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Investigation of the influence of manganese on the dynamic strain ageing of ferritic steels

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Extended Abstract

Abstract

Dynamic strain aging (DSA) in ferritic steels, such as C-Mn steels, significantly affects their mechanical behavior, yet the atomic-scale mechanisms remain not fully understood. In two complementary studies, we investigated DSA in model and welded steels across scales, ranging from macroscopic tensile tests to nanoscale investigations using in-situ TEM tensile tests and atom probe tomography (APT). This multi-scale study reveals how alloy chemistry, especially manganese and carbon, controls dislocation dynamics. In the first study, we performed in-situ TEM tensile tests on a binary Fe-C and a ternary Fe–Mn–C model steels over a wide temperature range (300K – 900K). We observed that in the DSA temperature window, plastic deformation proceeds either by sudden dislocation bursts or by slow, viscous, dislocation glide. By tracking dislocation glide velocities, we extracted activation energies for dislocation motion. In pure Fe–C alloys, the "high-temperature diffusion–controlled (HTDC) Peierls glide" of screw dislocations has an activation energy close to that for carbon diffusion, in line with classic models. However, in Fe–Mn–C, this HTDC-Peierls glide is suppressed. Instead, viscous glide of mixed dislocations dominates at higher temperatures, with an activation energy similar to that of manganese diffusion. These observations lead us to propose that Mn atoms co-segregate with carbon along dislocations even at relatively low temperatures, around 500K, thereby hindering the screw dislocation glide mechanism. This Mn enrichment also underpins the DSA behavior and controls the viscous dislocation motion. In the second study, we turned to an industrial as-welded C–Mn steel weld, combining macroscopic tensile tests in the DSA temperature range (423K – 623K), in-situ TEM tensile tests, and APT. On the macroscopic scale, we found a marked increase in ultimate tensile strength and a narrow window of Portevin–Le Chatelier (PLC) serrations (423K – 473K). In-situ TEM tensile tests again revealed dislocation bursts in the DSA regime. Interestingly, at higher temperatures, the onset of HTDC-Peierls glide suppresses PLC serrations. From the activation energy and APT data, we confirmed that interstitial carbon dominates DSA in the weld. No Mn enrichment was detected at dislocations, in contrast to the model alloy. The lower Mn content in the weld apparently fails to immobilize mixed dislocations strongly, allowing for mixed dislocations to re-arrange as screw dislocations. Consequently, HTDC-Peierls glide governs the deformation and terminate Mn-controlled DSA. Taken together, these two studies establish a coherent mechanistic picture: Mn addition can profoundly alter DSA behavior via segregation and dislocation-solute interactions, but its influence depends sensitively on composition and dislocation character. This insight opens new pathways for tailoring alloy chemistry to control DSA in ferritic steels.

Keywords:

Plastic deformation Dynamic strain-aging In-situ TEM Dislocation dynamics Steel