Impact of cooling rate during martensitic transformation on autotempering

The relation of cooling rate, martensite tetragonality and autotempering behavior was studied for two cooling rates. The slower cooling rate showed epsilon carbide precipitation, while no carbides were observed for the faster cooled sample even after short tempering. Additionally, a new approach for local martensite tetragonality determination was introduced.

Previous work by Kohne et al. [1,2] showed the significant impact of cooling rate during the martensitic transformation on the martensite tetragonality and carbon distribution and a heterogeneous distribution of both was observed. Atom probe tomography showed carbon clustering, but the results regarding carbide formation during cooling were not conclusive [2]. Therefore, the effect of cooling rate and local tetragonality on the autotempering kinetics in a high carbon steel was investigated during the visit at Furuhara Laboratory.

Three heat treatment conditions, 'fast', 'slow' and 'fast + tempered', were carried out and consisted of austenitization of the samples followed by cooling to room temperature with a change in cooling rate at 260 °C. The 'fast' sample had a cooling rate of approximately 30 °C/s to room temperature and the 'slow' 0.5 °C/s. The 'fast + tempered' condition is the sample 'fast' with an additional 3 min tempering at 180 °C.

In the next step, the local tetragonality was determined by electron backscatter diffraction (EBSD). In previous work [1,2], the method of Winkelmann et al. [3] has been used, but it was not possible due to the low fraction of austenite.

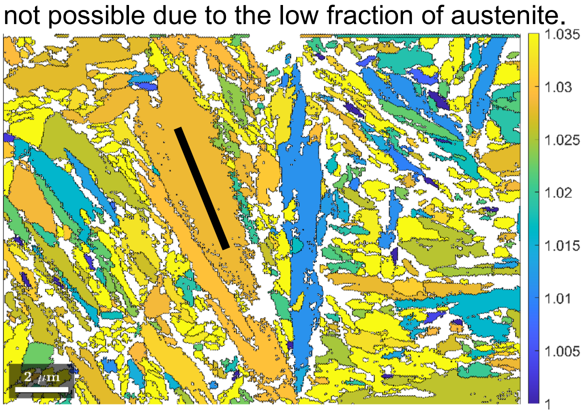

Fig. 1 Local martensite tetragonality for 'fast'

Therefore, an approach for determination of average tetragonality of EBSD maps that was developed in Furuhara Laboratory was used. It was extended to local determination of tetragonality by averaging over all pixels of each martensite unit. The resulting tetragonality is shown in Fig. 1 for the fast cooled sample. The heterogeneous distribution of martensite tetragonality is clearly visible. Transmission electron microscope (TEM) specimens were prepared by focused ion beam (FIB) lift-out based on the local tetragonality. The black line in Fig. 1 indicates the position of the FIB lift-out. For 'slow', a region of low tetragonality was chosen and for 'fast' a region of high tetragonality. The 'fast + tempered' specimen was taken from an area that had high tetragonality before tempering determined by previous EBSD scans.

In TEM, the specimens were investigated with bright and dark field (DF) as well as high resolution TEM and diffraction. The DF imaging showed elongated precipitates for sample 'slow', see Fig. 2. These precipitates were determined to be eta carbides by TEM diffraction. The 'fast' and 'fast + tempered' samples showed no conclusive evidence of carbides in DF and diffraction.

Overall, a new method for the local determination of martensite tetragonality was developed and further validation and comparison with existing methods is ongoing. Additionally, the clear difference in autotempering behavior for different cooling rates during the martensite transformation was shown.

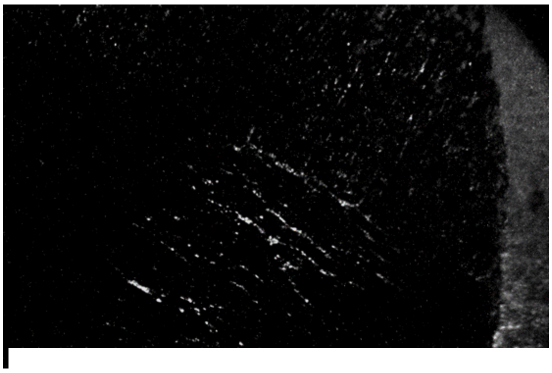

Fig. 2 DF TEM image of eta carbides of 'slow'

References

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[2] T. Kohne, A. Dahlström, A. Winkelmann, P. Hedström, A. Borgenstam, Materials, 15(19) (2022)

[3] A. Winkelmann, G. Nolze, G. Cios, T. Tokarski, Phys. Rev. Mater. 2(12) (2018)

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