Ultrafine-grained multi-phase medium-Mn advanced high strength steels

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Next generation advanced high-strength steels (AHSS) balance cost and mechanical properties by using alloy contents below 17 wt% and multi-phase microstructures of austenite, ferrite and martensite [1]. AHSS include medium-Mn steels with 3-12 wt.% Mn and <0.3 wt.% C that exhibit a deformed martensitic (α") microstructure after cold rolling; intercritical annealing (IA) produces ultrafine-grained (UFG) austenite (γ) and ferrite (α) [2]. The IA step is critical in medium-Mn steel production as the IA time and temperature determine the UFG phase fraction, size, composition and austenite stacking fault energy (SFE) [3]. An optimal SFE controls transformation- and twinning-induced plasticity (TRIP/TWIP) effects to further enhance the mechanical properties of steels containing austenite [4]. The present study uses scanning transmission electron microscopy energy-dispersive X-ray spectroscopy (STEM-EDS) and atom probe tomography (APT) to measure UFG phase compositions in a medium-Mn steel. The Fe-12Mn-3Al-0.05C (wt%) alloy was hot-rolled, homogenized for 2 h at 1100°C in an Ar atmosphere and water-quenched to room temperature (RT). After cold rolling the martensitic microstructure with a thickness reduction of 50% (average Vickers hardness of 390 HV), IA was performed for 0.5, 8 and 48 h at 585°C. Electron backscatter diffraction (EBSD) measurements (viewed in the normal direction) yielded an austenite area fraction of 35% (Figure 1) after IA for 8 h at 585°C. A focused ion beam (FIB) sample lifted out from a specimen annealed for 8 h (see Figure 2) revealed UFG austenite with compositions of ~21 wt% Mn, matching equilibrium Thermo-Calc simulations. STEM-EDS maps also yielded area fractions of 35% austenite (viewed in the rolling direction). APT offers improved spatial resolution for measurements of composition profiles across UFG austenite-ferrite boundaries (Figure 3). APT results are consistent with STEM-EDS, but also reveal C-rich and C-poor boundaries. 3D FIB-EBSD measurements are underway and will be coupled with crystal plasticity finite-element modeling to investigate the effects of phase morphology on strain partitioning, as well as high strain-rate mechanical properties of this multi-phase medium-Mn TWIP-TRIP steel.

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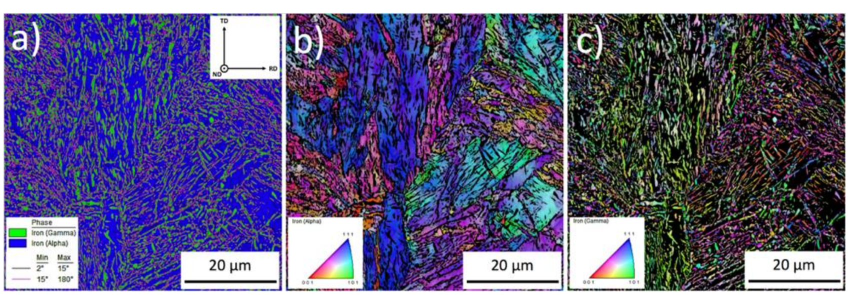

Figure 1: EBSD maps of Fe-12Mn-3Al-0.05C (wt%) steel annealed for 8 h at 585 °C. a) phase, grain boundaries and image quality (IQ), b) α-Fe orientation and IQ, c) γ-Fe orientation and IQ.

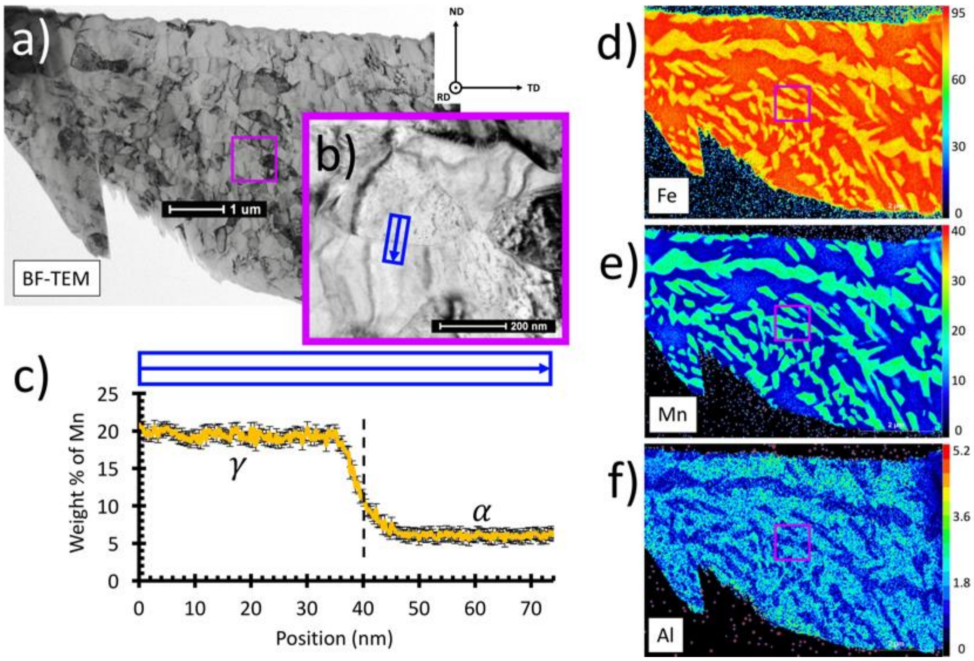

Figure 2: a) Bright-field (BF) TEM image of FIB lift-out from Fe-12Mn-3Al-0.05C annealed for 8 h. b) Inset BF-TEM image shows location of c) STEM-EDS linescan and d-f) STEM-EDS hypermaps (in wt%).

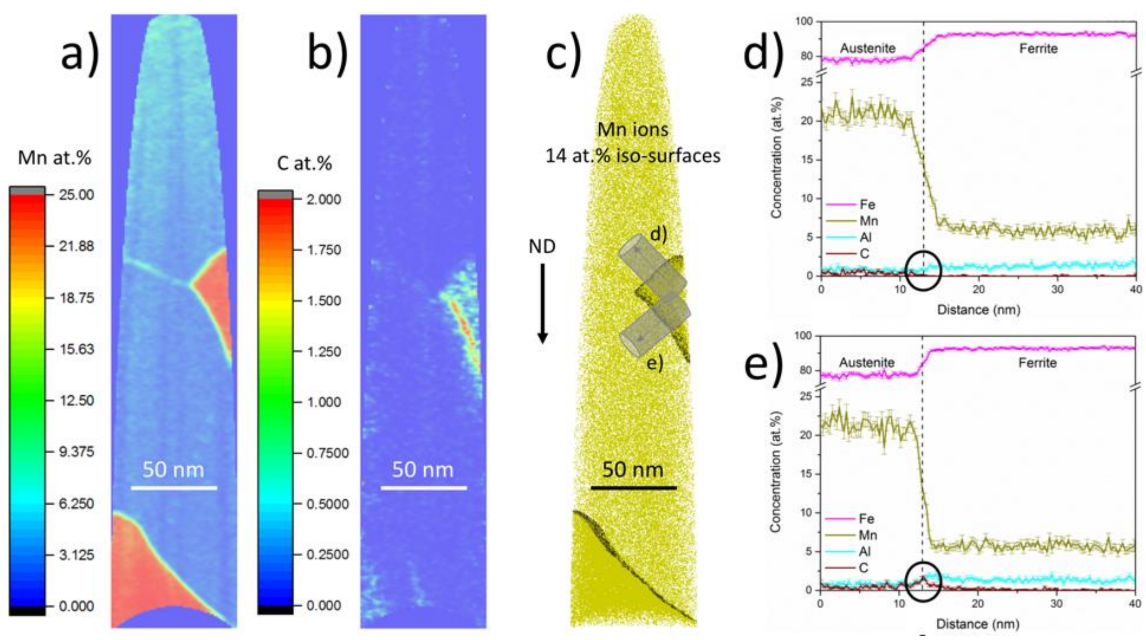

Figure 3: APT reconstruction of 270,000,000 ions measured from a FIB-prepared needle of Fe-12Mn-3Al-0.05C annealed for 8 h. The quantitative maps of a) Mn, b) C and c) 14% Mn iso-surfaces provide evidence of C-rich and C-poor boundaries, noted in the d-e) concentration profiles.

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