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# Texture induced grain coarsening in severe plastic deformed low carbon steel

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A low carbon steel sheet was deformed by equal-channel angular pressing with an intersection angle of the die channels of 130° for four passes, via route A. Using electron backscatter diffraction, a significant increase in the grain size was observed during testing. This could be explained by the coalescence of neighboring initial grains due to the evolution of the crystallographic texture. Polycrystal simulations could also reproduce the coarsening tendency, together with the evolution of the disorientation distribution.


*Keywords:* Low carbon steel; Grain coarsening; Equal-channel angular extrusion; Crystallographic texture; Polycrystal modeling

Large plastic deformation is an efficient tool for reducing the grain size of metals down to the ultrafine-grain regime or even to nanosizes in alloys. A large number of severe plastic deformation (SPD) processes have already been proposed for grain refinement, some of which are continuous processes (see the recent reviews in Refs. [1–3]). One continuous SPD process is equal-channel angular pressing–Conform (ECAP–Conform), in which a sheet is pressed through a die with the help of rotating wheels [4–6]. It is expected that continuous SPD processes will be introduced into industrial production, thus it is important to study the transformation of material properties in such processes.

The purpose of applying SPD processes is to obtain grain refinement, which is generally observed to lead to a steady-state grain size at very large strains [1–3]. In this work, however, we found grain coarsening during large plastic deformation. As recrystallization can be excluded during room temperature deformation of low carbon steel, the origin of the coarsening is attributed to the evolution of a crystallographic texture. Our modeling confirms this hypothesis. Coarsening can take place by coalescence of adjacent grains if their disorientation becomes sufficiently low. Such a decrease in disorientation can be explained by the plastic strain caused by the convergence of the orientations of adjacent grains that are initially separated by larger angles. When they approach the same ideal orientation, the orientation difference between them decreases, so they can coalescence into a single grain.

The phenomenon of grain coalescence due to texture development has never been observed experimentally before; this is the first report about it. The reason for this is that it requires the combined topological measurement of the grain structure and the crystallographic texture, and such combined studies are rare. The effect also has to be significant enough to make it evident, and this depends strongly on the initial texture, the topology of the adjacent grains and the grain refinement, which is a competing mechanism. This paper presents such a case where these three conditions are fulfilled and the grain coarsening phenomenon can be explained only as an effect of the texture evolution.

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Topological texture simulations were also carried out and reproduced the coarsening tendency.

The material studied was a low carbon steel in the form of a sheet (1000 mm × 58 mm × 2 mm) presenting a bimodal grain structure (Fig. 1a). The annealed low carbon steel sheet was processed using an ECAP–Conform machine at the Technical University of Ostrava which has a die of 130° for four passes via route A. The extrusion speed was 2 mm $s^{-1}$ and colloidal graphite was used as a lubricant. Microstructure characterization was performed using a JEOL 7001F field emission gun scanning electron microscope fitted with an HKL detector with a step size of 0.15 μm. Specimens were cut from the center of the ECAP–Conform sheet along the ND–ED plane. The samples were mechanically polished to 2400 grit using SiC paper, then electropolished for 5 s in an electrolyte of 10% perchloric acid/90% acetic acid at 35 V and 12 °C, using a current of 350 mA. From the obtained electron backscatter diffraction (EBSD) maps, boundaries were identified using a minimum disorientation angle of 5° between adjacent pixels. Post-analysis of the orientation maps was performed using the EBSDmcf software [7].

The as-received EBSD inverse pole figure map displays a bimodal grain size structure (Fig. 1a). A characteristic feature of the initial microstructure in Figure 1a is that there are many small green-colored grains forming groups; these belong to the <1 1 0>||TD fiber. The initial grain size was 3.75 and 8.96 μm (Fig. 2) by number- and area-weighted average, respectively. After four-pass deformation, the grain size increases significantly; this can be readily visualized by comparing the EBSD maps in Figure 1a and b. The grain sizes after deformation were 9.57 and 24.2 μm in the number and area fractions, respectively. A particular feature of the microstructural change is that most of the small grains disappeared. The black arrows in Figure 1b point to places where grain boundaries are not continuous, indicating that they are in the process of disappearing due to the coalescence process.

Due to the large deformation, the crystallographic texture is also changing. Figure 3 shows the textures in {1 1 0} pole figures by projecting on the plane perpendicular to TD. The initial texture is a mild rolling texture, which changes into a shear texture characteristic of body-centered cubic metals [8] rotated to the position of the shear plane of the test. The main experimental shear texture component is D2, defined by (−1 −1 2)||SPN, [1 1 1] ||SD, [1 −1 0]||TD, indicated by

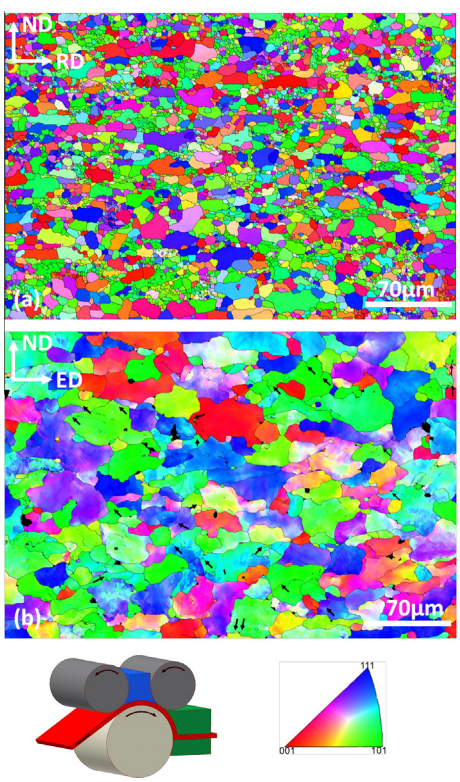


**Figure 1.** Inverse pole figure maps of (a) as-received low carbon steel; (b) four-pass ECAE–Conformed low carbon steel. Grain boundaries with disorientations larger than 5° are depicted by black lines. The color code displays the plane normal (TD) in the crystal reference system. Black arrows in (b) indicate disappearing grain boundaries. The schema of the sheet ECAP processing machine is also shown. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

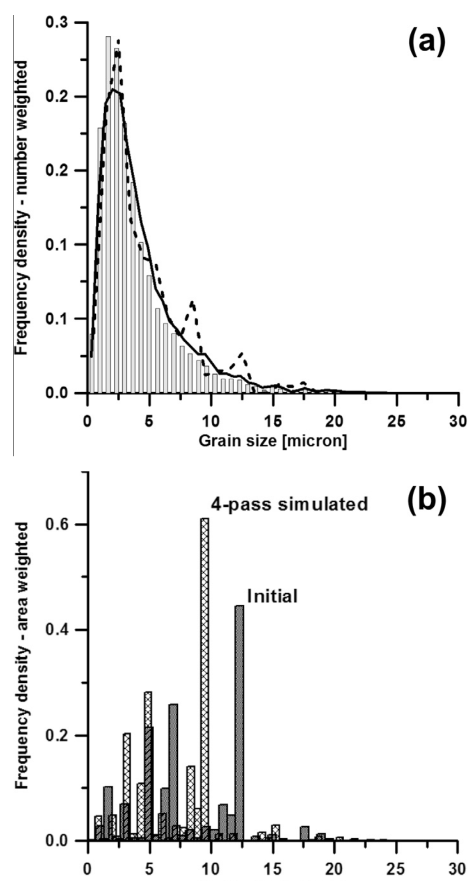


**Figure 2.** Grain size frequency distributions in number-weighted (a) in area-weighted (b) presentations. In (a), the bar chart represents the initial grain sizes while the solid line is after four deformation passes. The broken line in (a) corresponds to the coalescing grains in the simulation. In (b), the dark bar chart is for the initial state and the hatched one is after four deformation passes, obtained from the simulation.