surface division on prediction of contact length in coupled analysis of roll and strip deformation during sheet rolling

H.Furumoto et al.

In order to perform accurate three-dimensional rolling analysis of sheet deformation, it is required to predict the contact length accurately in consideration of the surface waviness due to the flattening deformation of work roll surface. Flattening deformation analysis based on theory of elasticity and three-dimensional elastic FEM have been developed, and their accuracy in predicting flattening deformation and contact length are validated in this report. As the flattening deformation of the work roll surface changes sharply at the boundary of contact area, the contact length is expected to change according to the number of work roll surface division, especially in circumferential direction, for calculation. Then, the influences of the number of division on roll profile and contact length used for numerical analysis are investigated. The following results are obtained; 1) The differences between the results obtained by three-dimensional elastic FEM and formula for roll flattening of Nakajima and Matsumoto is not significant. 2) When the number of division of work roll surface is increased, the end point of contact region moves toward the downstream side, therefore, the contact length becomes longer and it is necessary to divide the work roll surface into enough much elements. 3) As long as enough much elements are used for the calculation, solutions, such as rolling pressure distribution or thickness distribution of rolled strip, obtained by three-dimensional analysis reveal little difference from those obtained using formula for roll flattening given by Hitchcock.

(cf. *ISIJ Int.*, **42** (2002), 736)

Transformations and Microstructures

Ultrafine grain structure through dynamic recrystallization for type 304 stainless steel

I.Salvatori et al.

Ultrafine grain structure in the type 304 austenitic stainless steel are pursed through dynamic recrystallization. The recrystallization behaviors are studied at various combinations of deformation temperatures and strain rates accompanying the higher strain under a plain strain compression. The effects of the strain, the strain rate and the deformation temperature are investigated, and the relationship between the deformation conditions and the dynamic recrystallized grain size is analyzed. The critical strain needed for the initiation of recrystallization increases with the Z–H parameter. Empirical equations concerning the critical strain and the dynamic recrystallized grain size are discussed, and processing parameter maps are proposed for the complete dynamic recrystallization.

(cf. *ISIJ Int.*, **42** (2002), 744)

The deformation microstructure and recrystallization behavior of warm rolled steels

D.Liu et al.

The deformation microstructure of various warm (ferritic) rolled steels was characterized and its influence upon the subsequent annealing behavior determined. The materials investigated included three interstitial-free (IF) steels (stabilized with either titanium or niobium), an extra low carbon (ELC) steel, and four experimental low carbon chromium steels with varying levels of boron, nitrogen and phosphorus. Single pass rolling experiments were conducted in a pilot mill at temperatures between 440 and 850°C and the as-rolled microstructures were examined using optical microscopy. Particular attention was paid to the nature and intensity of the in-grain shear bands produced. Partial annealing was conducted to examine the nucleation of recrystallization in the deformed microstructure. Shear bands of moderate intensity were usually formed in the IF steels, which tended to be insensitive to rolling temperature. For the ELC steel, intense shear bands were formed at low rolling temperatures, but at higher temperatures this intensity was found to be drastically reduced. The development of shear bands at the higher rolling temperatures was significantly enhanced by alloying with chromium. The differences in shear band frequency and intensity are explained in terms of the dynamic strain aging behaviors of the various materials. Recrystallized grains were found to nucleate preferentially on the shear bands during annealing, regardless of their morphology or intensity.

(cf. *ISIJ Int.*, **42** (2002), 751)

Modelling simultaneous alloy carbide sequence in power plant steels

N.Fujita et al.

A method has recently been developed to estimate the speed with which precipitation reactions occur in power plant steels. It is based on Avrami theory but with an adaptation that allows the treatment of simultaneous reactions. In the present work, a number of approximations and inconsistencies in the theory have been eliminated and this kinetic theory for simultaneous reactions has been modified with the treatments of both diffusion-controlled growth and capillarity effect in multicomponent systems. The modified model can predict not only volume fraction changes of each carbide but also particle sizes. New experimental results on alloy carbide in 3Cr1.5Mo and $2\frac{1}{4}$Cr1Mo steels are reported and shown to be comparable to the modified theory.

(cf. *ISIJ Int.*, **42** (2002), 760)

Development of cold rolled texture and microstructure in a hot band Fe–3%Si steel

S.Cicalè et al.

Hot band Fe–3%Si steel (CRGO or cold rolled grain oriented) was cold rolled with different reductions. The main objective of this study was an overall understanding of deformation texture and microstructure development. Hot band CRGO had a strong α-fiber (RD//⟨110⟩) texture. Cold reduction strengthened the α and γ (ND//⟨111⟩) fibers, but weakened θ (ND//⟨100⟩). All Taylor type deformation texture models were reasonably successful in predicting these bulk texture developments, and the Lamel model seems to be the 'best-fit' model, both in terms of a 'deviation' parameter (indicating differences between experimental and simulated values of idealized texture components) and a 'trend' parameter (indicating the relative change(s) in texture components with strain). The striking feature of the microstructure was the 'selective' appearance of grain interior strain localization's. These appeared at approximately 37° with the rolling direction (RD). Though 37° bands appeared only in orientations with high Taylor factor (M), the absolute value of the Taylor factor alone, was not enough for the appearance of such bands. Negative textural softening or ($dM/d\varepsilon$) values, on the other hand, were always associated with the appearance of 37° bands, justifying or explaining their formation on the basis of a macroscopic plastic instability theory.

(cf. *ISIJ Int.*, **42** (2002), 770)

Mechanical Properties

Effect of heat treatment on precipitation kinetics in high-Cr ferritic steels

K.Yamada et al.

Precipitation strengthening is important to improve creep strength of heat resisting steels at elevated temperatures. Especially, in the high-Cr ferritic steels recently developed for Ultra Super Critical Power Plants, precipitation behavior is complicated and should be clarified because the correlation between various strengthening factors are still not well