In situ recording of Debye-Scherrer rings during tensile tests at room temperature in FeMnC and FeNiC austenitic steels showing plastic instabilities


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Austenitic FeMnC TWIP steels deform by mechanical twinning in addition to dislocation glide and undergo plastic instabilities due to dynamic strain aging which mechanism is still not well known. Indeed, although it shows similarities with Portevin-Le Châtelier (PLC) effect, a dynamical pinning and unpinning of dislocations by carbon atoms is not consistent with the bulk diffusion of carbon at room temperature. Previous studies based on local extensometry measurements showed that the propagating bands (type A) regime extends to very low strain rates, contrary to PLC. It suggests strong mechanical correlations between the plastic events, in which deformation twins, also known as a potential mechanism of plastic instability, may play a major role. A complex mechanism involving both carbon in insertion and twins is expected to cause the plastic instabilities.

Tensile tests have been carried out on flat tensile specimens of 0.7 mm thick Fe22Mn0.6C (wt%), with gage 4 mm wide and 30 mm long, at room temperature and strain rates from about $2 \times 10^{-5}$ up to $2 \times 10^{-3} \text{s}^{-1}$, to measure the elastic strain distribution around a moving band. In situ recording of Debye-Scherrer patterns have been performed at an energy of 74.5 keV, using the PerkinElmer XRD1622 flat panel detector (2048 x 2048 32 bit pixels) at frequencies up to 5 Hz for the highest strain rates. A beam slit of 0.2 x 0.2 mm2 has been used for all tests. To increase the precision of the measurement, the detector has been positioned at a greater distance from the sample for the last tests. With this setup, only a quarter of the whole pattern has been recorded, with a higher spatial resolution. A reference LaB6 powder has been used to calibrate the distance of the detector.

All the tested samples show plastic instabilities on the tensile curves. Fig. 1 shows an example of raw recorded patterns with a linear grey scale. Before tensile testing, the discontinuous rings reveal the fully recrystallised structure (grain size of 10 to 15 µm). At the onset of plasticity, the strain gradients within the grains lead to continuous rings. At the end of the test, a distinct texturation of the sample is revealed by the varying intensity along each ring. Fig. 2 shows the evolution during the test of the corresponding diffraction pattern after circular integration of the rings. A decrease of the peaks associated with their widening is observed.

The same kind of instabilities is observed in austenitic steels, with carbon in insertion, which undergo martensitic transformations instead of mechanical twinning as additional plastic deformation mechanism. Fe19Mn0.6C, showing ε (h.c.p.) martensitic transformation and
Fe24Ni0.4C, showing \( \alpha' \) (c.c.) martensitic transformation, steels have been tested to compare the observations with materials in which the amount of induced transformation can be measured. The first analyses of the recorded patterns confirm the presence of \( \alpha' \) martensite in FeNiC (fig. 3) and \( \epsilon \) martensite in Fe19Mn0.6C (fig. 4) at the end of the tests.

Figure 2: diffraction peaks after circular integration of the rings of fig. 1. Evolution of the diffraction pattern during the test

Figure 3: part of the Debye-Scherrer pattern obtained for FeNiC (logarithmic color scale). Left: before testing, right: at the end of the test - additional rings due to the presence of \( \alpha' \) martensite (*).

Figure 4: part of the integrated diffraction pattern obtained in Fe19Mn0.6C. Increasing intensity of a peak characteristic of \( \epsilon \) martensite (*).