Research on Strain Partitioning and Mechanical Properties of a Cast Multiphase Stainless Steel

Zixiang Wu[1], Xiang Chen[1,2,*]

1. School of Materials Science and Engineering, Tsinghua University, Beijing 100084, China;
2. Key Laboratory for Advanced Materials Processing Technology, Ministry of Education, Beijing 100084, China;
*Correspondence: Xiang Chen; E-mail: xchen@tsinghua.edu.cn

Abstract: Multiphase stainless steels can offer very attractive combinations of high strength, high toughness and good corrosion resistance due to the characteristics of multiphase, metastable, and multi-scale. In this study, the strain partitioning in ferrite of a cast multiphase stainless steel was investigated by EBSD. The deformation occurs first in the softer ferrite and later transfers to the martensite/austenite regions. As the strain increases, subgrains form within the ferrite, effectively accommodating the deformation of different phases.

Keywords: multiphase stainless steel; strain partitioning; geometrically necessary dislocations; subgrains

1 Introduction

Multiphase stainless steel containing ferrite, martensite, and a moderate amount of austenite can combine high strength and ductility with excellent formability, making it a widely choice for turbine blades, valve bodies, and ship propellers. The enhanced strength and plasticity are attributed mainly to the transformation-induced plasticity (TRIP) resulting from the metastable austenite and strain partitioning into different constituent phases[1-2].

During the deformation, the softer phase yields first, and after appropriate work hardening, sufficient strain is transferred to the harder phases to cause them to yield later[3]. For dual-phase steel, local plasticity generated in ferrite adjacent to martensite can lead to the generation of geometrically necessary dislocations (GNDs) to maintain lattice continuity and thus improving work hardening[4]. As the deformation continues, the dislocation subgrain structures are more likely to be generated within grains due to the increased GNDs and divide the grain into different subgrain regions[5-6]. Therefore, strain partitioning in ferrite is important to mechanical properties.

In this study, a novel cast stainless steel was prepared and processed by intercritical tempering (IT) and aging treatment to obtain a multi-phase microstructure. The role of ferrite in strain partitioning during deformation was carefully investigated.

2 Experimental procedure

The tested steel with a composition of Fe-0.03C-13.88Cr-6.88Ni-1.54Mo-1.08Mn-2.60Si-1.01Cu-1.07Al-0.30Nb (wt.%) was prepared in a 10 kg vacuum induction furnace. Samples were heated at 1050 ℃ for 30 minutes and quenched to 25 ℃ in water (labeled as S1050), followed by IT at 620 ℃ for 1h (IT620) and aging at 500 ℃ for 4 h (AG500). The relevant testing methods can be found in Ref[7].

3 Result and discussion

Mechanical Properties

Fig. 1a shows the SEM micrograph of the S1050 sample characterized by the presence of δ-ferrite and martensite, while there is barely no retained austenite (RA) (as shown in Fig. 1c). Besides, NbC particles are found to distribute at the phase boundaries. Fig. 1b shows the SEM micrograph of the AG500 sample which combines δ-ferrite, lath martensite and RA (11.8%, as shown in Fig. 1c). Fig. 1d shows the tensile properties of the investigated samples. The AG500 sample has the best combination of mechanical properties (UTS:1260 MPa, YS: 1072 MPa, TE: 17.7%).

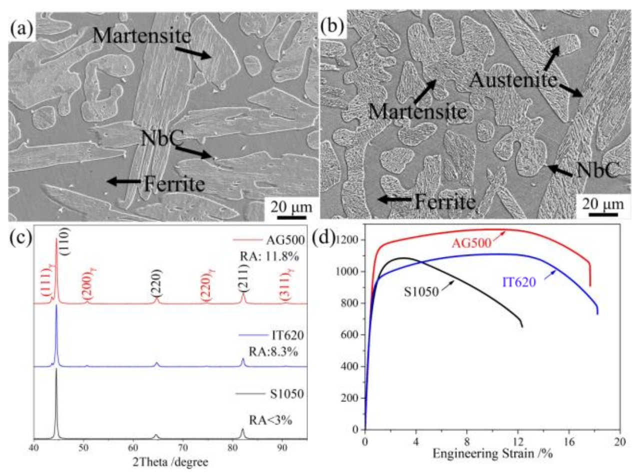

Fig. 1 (a-b) Sem micrograph of the investigated samples; (c) XRD patterns of the investigated samples; (e) tensile curves of the investigated samples.

Strain partitioning in ferrite

Fig. 2a shows the lateral side of fracture in the AG500 sample which exhibits the characteristics of ductile fracture and region B experiences more severe deformation to region A. Fig. 2b-c show the image quality (IQ) map and the kernel average misorientation (KAM) map taken from region A. The tensile direction is vertical and slip bands occur in the deformed ferrite region (as shown by red arrows in Fig. 2b). Fig. 2c shows that relatively higher KAM along the slip bands, which suggests that the slip bands are the regions with relatively higher dislocation density[8]. This is related to the formation of GNDs accommodating the strain gradient[7]. The density of GNDs on the phase boundary is smaller compared to the ferrite interior which indicates that the deformation occurs first within ferrite. When deformation encounters the hard martensite, it turns and deforms along the martensite plate (as shown by yellow arrows in Fig. 2c). This leads to the accumulation of GNDs on the phase boundaries.

Fig. 2d-f show the IQ map, the KAM map and the inverse pole figure (IPF) color map taken from region B. The tensile direction is also vertical and significant necking occurs in this region, corresponding to large plastic deformation. Fig. 2d indicates that the higher dislocations created within the ferrite region rearranged itself as subgrains due to more drastic deformation (as shown by green arrows). Fig. 2e shows that the substructures have a higher density of GNDs. In contrast to Fig. 2c, the martensite regions in Fig. 2e have a greater degree of deformation due to the very high misorientations especially on the phase boundary. This indicates that as the strain increases, the deformation within the ferrite is transmitted to the martensite through the accumulation of GNDs at the phase boundaries, which in turn leads to the TRIP effect of RA in martensite regions. Fig. 2f shows the IPF map in Y direction, subgrains form within ferrite and distribute in bands parallel to each other, thus refining the ferrite grains. Strain partitioning and subgrains formation in ferrite are beneficial for accommodating the strain of different phases and retarding strain to fracture[8].

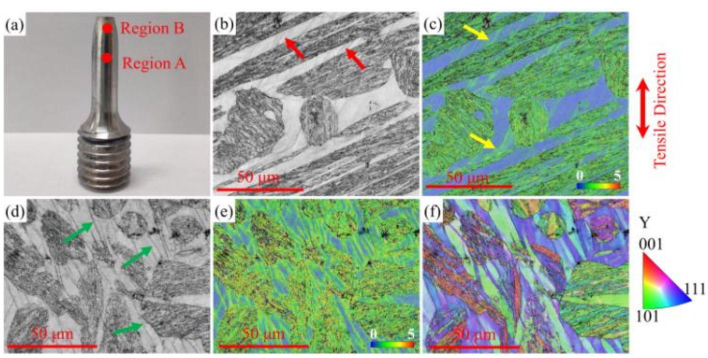

Fig. 2 (a) Lateral side of the fracture of the AG500 sample; (b) IQ map of the deformed AG500 sample in region A; (c) KAM map of the deformed AG500 sample in region A; (d) IQ map of the deformed AG500 sample in region B; (e) KAM map of the deformed AG500 sample in region B; (f) IPF map of the deformed AG500 sample in region B.

4 Conclusion

In this study, a novel cast stainless steel was prepared and processed by IT and aging treatment to obtain a multi-phase microstructure. The deformation first occurs in the softer ferrite and later transfers to the martensite/austenite regions. Strain partitioning and subgrains formation in ferrite can accommodate the deformation of different phases. The AG500 sample has the best combination of mechanical properties (UTS:1260 MPa, YS: 1072 MPa, TE: 17.7%).

Acknowledgments

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