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Electron backscatter diffraction study of deformation and recrystallization textures of individual phases in a cross-rolled duplex steel

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ABSTRACT

The evolution of microstructure and texture during cross-rolling and annealing was investigated by electron backscatter diffraction in a ferritic–austenitic duplex stainless steel. For this purpose an alloy with nearly equal volume fraction of the two phases was deformed by multi-pass cross-rolling process up to 90% reduction in thickness. The rolling and transverse directions were mutually interchanged in each pass by rotating the sample by 90° around the normal direction. In order to avoid deformation induced phase transformation and dynamic strain aging, the rolling was carried out at an optimized temperature of 898 K (625 °C) at the warm-deformation range. The microstructure after cross warm-rolling revealed a lamellar structure with alternate arrangement of the bands of two phases. Strong brass and rotated brass components were observed in austenite in the steel after processing by cross warm-rolling. The ferrite in the cross warm-rolling processed steel showed remarkably strong RD-fiber (RD//<011>) component {001}<011>. The development of texture in the two phases after processing by cross warm-rolling could be explained by the stability of the texture components. During isothermal annealing of the 90% cross warm-rolling processed material the lamellar morphology was retained before collapse of the lamellar structure to the mutual interpenetration of the phase bands. Ferrite showed recovery resulting in annealing texture similar to the deformation texture. In contrast, the austenite showed primary recrystallization without preferential orientation selection leading to the retention of deformation texture. The evolution of deformation and annealing texture in the two phases of the steel was independent of one another.

1. Introduction

Thermo-mechanical processing of materials by heavy rolling and annealing is usually accompanied by the development of characteristic crystallographic texture which influences the mechanical properties of the processed materials. As a result, the origin of crystallographic texture during thermo-mechanical processing has been energetically studied [5]. As has been summarized by Hirsch and Lucke [9], medium to high stacking fault energy (SFE) fcc materials develop a copper type (or pure metal type) texture characterized by the presence of strong S ({123}<634>), brass or B_S ({110}<112>) and copper or Cu ({112}<111>) components during heavy cold-rolling and a strong cube texture ({001}<100>) during subsequent annealing. In contrast, in low SFE FCC materials the deformation texture is brass type (or alloy type) dominated by the B_S component. This leads to different annealing textures, notably, the brass recrystallization component (B_S^R) {236}<385>. The evolution of recrystallization texture in low SFE fcc materials has been extensively discussed by Humphreys and Hatherly [12].

The deformation texture of BCC metals and alloys (for e.g. low carbon ferritic steels) is generally described by the relative strength two fibers, namely, the RD (or α) (RD//<110>) and ND (or γ) (ND//<111>) fibers. However, development of stronger ND fiber during annealing is desired for achieving deep drawing properties [19].

Suwas and Singh [21] and Gurao et al. [8] have shown that change in strain path can greatly affect the texture development. The strain path change during rolling can be achieved by cross-rolling where the sample is rotated by 90° around the sheet normal direction (ND) in every pass. In this process the rolling (RD) and the transverse directions (TD) are mutually interchanged in every pass (Fig. 1). Suwas and Singh [21] and Gurao et al. [8] have clarified the effect of cross-rolling in single phase FCC metals and alloys and shown that cross-rolling texture is dominated by brass and rotated brass components and significantly different from that developed during unidirectional (or straight) rolling. Bhattacharjee et al. [2] have shown that annealing of cross-rolled nickel may result in the development of rather unusual texture.

It is interesting to note that while texture development has been intensely investigated in various materials, texture of duplex alloys (where both the phases have a grain structure), such as, duplex steels has received less attention. This is despite the fact that there have been considerable recent developments in designing low density duplex steels as reported by Park et al. [18]. It has been pointed out by Humphreys and Hatherly [12] that the deformation and recrystallization of duplex alloys may be affected by the volume fraction of the second phase, homogenization (the temperature at which the

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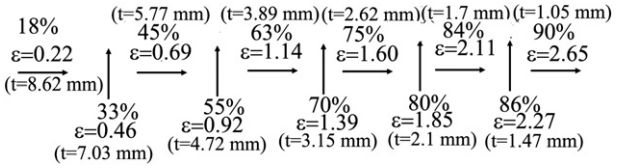

Fig. 1. Schematic illustration of the CWR processing routes. The RD of the first and final pass is parallel to the prior hot rolling direction.

volume fraction of the two phases are stabilized) and annealing temperatures. Importantly, the effect of cross-rolling on texture evolution in duplex alloys has received far less attention and been studied only very recently in ($\alpha + \beta$) brass by Garg et al. [7].

The present work makes an attempt to study the microtextures of individual phases in a heavily cross-rolled ferritic–austenitic duplex stainless steels (DSS). In order to avoid additional complexities resulting from deformation induced phase transformation of austenite, the cross-rolling is carried out in the warm-deformation range in the present research. Interestingly, the warm-rolling of DSS is only recently investigated but has significant potential as a novel thermo-mechanical processing route for DSS alloys [3].

2. Experimental

2.1. Processing

An as cast 0.08%C–24.18%Cr–10.5%Ni DSS ingot having the shape of a tapered cylinder (top diameter: 72 mm; bottom diameter: 62 mm; height: 290 mm) was used as the starting material. The detailed chemical composition of the as cast DSS is given elsewhere by Bhattacharjee et al. [3]. The as cast ingot was first processed by cogging at 1473 K (1200 °C) to dimensions 60 mm (thickness) × 55 mm (width) × 300 mm (length) followed by hot-rolling at 1398 K (1125 °C) to a plate with thickness ~10.5 mm. The starting coupons for warm-rolling with dimensions 30 mm (width) × 80 mm (length) were machined out from the hot-rolled plate and homogenized in a tubular furnace in argon atmosphere at an optimized temperature of 1448 K (1175 °C) for 7200 s (2 h) to achieve nearly equal volume fraction of the two phases. These homogenized samples were subjected to cross warm-rolling (CWR) at 898 K (625 °C) up to ~90% reduction in thickness (Von Mises equivalent strain (ε_{eq}) = 2.65) to a final thickness of ~1 mm using a laboratory rolling equipment (SPX Precision Equipment, USA) with oil lubricated rolls having roll diameter of 140 mm. The total thickness reduction during CWR was achieved in eleven passes as schematically shown in Fig. 1 together with the percentage thickness reduction, equivalent strain and thickness at each deformation pass. The warm-rolling temperature of 898 K (625 °C) was carefully selected based on the previous results reported by Bhattacharjee et al. [3] to avoid deformation induced phase transformation and dynamic strain aging. The samples were pre-heated to 898 K (625 °C) and soaked for 900 s (15 min) before each warm-rolling pass. The rolls were pre-heated to 523 K (250 °C). Samples were quenched in cold water after each pass.

The 90% CWR processed samples were isothermally annealed in a conventional tubular furnace in argon atmosphere at 1448 K (1175 °C) for time varying from 120 s (2 min) to 7200 s (2 h). The isothermal annealing was carried out at the homogenization temperature in order to minimize the effect of phase transformation during annealing. The samples were immediately water quenched following the heat treatments.

2.2. Characterization

The microstructure and microtexture were analyzed using electron back scatter diffraction (EBSD) system (Oxford Instruments, UK) mounted on a SUPRA 40 scanning electron microscope (SEM) (Carl Zeiss, Germany) equipped with field emission gun (FEG). The EBSD samples were prepared by mechanical polishing followed by electropolishing (electrolyte: 700 ml ethanol, 120 ml distilled water, 100 ml glycerol, and 80 ml perchloric acid, temperature: ambient). The EBSD data from the warm-rolled materials was acquired using a scan step size (S) of 0.05 μm (50 nm). For annealed materials the scan step size varied from 0.30 μm to 1.5 μm. Several EBSD scans were acquired from the central regions of each deformed and annealed sheet so that orientation of at least 2500 individual grains of each phase could be analyzed. The scan data was analyzed using the TSL-OIM™ software (version 6.2). The pole figures (PFs), orientation distribution function (ODFs) and volume fraction of different texture components for each condition were determined after merging several EBSD scans. The PFs and ODFs were calculated using the series expansion method with series rank 22. The volume fraction of different texture components was determined using a cut-off angle of 15°.

3. Results

3.1. Microstructure and Texture Evolution During Cross-Rolling

The phase map of the homogenized DSS used as the starting material for warm-rolling shows nearly equal volume fraction of the two phases. The microstructure shows elongated morphology of the two phases along the prior hot-rolling direction with average phase band thickness of ~6 μm. The ferrite shows the presence of stronger ND-fiber as compared to the RD-fiber. The texture of austenite reveals the presence of a weak pure metal type texture. The microstructure and texture of the homogenization annealed DSS are given in detail elsewhere by Bhattacharjee et al. [3].

Fig. 2 shows the evolution of microstructure after 90% thickness reduction by the CWR route. The phase map (Fig. 2(a)) after 90% thickness reduction shows an elongated morphology along the RD with alternate arrangement of deformed bands of the two phases. The RD shown in the phase map is for the current pass which is parallel to the RD for the first pass, and also to the prior hot-rolling direction (Fig. 1). It may be noted that structural rotation is observed throughout the CWR processing, so that the microstructure appears elongated along the principal direction of working i.e. RD for the current pass. The austenite fraction is ~54%

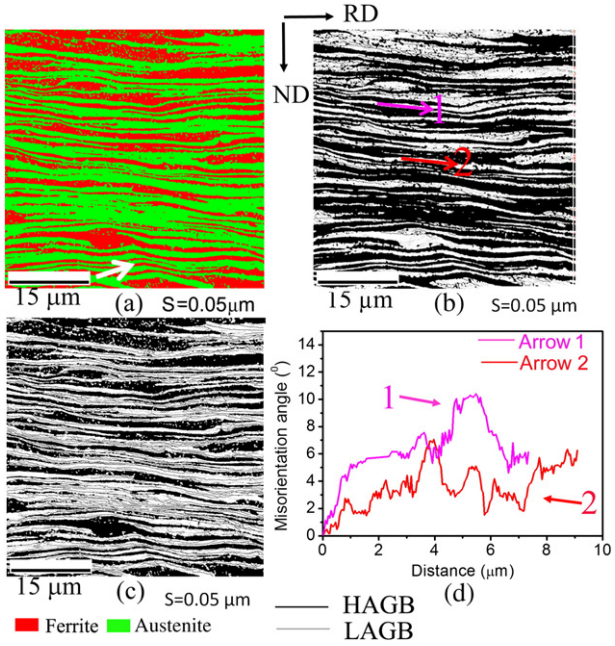

Fig. 2. (a) shows the phase map, (b) and (c) show the GB maps of ferrite and austenite, respectively of the 90% CWR processed DSS; (d) shows the accumulated misorientation inside the ferrite bands along the arrow marks shown in (b). S mentioned in each map is the scan step size.