Microtexture of constituent phases in a heavily warm- rolled and annealed duplex stainless steel

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Microtexture of constituent phases in a heavily warm-rolled and annealed duplex stainless steel

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Abstract. Evolution of microtexture during isothermal annealing of a heavily warm-rolled Fe-0.08%C-24.18%Cr-10.5%Ni duplex stainless steel (DSS) having approximately equal volume fraction of ferrite and austenite was investigated in the present work. The DSS was warm-rolled to ~90% reduction in thickness at three different temperatures, namely, 225°C, 425°C and 625°C followed by isothermal annealing at 1175˚C for different length of time. Austenite showed pure metal or copper type texture at different warm-rolling temperatures. In contrast, the texture of ferrite in different warm-rolled DSS revealed the presence of RD (RD//<110>) and ND (ND//<111>) fibers. The annealing texture of austenite showed retention of the deformation texture components while ferrite revealed strong RD-fiber.

1. Introduction

The evolution of microstructure and texture during recrystallization of heavily deformed two phase alloys has been reported extensively. However, amongst the two-phase alloys the main focus has been on those materials having the second phase present in the form of dispersoids or precipitates. In contrast, the recrystallization behavior of duplex alloys in which both the phases have grain structure, such as ($\alpha+\beta$) brass or duplex stainless steels (DSS), have been studied to a much lesser extent. The focus of the present work is to study the recrystallization behavior of heavily warm-rolled DSS having approximately equal volume fraction of ferrite and austenite. Thermo-mechanical processing involving cold-rolling and annealing of DSS has been reported extensively [1-4], however, the evolution of microstructure and texture during warm-rolling has been clarified only recently by the present authors [5]. The present investigation is aimed to clarify the evolution of microstructure and texture during subsequent annealing which should be of interest for designing novel thermo-mechanical processing routes for DSS alloys.

2. Experimental

The DSS alloys were obtained in the form of an as-cast ingot having a chemical composition shown in Table 1. The as-cast ingot was initially processed through a series of thermo-mechanical treatments to obtain a hot-rolled slab which was homogenization annealed at 1175°C to obtain nearly equal volume fraction of the two phases [5]. The homogenization annealed slab was subjected to multipass warm-rolled up to ~90% reduction in thickness at three different temperatures, namely 225°C, 425°C and 625°C using a laboratory scale rolling equipment (SPX Precision Equipment, USA). In order to minimize the sudden quenching effect the rolls were pre-heated to 250°C during warm-rolling. The warm-rolled samples were immediately water quenched after every warm-rolling pass. The 90% warm-rolled samples were subsequently isothermally annealed in a conventional horizontal cylindrical furnace at 1175°C for different time intervals varying from 2 minutes to 120 minutes and immediately water-quenched. The microstructure and texture of the deformed materials were characterized using electron back scatter diffraction (EBSD) system (Oxford Instruments, UK) attached to a FEG-SEM (Make: Carl Zeiss, Germany, Model: SUPRA-40).The acquired EBSD dataset were analyzed using TSL-OIM™ software.

Table 1: Chemical composition of the experimental DSS

Element	C	S	Cr	Mn	Ni	P	Si	Mo	Fe
Weight%	0.08	0.001	24.18	0.14	10.5	0.017	0.45	3.11	balance

3. Results and discussion

Evolution of texture during warm-rolling
The texture of the two phases in the starting homogenization annealed material is shown in Fig.1. Figure 1(a) shows the $\varphi_2=45°$ section of the ODF of ferrite indicating the presence of ND (ND//<111>) along with a rotated cube component shifted along the φ_1 by $\mp$ 15°. The $\varphi_2=45°$ section of the ODF of ferrite in DSS warm-rolled at 225°C (Fig.1(b)) and 625°C (Fig.1(d)) shows the presence of both RD and ND fibers. However, $\varphi_2=45°$ section of the ODF of ferrite in DSS warm-rolled at 225°C (Figure 1(c)) shows remarkably stronger RD-fiber as compared to the ND-fiber. The strongest component along the RD-fiber is {001}<110>. The evolution of strong RD-fiber texture in ferrite in DSS warm-rolled at 425°C is explained on the basis on dynamic strain aging effect due to which carbon atoms preferentially lock dislocations and restricts slip on the {110}<111> system [5]. Further deformation by slip occurs preferentially on the {112}<111> system. This leads to a stronger RD fiber than ND fiber.
(111) pole figure (PF) of the austenite in the starting homogenized DSS (Fig.1(e)) shows the presence of weak pure metal (or copper type) texture characterized by S ({123}<634>), Cu ({110}<112>) and the brass ({110}<112>) component. The (111) PFs of austenite in DSS warm-rolled at different temperatures (Fig.1(f)-(h)) shows the development of predominantly pure metal type texture. The mechanism for the above observation has been recently reported by the present authors [5].

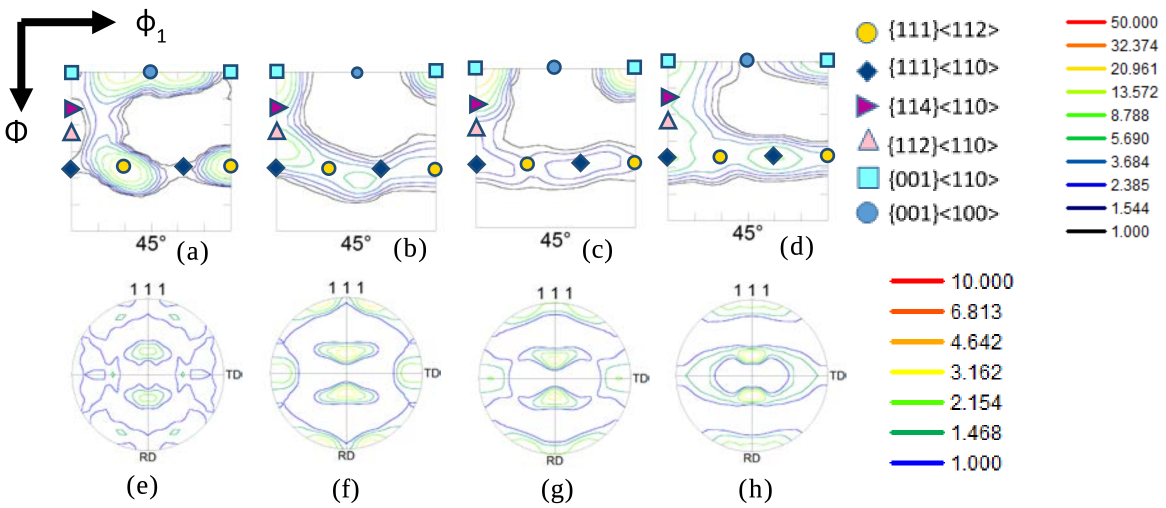

Fig. 1: $\varphi_2=45°$ section of ODFs of ferrite in DSS (a) homogenized and warm-rolled at (b) 225°C, (c) 425°C and (d) 625°C. (111) PFs of austenite in DSS (e) homogenized and warm-rolled at (f) 225 °C, (g) 425°C and (h) 625°C.

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3.2 Evolution of recrystallization texture during annealing

Isothermal annealing of the different 90% warm-rolled DSS is carried at 1175°C out for 2 minutes to 120 minutes. However, specimens annealed for 2, 30 and 120 minutes are only discussed here as major microstructural transformations happen in these temperatures. These microstructural transformations are clearly shown in Fig.2 for the DSS warm-rolled at 625°C but also holds good for DSS warm-rolled at other temperatures. The ultrafine microstructure obtained after warm-rolling (Fig.2(a)) is transformed to a bamboo type morphology for short isothermal holding time (Fig.2(b)). A globular morphology is gradually evolved due to the breakdown of the lamellar structure. Any significant changes could not be observed during prolonged annealing (Fig.2(c)).

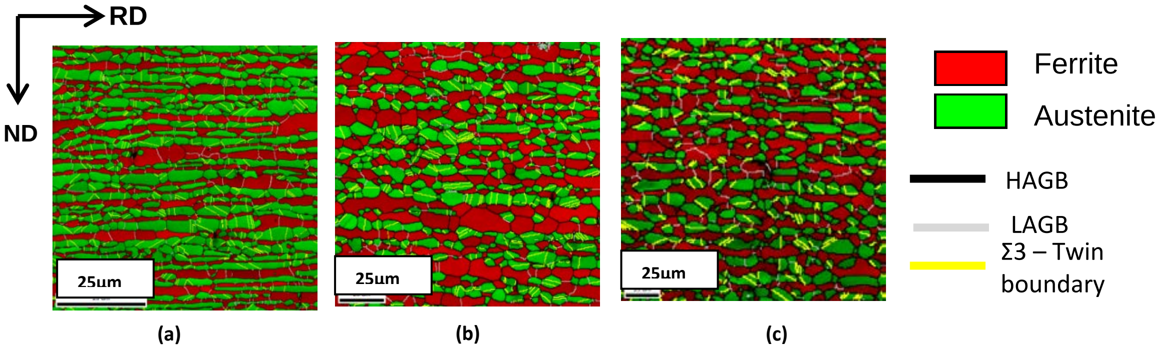

Fig. 2: Phase maps of DSS 90% warm-rolled at 625°c and annealed at 1175°C for (a) 2 minutes, (b) 30 minutes and (c) 120 minutes.

Despite the apparent differences in the texture of ferrite in as warm-rolled conditions as discussed above, the texture of ferrite in the three warm-rolled and annealed DSS (Fig.3(a)) shows much stronger RD-fiber than ND-fiber. The development of stronger RD-fiber components is attributed to recovery behavior of these components [1] as opposed to the typical recrystallization type behavior of the ND-fiber components. Warm-rolling of DSS results in diminished driving force for recrystallization and results in the formation of much stronger RD-fiber.

The recrystallization texture of austenite in different warm-rolled and isothermally annealed DSS is represented the by (111) pole figures (PFs) in Fig.3(b). The (111) PFs of austenite in annealed materials appear to be very similar to those of the as warm-rolled DSS (Fig.1(f)-(h)) indicating the retention of deformation texture even after prolonged annealing. Thus, annealing textures for the three warm-rolling conditions show retention of the deformation texture components. The retention of deformation texture during recrystallization indicates discontinuous recrystallization without preferential orientation selection. Interestingly brass recrystallization component ({236}<385>) is not found strong after annealing. Since Brass is not the dominant component of the warm-rolled texture, the preferential growth advantage of {236}<385> grains would be greatly reduced, preventing it from emerging a strong texture component after annealing.

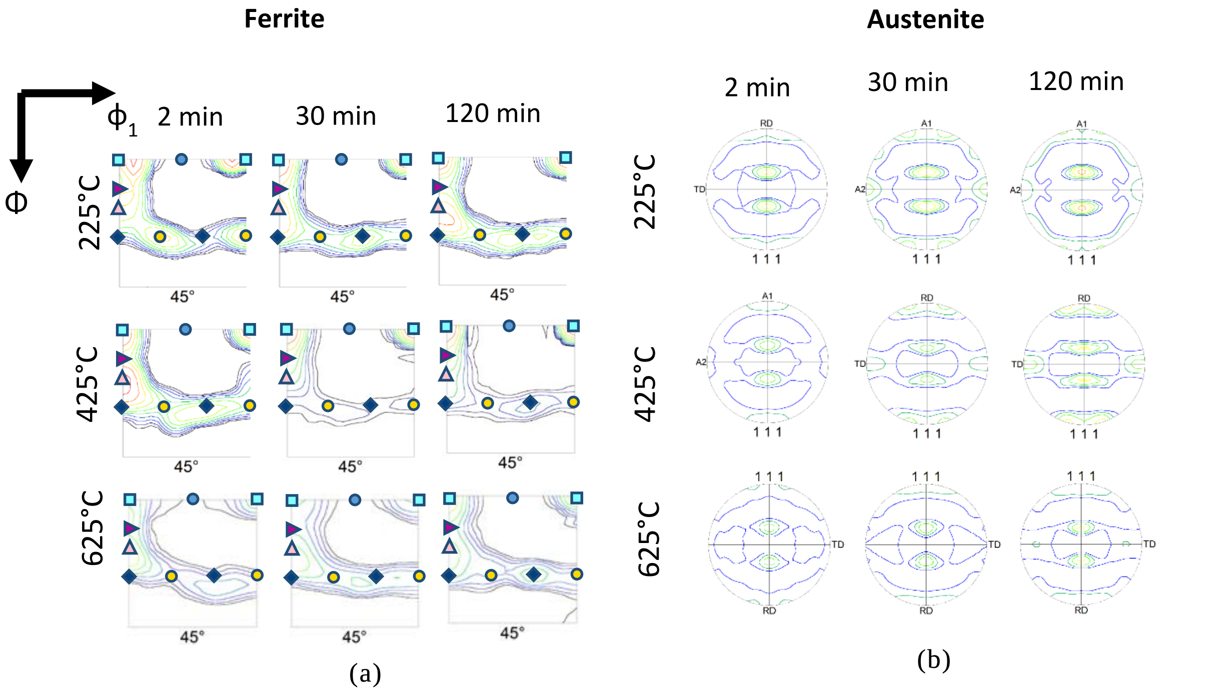

Fig. 3: (a) φ2=45° section of ODFs of ferrite and (b) (111) PFs of austenite in DSS 90% warm-rolled at different temperatures and then isothermally annealed at 1175°C for different time intervals. The intensities of the contour lines are same as those shown in Fig.1.

Conclusions

- The deformation texture of the two phases in DSS is significantly affected by the warm-rolling temperature, although, the recrystallization texture remains unaffected.
- RD-fiber strengthens due to strong recovery behavior of ferrite in DSS during annealing.
- Austenite in DSS shows retention of deformation texture components after annealing which is attributed to discontinuous recrystallization without preferential orientation selection.

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