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Characterisation of transgranular crack propagation by EBSD in a soft steel

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Abstract  
This study is concerned with crack propagation in a soft steel sheet during drawing. The drawability is considered in relation with the structural anisotropy. Most existing studies on crack propagation are based on the global mechanical properties. However, microstructural inhomogeneity can lead to micro-crack formation. Micro-texture can affect crack propagation and stops in soft steel during drawing. The EBSD technique is used to show that the adjustment of the grain orientation from the initial recrystallization component \{111\}<112> towards the deformation orientation \{111\}<110> incites a trans-granular crack inside a \{111\}<112> grain in a globally ductile material.

1. Introduction  
Industrial metals always undergo various external stresses during fabrication and under service conditions. When they possess a heterogeneous microstructure, the usual mechanical properties do not allow accurately determining the risks of cracking that often occurs throughout manufacturing and service. In the plastic deformation studies, the microstructure is a basic factor of predicting the mechanical material behaviour. The presence of microstructural inhomogeneities will certainly affect the agreement between predictions based on homogeneous deformation and the experimental observations [1-3]. Crack propagation and stops is an important topic in the formability field [4-6]. It is often required in safety analysis to consider that a crack might be initiated and lead to its propagation. It is important to know whether or not the material will be able to stop the crack before it goes through the entire structure, during its response to the external stresses. To answer this question, it is essential to consider the combination of “micro and macro” effects [7-9]. Undeniably, the phenomenon of localization is a result of both the external solicitation (loading, piece geometry) and the microstructure properties. It is this duality that makes the success of the micro-macro approaches which are based on changes of dimension scales. Therefore, such approaches allow a more comprehensive study, closer to the material behaviour during use.

The global behaviour of industrial metals is essentially controlled by the local micro-stress concentrations. Strain localization that appears may locally lead to a strong decrease of the ductility and therefore to a material rupture. The EBSD technique (Electron Back Scattering Diffraction) allows the correlation between the microstructure characteristics and the distribution of plastic deformation and stresses [10,12]. EBSD is presently used predominantly in nearly all metallurgy research approaches and has become a common technique used in the characterization of polycrystalline materials [13-16]. Since its advent, the method has become increasingly useful in the analysis of grain size and distribution, grain boundary disorientations and texture analysis of materials. The EBSD technique makes it possible to
extract both local and global information about the material structure; it allows a complete microstructure characterization from local measurements. The initial texture of the material is an essential parameter related to its mechanical behavior. In the metallurgical considerations of formability, the texture analysis links the crystallographic characteristics of the material to stress distribution [17-19]. The strong drawing deformations are accompanied by a noticeable modification of the initial texture. The low carbon steels generally possess a γ fiber texture {111}<uvw>, favorable to deep drawability [20-22]. In the present study, the investigated sheet possesses such fiber with a main component {111}<112>. After drawing, this fiber is kept with a change of the main component to bcc orientation deformation {111}<110>. The industrial problem is the initiation and propagation of cracks during forming. The average mechanical parameters of the sheet (Re=230 N.mm\(^{-2}\), Rm=311 N.mm\(^{-2}\), A%=36, HV= 140 Kg.mm\(^{-2}\)) are correct and do not allow an appreciation of the risk of cracking.

2. Experimental procedure

The material used in the present study is a primary recrystallized steel sheet of 1.5mm thickness, containing 0.07% C, 0.03% Si, 0.38% Mn, 0.025% P, 0.012% S, 0.02% Al, 0.007% N (wt%). The samples (1cm\(^2\)) examined by EBSD are polished on standard emery papers up to grade 1200 and with the diamond paste up to 0.5µm. They are subsequently electropolished in a solution of: 25vol. perchloric acid (d=1.67), 235 vol. acetic acid (d=1.05) and 250vol. monobutyl ethylene glycol ether (d = 0.9), at (-5 ≈ -2) °C, using an applied voltage of 25V with 0.5A. The characterization of the global matrix texture is performed by X-Rays analysis and locally completed by the EBSD technique near the crack. Mapping was also performed in the area around the crack. However, it was difficult to obtain good patterns and thus to determine the crystallographic grain orientation close to the crack. Therefore, the misorientation profile across the crack is used in the present study in addition to mapping.

3. Observations

The preliminary micro-graphical analysis showed that the central crack progress with a zigzag by a globally ductile rupture of the material with some secondary fissures around the main line (figure 1).

Figure 1
SEM micrograph of the analysed crack

Figure 2
Initial inhomogeneous microstructure

Figure 2 shows the initial microstructure. The average grain size is about 150 µm², but the noticeable inhomogeneity does not make it a reliable parameter. The grain size distribution is very heterogeneous; there is a gathering together of small and large grains shared in clusters. These two grain populations behave differently during forming. This risk is not taken into account when only the average size is considered, while the grain distribution is heterogeneous. In that clustered matrix, the distribution of stresses will be also heterogeneous [1-3]. The existence of these different populations can lead to local thinning or micro-cracking. The reduction in grain size is accompanied by a strengthening the plastic stress flow. Therefore, more global plastic deformation is increased, more important deformation is localised in the small grain clusters, where the risk of crack appearing is high. The existence of a heterogeneous distribution of grain sizes involves the existence of important stresses locally, which can incite local thinning or micro-cracks initiation.
Figure 3 shows the local orientation characterization around the crack. We can note the existence of a fiber texture $\{111\}<uvw>$, with a variation from $\langle110\rangle$ to $\langle112\rangle$ for $\langleuvw\rangle$ orientation. This local characterization gives a similar component texture to the one obtained by global analysis.

Figure 4 shows a misorientation profile across the crack. Except for the pic that corresponds to the crack position, the misorientation profile shows a perfect continuity of the observed evolution. This continuity of the observed evolution clearly indicates that it is the same grain along the considered profile, on the two sides of the crack. The right side corresponds to orientation $\{111\}<112>$ whereas the left side includes orientations from $\{111\}<112>$ towards $\{111\}<110>$.

4. Discussion
There is a continuous variation of site orientations from $\{111\}<112>$ towards $\{111\}<110>$. This observation confirms that the observed crack is trans-granular and not inter-granular, as will let it expected by the globally ductile character of the considered material. It could be suggested that the apparently local brittle-mode of fracture is actually the result of grain reorientation. In deformation mechanism by slip, each grain undergoes a lattice rotation, it is certain that the grain reorientation from the initial orientation $\{111\}<-112>$ towards the bcc deformation orientation $\{111\}<110>$ implies an important micro-constraint state, which is able to initiate a trans-granular evolution of the crack, if the slip planes present some sufficiently weak angles with the propagation direction. Figure 5 shows the global evolution of texture main component from initial orientation $\{111\}<112>$ to $\{111\}<110>$ for deformed samples by tensile tests with different angles $\alpha$ of tensile axis rapport the rolling direction for all tensile axis ($\alpha = 0^\circ, 45^\circ, 90^\circ$). An analysis of different tensile cracking samples is performed in order to confirm the possibility of fragile micro-zone existence in the considered soft steel. Figure 6 shows the existence of a cleavage micro-zone, merged in a global ductile neighbourhood generally observed on most the analyzed samples.
Conclusion

This study considers the texture effect on the propagation of cracks in soft steel during forming. The misorientation profile across the crack is used in EBSD in addition to mapping of the neighbourhood of the crack. The misorientation profile permits to clearly show adjustment of the grain orientation from $\{111\}<112>$ initial orientation towards the bcc deformation orientation $\{111\}<110>$. This process can explain the possibility of transgranular crack propagation in a globally ductile material. In a heterogeneous structure the risk of cracking seems to increase in the presence of small grains $\{111\}<112>$ clusters.

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