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Abstract. The objective of this work is to study the texture and microstructure evolution of an IF steel deformed by Accumulative Roll Bonding (ARB) using Electron Backscatter Diffraction. Texture changes occur with increasing number of ARB cycles. For the early cycles, the main components are the α and γ fiber components characteristic of steels. With increasing the number of ARB cycles a tendency towards a random texture is obtained. In the initial state, the mean grain size is 30 μm and after 5 cycles it decreases to 1.2 μm. For the first ARB cycles, the fraction of high angle grain boundary is low but it increases with the number of cycles to about 80% for 5 cycles. The Kernel Average Misorientation (KAM) has no appreciable changes with the number of ARB cycles for all the texture components.

1. Introduction.

Materials with ultra-fine grain size (UFG) have been produced by different severe plastic deformation (SPD) processes, including equal-channel angular pressing, high-pressure torsion, Accumulative Roll Bonding (ARB), etc. [1, 2].
The interest in these materials is related with two aspects. One is their attractive mechanical properties, in particular the increase in strength and ductility for industrial applications [3, 4]; the other aspect is related with the clarification of the microstructure evolution and deformation mechanisms occurring during the processing of these materials. Grain Boundary Sliding (GBS) takes place when the materials have a nanocrystalline structure, with preponderance of High Angle Grain Boundaries (HAGB), and very low strain inside the grains. However in UFG structure, despite a mixture of deformation mechanisms have been detected as active by many authors and that GBS could be active at least at the latest stages of deformation, dislocation glide could be still one of the most important deformation phenomena [5]. Texture, which is highly correlated with microstructure development, is another aspect that can influence the mechanical properties.
The Electron BackScatter Diffraction (EBSD) technique is ideal for characterizing these microstructural features, including texture components and their volume fraction, grain size (GS), boundary character (HAGB, and Low Angle Grain Boundary, LAGB), grain inner misorientation (Kernel Average Misorientation, KAM, which is an indicator of the dislocation density) [6].
In this work we study texture and microstructure evolution by EBSD of an interstitial free (IF) steel deformed by ARB after different number of strain cycles.

2. Material and Experimental Techniques.

The ARB process is described in references [1-3]. In our particular case as received samples were reduced until 1 mm thickness by several cold rolling passes. Then the samples were recrystallized in a high vacuum furnace 3 h at 750 °C. The mill

cylinders for ARB have 20.4 cm in diameter and the rolling speed was 13.4 m/min. Between each ARB pass, the samples were brushed, degreased and heated in a cylindrical furnace for 10 min at 550 ^{0}C under Ar atmosphere. The accumulated equivalent plastic strains for each pass [5] are 0 (o cycle), 0.8 (1 cycle), 1.6 (2 cycles), 2.4 (3 cycles), 3.2 (4 cycles), 4 (cycles). The composition of the steel, provided by ArcelorMittal, France is shown in table 1.

Table 1 Chemical composition of the steel (ppm).

C	Mn	P	S	Si	Al	Ni	Cr	Cu	Mo	Sn	Nb	V	Ti	B	N
15	1022	131	107	58	600	158	225	138	7	29	2	20	532	1	26

For EBSD study, the samples were prepared in a conventional form (mechanical polishing with colloidal silica) on a plane formed by the Rolling Direction (RD) and the Normal Direction (ND). Kikuchi pattern acquisition was made using a TSL EDAX equipment mounted on a FEG-SEM (Quanta, FEI). Scans were run with a step of 0.04 µm. The data were processed with TSL OIM 7.1 software. For grain size calculation, a grain tolerance angle of 5^0 was used, and the data were cleaned up with grain dilation method with a minimum grain size of 4 points. Limits of HAGB (>15^0), LAGB (2°-15^0) and KAM (<5^0) and third neighbors were used.

3. Results and Discussion.
3.1 Grain Size.
Figure 1 shows the Inverse Pole Figure (IPF) maps (Normal direction to the sheet) measured on the RD-ND plane.

cycle 0   cycle 1   cycle 2

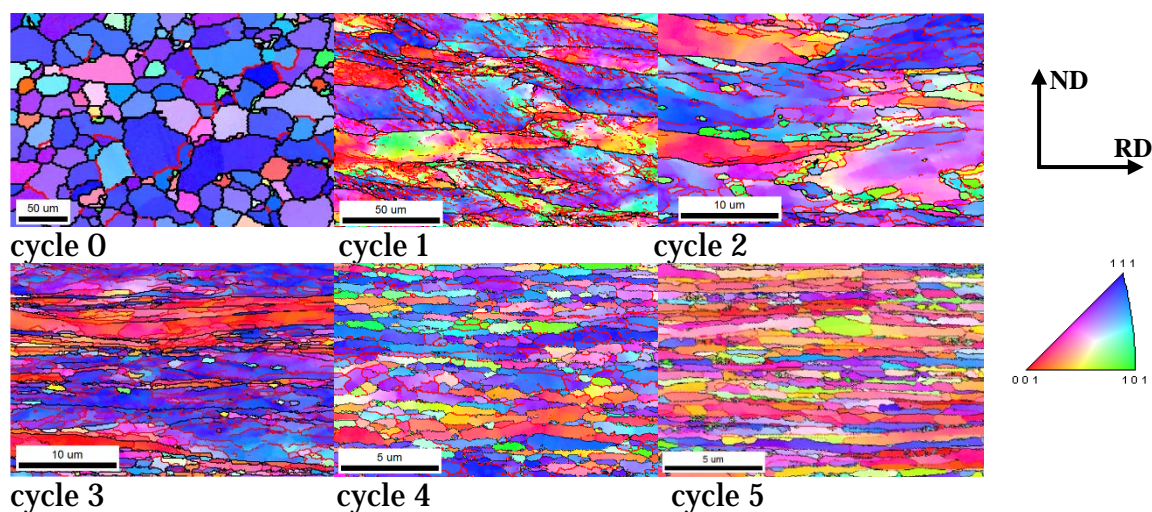cycle 3   cycle 4   cycle 5

Fig 1 EBSD maps (IPF contrast) from the RD-ND plane for different numbers of ARB cycles (▬ LAGB ▬ HAGB). The stereographic triangle shows the color code for ND.

It is clear from figure 1 that the grain morphology changes with increasing number of ARB cycles, going from equiaxed grains to elongated ones along RD. The grains in specimens subjected to 1, 2 and 3 cycles are grouped together forming bands (pancake-like grain structure) with grains in approximately the same orientation; within these bands, the (sub-) grains are separated by LAGB. The samples with

cycles 4 and 5 show a reduction of grain size and an increase of orientation randomness.

In figure 2, the evolution of the mean grain diameter with the number of cycles is shown. In the first cycles, the evolution is fast, but after 3 cycles there is a decrease in the rate of reduction of grain size, which tends to a size close to 1 μm.

This tendency to grain size stabilization for cycles 4 and 5 could be related with several factors, such as dynamical recrystallization.
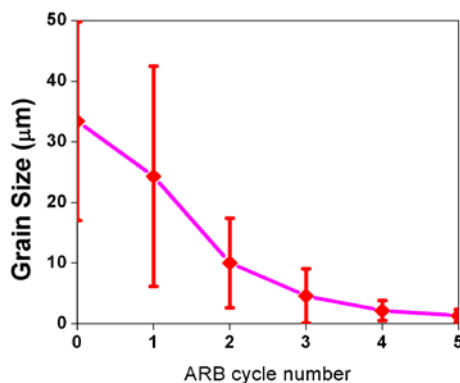

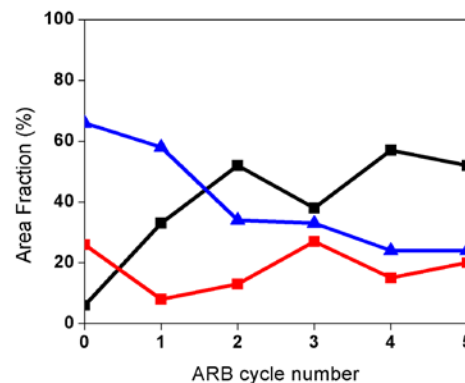Fig 2 Evolution of the grain size vs. the number of ARB cycles.

Fig 3 Evolution of the area fraction of α (red), γ (blue) fibers and of other components (black) vs. ARB cycles.

3.2 Texture components.

Figure 3 shows that area fraction of grains randomly oriented tends to increase and stabilizes after 2 ARB cycles. This figure shows also that the α fiber tends to remain approximately constant during the ARB cycles, while the γ fiber tends to decrease and to stabilize after 2 cycles.

Let us note that it was observed that both orientations {111}<110> and {111}<121> of the γ fiber have approximately the same acuity.

3.3 Grain boundaries (HAGB and LAGB).

Figure 4 shows the evolution of HAGB (>15°) and LAGB (2^0-15°) fractions with the number of ARB cycles. After the first cycle the fraction of LAGB is greater than the one of HAGB, but after 3 cycles this proportion is reversed. After 5 cycles the HAGB percentage is about 80%.

3.4 Misorientation (KAM).

In figure 5, an example of the KAM value distribution is shown for the sample that underwent 5 ARB cycles. The great majority of points have KAM values between 0^0 and 1° (blue color). This means that very low misorientation values are present inside the grains. No appreciably differences in values are present between cycles. This implies that all the orientations have more or less the same dislocation density.

4. Conclusion

The results show that the grain size decreases very quickly for the first three cycles, and at a slower rate with additional cycles, until a mean size of about 1 μm is obtained after 5 cycles.
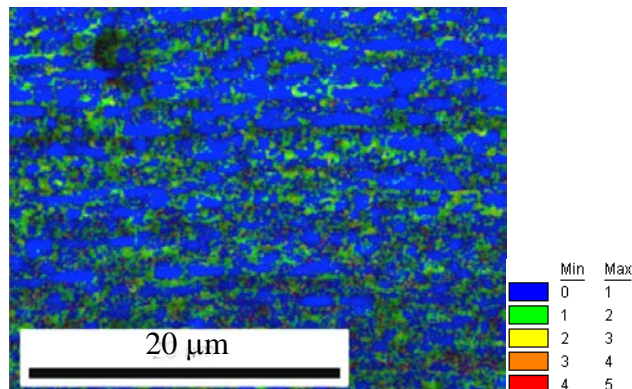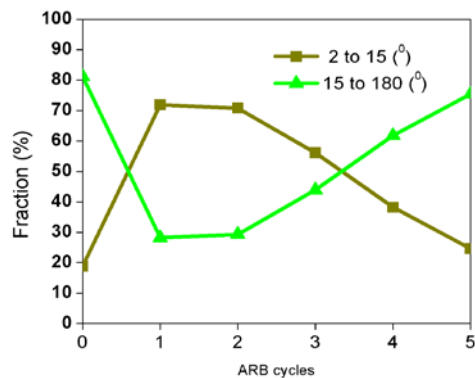
Fig 4 Evolution of HAGB and LAGB fractions with the ARB cycle.

Fig 5 EBSD map of KAM contrast for the sample subjected to 5 ARB cycles.

At the same time, changes in the grain boundary type happened with a tendency to form HAGB (≈80 %). The texture tends to become random with increasing number of ARB cycles.

Acknowledgments

References

[1] Tsuji. N2009 *Bulk Nanostructure Materials* Ed. Zehetbauer M.J. and Zhu Y T. Ed. WILEY-VCH (Weinheim, Germany) pp 235-252.

[2] Valiev R Z, Zhilyaev A P and Langdon T G, 2014 Bulk Nanostructured Materials: Fundamentals and Applications, TMS-WILEY, Hoboken, New Jersey, USA.

[3] N. Tsuji 2002 Strength and ductility of ultrafine grained aluminum and iron produced by ARB and annealing. *Scripta Materialia* 47 pp 893−899.

[4] http://www.autospeed.com/cms/title_Steel - Identification - Using - Hardness - Testing/A_109717/article.html

[5] Toth L S, Gu C. 2014 Ultrafine-grain metals by severe plastic deformation. Materials Characterization **92**, pp 1−14.

[6] Wright S I, Nowell M M, Field D P. 2011 A review of strain analysis using electron backscatter diffraction. *Microscopy and Microanalysis* **17** pp 361-329.

[7] Grains in OIM. OIM ANALYSIS 7.0. TSL-EDAX 2013, TexSEM Laboratories, Incorporated. pp 440.

[8] Kolahi A, Akbarzadeh A, Barnett M R. 2009 Electron back scattered diffraction (EBSD) characterization of warm rolled and accumulative roll bonding (ARB) processed ferrite. *Journal of Materials Processing Technology* **209** pp 1436−1444.