Report on the experiments performed at ESRF – Beamtime MA-861

Subject: In-situ characterization of the bainitic transformation kinetics and resulting microstructures in carbide-free bainitic steels

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The aims of this study were to perform in-situ characterizations of the bainitic transformation kinetics under stress in carbide-free bainitic steels (CFB steels) using high energy X-Ray diffraction. We succeeded several experiments in various conditions on two CFB steels with different carbon content (0.2%C and 0.3%C) with or without applied stresses.

A tensile device, the ETMT 8800 system from Instron, was available to perform our experiments. It allows applying a defined thermomechanical cycle in which thermal and mechanical variations are collected. This thermomechanical system allows reaching high temperatures needed to recrystallize our samples and then cool them sufficiently quickly to avoid any formation of ferritic or perlitic phases before the bainitic transformation. The heating is performed by DC current which intensity is controlled by PID regulation. The stress is applied via an electrical actuator which allows reaching a maximum load of 3 kN.

Tensile samples were designed to fit the ETMT system specificities. In order to collect well defined diffraction rings, one of our main concerns was to use samples with a sufficient amount of grains with an average grain size high enough to obtain model microstructures. Therefore we designed tensile samples with large thickness section (4 x 1.4 mm^2). This geometry allows us to conduct our experiments thoroughly whereas diffraction rings were not complete at high temperatures due to the high austenitic grain size.

During the beam time, experiments were conducted in various conditions. We successfully performed in-situ characterizations of the bainitic transformation at austempering temperatures ranging from Ms – 50°C to Ms + 100°C without any stress applied. Conclusive data were acquired and allowed us to observe variations of the amounts of the austenitic phase as well as the bainitic ferrite. The austenitic cell parameter shows a rapid increase as soon as the austempering temperature is reached (Figure 1). This behavior is attributed to a local enrichment of carbon of the austenite. The source of this carbon enrichment is still controversial nowadays. It could either come from the rejection of carbon from the supersaturated bainitic ferrite as formed[1], or come from a partitioning of carbon in the austenite, by spinodal decomposition, just before the bainitic transformation occurs[2].

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[1] H.K.D.H. Bhadeshia, "Bainite in steels", 2nd Edition, IOM Communications, London, (2002)

[2] S.S. Babu, E.D. Specht, S.A. David, E. Karapetrova, P. Zschack, M. Peet, and H.K.D.H. Bhadeshia, Metallurgical and Materials Transactions, Vol. 36A, No.12 (2005) pp.3281 to 3289

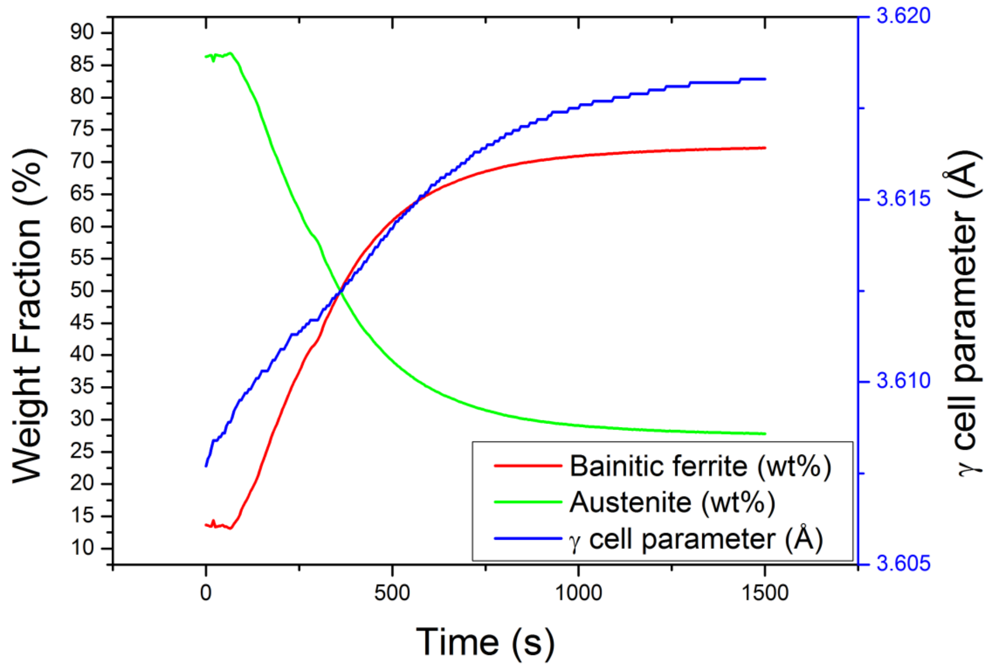

Figure 1: Evolution of the austenite and bainitic ferrite weight fraction and austenitic cell parameter during the bainitic transformation

We also managed to perform a few tests under stress. We successfully applied a tensile load of about 700 N (about 135 MPa considering our samples geometry), which ensures a concrete stress on the samples and that it would not slip from the grips (which was the case with loads higher than 1 kN). The results are promising and early data analyses allow observing an evolution of the kinetics of the bainitic transformation compared with the one without stress.

Unfortunately we ran out of time to complete our scheduled experiments. We could not perform characterizations under stress on both CFB steels and at different austempering temperatures. We also encounter some issues with the ETMT system which has delayed our experiments even more. Most of them could be fixed right away but others could not. The most frustrating problem concerns the main switch of the ETMT system which could not maintain in the "ON" position. Therefore, some of our experiments stopped without warning and leaded to unworkable data.

From our tests different comments could be pointed out:

- The program and control of the thermal cycle and of the load are efficient.
- The use of the DC current heating leads to some error in the measurement of the temperature. As the thermocouple is spot welded on the surface of the sample, an additional tension associated with the DC current is measured. This error was estimated as 30°C at high DC current (above 100 A).