Atomic Observations of Warm Rolled Low Carbon Steels Alloyed with Cr and P

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Low carbon steels exhibit the high positive rate sensitivities of flow stress and dynamic strain ageing effect (DSA) associated with high warm rolling temperatures. This leads to poor formability of warm rolled and annealed sheet [1,2]. One approach to lower the rate sensitivity of these steels is to remove the carbon from solid solution by adding carbide forming elements such as Cr [1,3,4]. The aim of this work was to investigate solute segregation and Cottrell atmosphere formation in warm rolled low carbon steels.

The low carbon steels used in this investigation contained 0.17±0.01 at. % C, 0.32±0.02 at. % Mn, 0.55±0.01 at. % Cr with and without addition of 0.0072 at. % P. The atomic level microstructural characterizations were performed in the ORNL local electrode atom probe. This state-of-the-art instrument features a substantially larger field of view and a significantly faster data acquisition speed compared to previous three-dimensional atom probes [6]. These improvements facilitate the characterization of low densities of microstructural features such as dislocations.

The results revealed that DSA had occurred during warm rolling of alloyed low carbon steels. Several C and C-Cr clusters were observed distributed relatively uniformly in the ferrite matrix, as shown in Fig. 1. These clusters comprised 20 to 600 atoms and had a nearly equiaxed morphology.

Many predominantly carbon Cottrell atmospheres were detected in the vicinity of dislocations in both steels. A number of configurations were encountered: single dislocations, tangles and arrays of dislocations. In the P containing steel, some P atoms were also present in the Cottrell atmospheres, Fig. 2. The lateral extent of the solute at all atmospheres was estimated to be 4-8 nm in diameter. The maximum carbon concentration was in the range 0.9 to 5 at. % C. Calculations yielded approximately 28±23 carbon atoms per equivalent 110 plane in the Cottrell atmosphere. These results differ slightly from a previous isolated observation of a dislocation [5]. The analysis of solute segregation to the boundaries in the steel alloyed with Cr and P with a method based on the Gibbsian interfacial excess [6] and from concentration profiles revealed C and P enrichments and Mn and Cr depletions, as shown in Fig. 3.

From these observations, it is evident that the additions of such levels of Cr and P are insufficient to deplete the ferrite matrix with carbon and prevent the DSA taking place during warm rolling.

References

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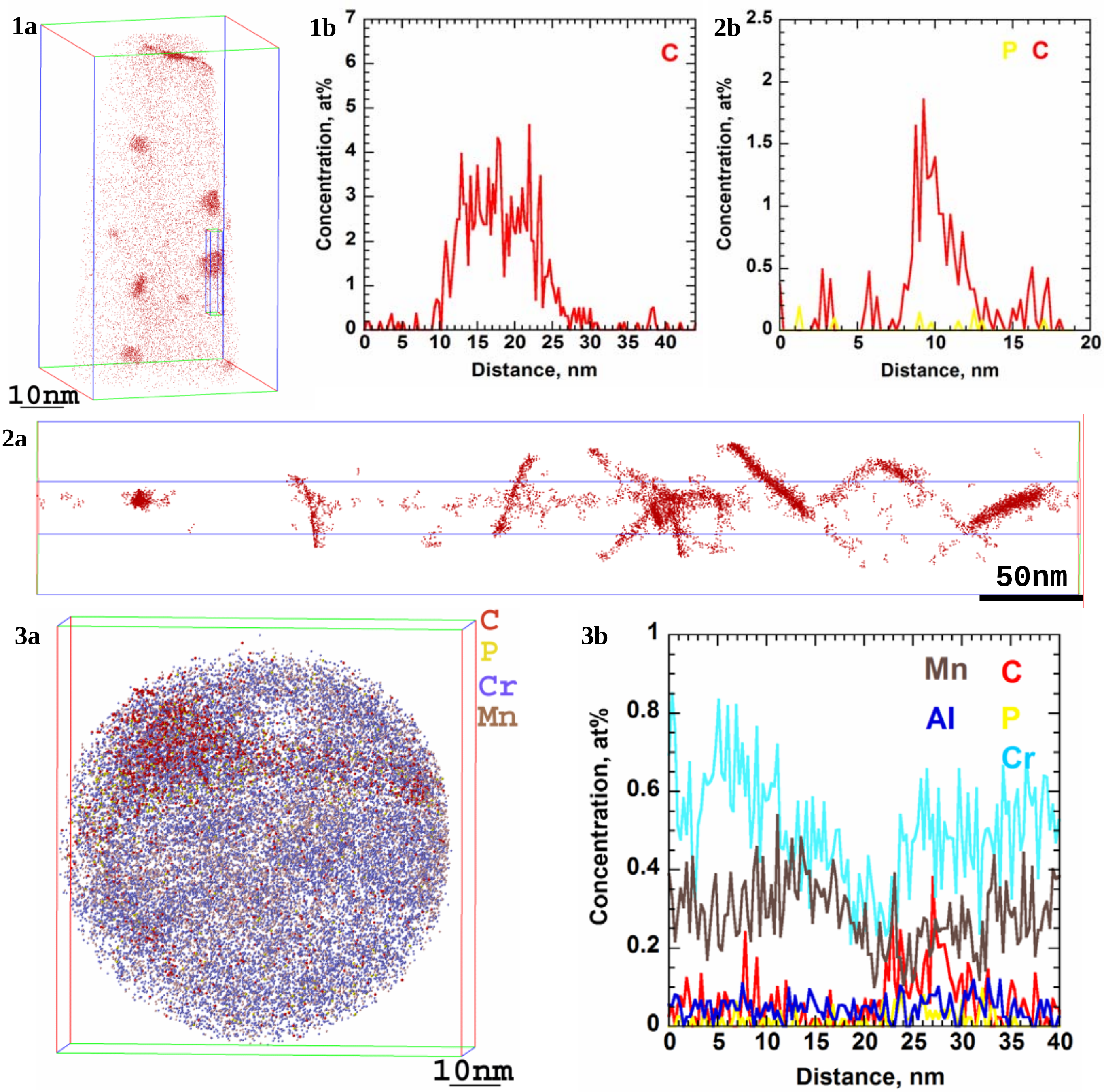

Fig. 1 (a) Atom map showing C clusters in Cr steel and (b) corresponding concentration profile along the blue line of selection box shown in (a).
Fig. 2 Observations of Cottrell atmospheres in Cr-P steel: (a) representative concentration profiles across an atmosphere and (b) atom map (maximum separation 2 nm)
Fig.3 (a) Atom map of Cr-P steel showing boundary segregation and (b) corresponding concentration