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# Characterization of Embedded Secondary Phase Carbides in Low-Alloyed Martensitic Steels Using a Combination of High-Resolution Techniques

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Steel is the most widely used metal material in engineering today. There is an enormous variety of steel grades and types, suitable for a wide range of applications and environments. Still, the development of high-performance steels for future applications is for the industry a never-ending task. In the development of steel alloys, controlling the microstructure is a key factor when optimizing the material properties. Steels are often alloyed with strong carbide forming elements, in order to form carbides that will increase the hardness of the material. In this work, we have investigated the formation of small (diameter ~2 - 40 nm) secondary carbides in low-alloyed martensitic steels during tempering. Accomplishing high number density of nanometer-sized, well-dispersed secondary carbide precipitates will increase and optimize the strength of the steels, inhibiting dislocation movement, but optimizing these parameters require exact alloy composition and that heat treatments are performed at very specific temperature and time intervals. Tailoring the alloy composition and using the exact heat treatment is meticulous work, often aided by computational tools, e.g. thermo-dynamical calculations. To validate the calculations and resolve and identify these small precipitates, high-resolution techniques are needed. In this work, (S)TEM together with EDX was used to visualize the precipitates and get chemical content; using Atom Probe Tomography (APT) to resolve the smallest carbides. To be able to analyze such small embedded particles in the TEM, samples were prepared using the extraction replica method. To determine the phases of the carbides, 4D Scanning Precession Electron Diffraction (SPED) was used, where a full collection of diffraction patterns is acquired from each pixel in a 2D map, and the particle phases identified automatically. In addition, to obtain high statistics of volume fraction and size distribution of the precipitates and the evolution of these parameters as a function of time and temperature, Small Angle Neutron Scattering, (SANS), was performed meanwhile tempering the steel specimens in situ. Thus, the precipitation process can be observed in real time. Selected samples were quenched to stop the precipitation, freezing the microstructure for that specific time and temperature, allowing analysis using TEM and APT. The combination of these powerful tools resulted in a very good understanding of the microstructure of the steels on the nanometer scale, during and after tempering.

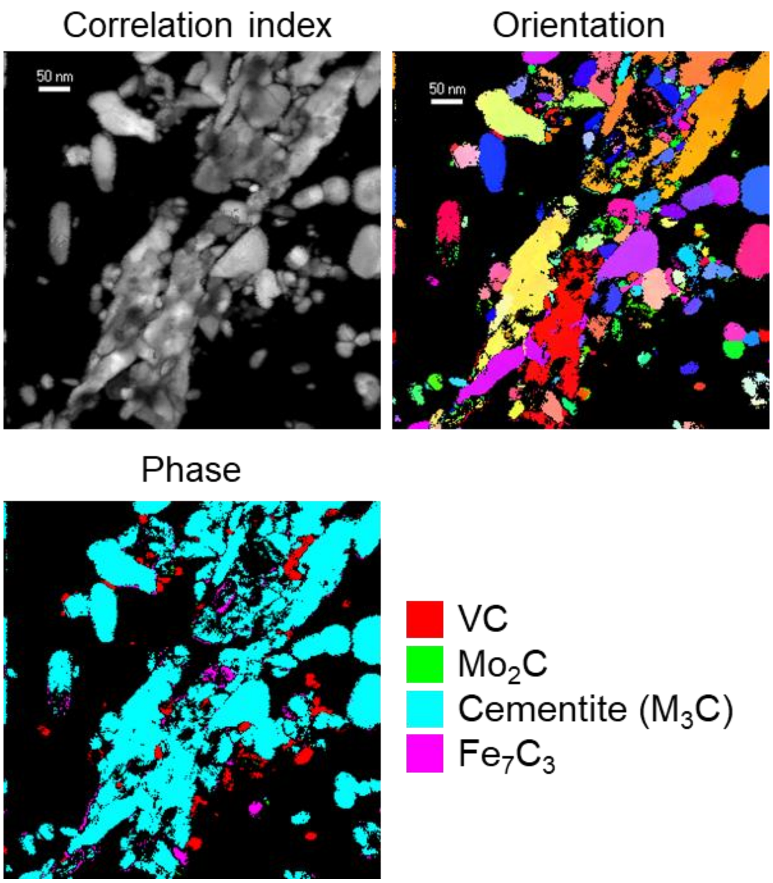


**Figure 1.** Precession Electron Diffraction maps displaying correlation index, orientations, and phases. The maps are 300 x 300 pixels and were acquired using 1.2$^o$ precession angle at 100 Hz and 2 nm stepsize on a JEOL 2100F FEG-TEM at 200 kV acceleration voltage. The TEM was equipped with the "Digistar" precession system from NanoMEGAS.

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