Study of the deformation mode of Fe-Mn-C high strength steels by X-ray diffraction

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Aims of the experiment and scientific background

The need for making lighter structures in the automotive industry for lowering the fuel consumption requires the development of new generations of steels offering both a very high strength (for mass reduction) and a good formability (for making complicated shapes). Such steels are being currently developed based on the Fe-Mn-C system, with composition in Mn in the range of 20% and C in the range of 0.5%, which satisfy both criteria.

Depending on the steel composition, the stable phase at room temperature can either be austenite (FCC) or a mixture of austenite and martensite (BCT or HCP). The most interesting properties are met for purely austenitic steels, which in turn can deform either by intense twinning or by dislocation motion. Again, the targeted deformation mode is mainly twinning, which occurrence depends notably on the stacking fault energy (SFE) of the material [1]. The detail of the deformation mode as a function of composition and nature of deformation (e.g. with or without hydrostatic pressure) is poorly known at present.

Experimental

Two steel compositions have been investigated: 22.6%Mn-0.58%C-0.041%Mo (Alloy 1); 22.23%Mn-0.63%C-0.21%V (Alloy 2) (all in weight %).

Measurements have been carried out in transmission at 20keV through 50 µm thick samples at 50cm distance. A CCD camera has been used, in order to optimise the averaging of different texture components on a diffraction ring, and to decrease the acquisition time. Due to the sample to detector distance used, 12 2θ positions have been selected each centred on a Bragg peak. LaB_6 has been measured in order to provide the overall resolution of the setting. Molybdenum fluorescence was measured as flat field.

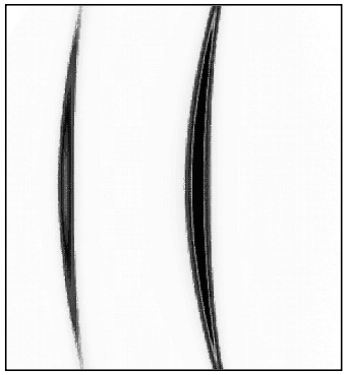

Figure 1: CCD image of transmitted Debye-Scherrer rings of (111) and (200) peaks of the 10% deformed alloy 1.

Measurements have been carried out after 5 different levels of deformation in uniaxial tension and 4 levels in biaxial tension at room temperature. Alloy 1 has been investigated at fracture strain at different temperature deformation.

Results

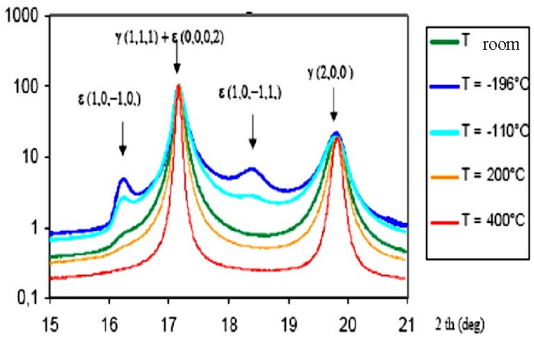

Figure 2: Intensity versus 2θ for the 22%Mn-0.6%C-0.2%Si alloy deformed at fracture strain for different temperatures.

The measurements on samples of Alloy 1, deformed at many temperatures, have shown a temperature dependence of the stacking fault energy.

At low temperature deformation, the stacking fault energy is very low and ε martensite formation is induced by plastic deformation. At -196°C ε martensite represents 15% in volume of the sample at fracture strain and 2.5% at -110°C. For deformation at room or higher, there is no more formation of ε martensite induced by plasticity.

According to Groma , the asymptotic behavior of intensity distribution of the tails of the peak due to dislocations is proportional to $|\Delta K^{-3}|$, with $K=4\pi\sin(\theta)/\lambda$. $\Delta K= K-K_{hkl}$ where K_{hkl}, is the position of the maximum of intensity for the hkl peak. At room temperature deformation, the asymptotic behavior of intensity distribution of the peak tails is proportional to $|\Delta K^{-2}|$ (Figure 3), which corresponds to a small crystallite domain size. This small crystallite size is due to both twinning and stacking faults, which are anisotropic phenomenon. At a temperature

deformation of 673K, it is proportional to $|\Delta K^{-2.5}|$ (Figure 3), which corresponds to both small size crystallite and dislocations.

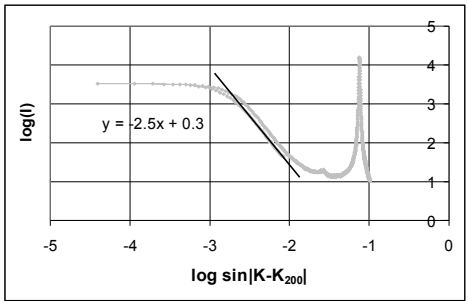

Figure 4: (200) peak of the sample deformed at fracture strain at 673°C.

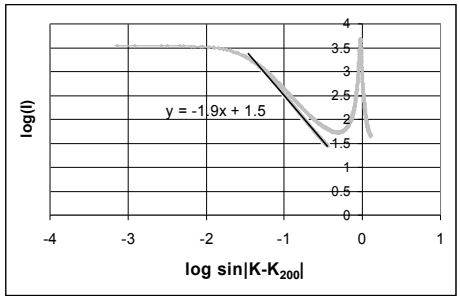

Figure 3: (200) peak of the sample deformed at fracture strain at room temperature.

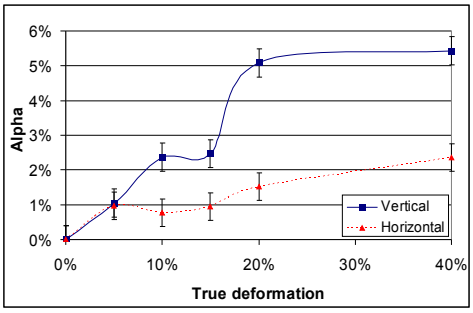

Figure 5: Evolution if the stacking fault probability with uniaxial strain.

The stacking fault probability (Figure 5) is calculated according to Warren theory [3]. α the stacking fault probability is proportional to the peak displacement and β the probability of a compact plane to be a twin boundary is proportional to the peak asymmetry. The uncertainty on peak asymmetry is too high in order to achieve a first approximation of β. Dislocation density (Figure 6) is calculated from the Williamson-Hall modified equation [4], ρ is proportional the full width at half maximum corrected of the broadening of grain size (calculated using α value and with β = α). This is a very row approximation but gives coherent Williamson-Hall plot.

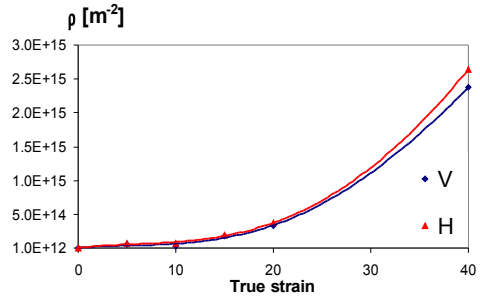

Figure 6: Evolution of the dislocation density with uniaxial strain.

At fracture strain at room temperature, the dislocation density calculated corresponds to a hardening of 600MPa against 1000MPa in reality. The density of stacking faults at failure corresponds to an average separation of 15 nm between each fault on <111> planes.

The value of α is only a first approximation. Textured samples do not match with Warren hypothesis. The distribution of hkl-component is not random so the value of the coefficient of proportionality between α and the peak displacement is not exactly the one calculated by Warren. On top of that dislocation distribution may introduce a peak displacement.

Conclusions

Theses measurements have led to the understanding of the evolution of ε martensite formation with the straining temperature. It had also provided, from the broadening and the displacement of the peak, a first approximation of the dislocation density and stacking fault probability but has failed to provide a quantification of twinning. On textured samples this could only be done from a profile analysis. Samples with only twins must be analysed in order to unfold the influence of twinning and dislocations.

References

[1] O. Grässel, L. Krüger, G. Frommeyer, L.W. Meyer, Int. Journal of Plasticity 16 (2000) 1391.

[2] Groma, I., T. Ungar, and M. Wilkens, *Asymmetric X-ray line broadening of plastically deformed crystals. I. Theory.* Journal of Applied Crystallography, 1988. **21**(1): p. 47-54.

[3] Warren, B.E., *X-ray studies of deformed metals.* Progress in Metal Physics, 1959. **8**: p. 147.

[4] Groma, I., T. Ungar, and M. Wilkens, *Asymmetric X-ray line broadening of plastically deformed crystals. I. Theory.* Journal of Applied Crystallography, 1988. **21**(1): p. 47-54.