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Use of LOM and EBSD to Identify Bainite in Complex Phase Steel

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Complex-Phase (CP) steels are a class of Advanced Hight Strength Steels (AHSS) that has come as an alternative to the traditional Dual-Phase ones[1–5]. CP steels are constituted of a bainitic matrix, with ferrite, martensite and retained austenite. With such a complex microstructure, the identification (ID) and quantification of the phases are a challenge in this type of steel. Dilatometry is among the best techniques to understand the development of a microstructure, and has been consistently used for that[6–8]. However, when characterizing a processed steel, dilatometry is not a good choice, since it is a characterization that needs to be done during the processing of the steel.

Color etching[9] and Electron Backscatter Diffraction (EBSD)[5,10,11] can be used to directly identify ferrite, martensite, and retained austenite, but not bainite. One alternative solution would be an indirect bainite ID using Light Optical Microscopy (LOM) and EBSD data. In this work, the combination of these two techniques was used aiming to quantify the bainite amount of a CP1100 steel. A color etching using a 2% Nital solution followed by a 10% $Na_2S_2O_5$ water solution was used to reveal the microstructure for LOM imaging. This anodic surface etching reveals a whitish ferrite region, a brown/dark-brown martensitic/bainitic region and a black retained austenite (Figure 1A). The LOM image was segmented using the Waikato Environment for Knowledge Analysis (WEKA) segmentation from the FIJI software (Fig. 1B). Imaging was performed at Instituto Nacional de Tecnologia (INT, Brazil) using an Olympus BX51M capable of doing 2000x optical magnification

Considering that bainite is a microconstituent consisting of ferrite and carbides[12], during the EBSD analysis both ferritic and bainitic regions are indexed as ferrite. Therefore, assuming that the ferrite quantification performed using LOM is reliable and its distribution is homogeneous, subtracting the amount of ferrite measured in the LOM images from that obtained through EBSD maps resulted in an estimated bainite percentage of 22,3% in the CP steel, as indicated in Table 1 (bainite I). To improve the sampling precision, several different regions were observed; Figure 2 shows an example of the EBSD analysis, which were performed in a SEM Jeol 7100FT equipped with an Oxford Nordlys Max 2 EBSD detector located at LabNano in the Centro Brasileiro de Pesquisas Físicas (CBPF).

An additional estimation of the bainite percentage was derived from the martensite/bainite amount (bainite II) obtained with LOM. In this case, the percentage of martensite obtained with EBSD was deducted from the martensite + bainite amount measured using LOM, producing a value of 22,8%.

Finally, another alternative to bainite ID is to consider the deformation in the ferritic microstructure. It is expected a higher dislocation density[11] which could be seen using the kernel average misorientation (KAM) map and the grain orientation spread. The bainite can then be segmented as the deformed region. Figure 2 D-F shows that alternative segmentation with a 20.3% of bainite ID. Table 1 shows the final quantification found by LOM and EBSD. These results are in agreement with dilatometric analysis.

Phase	LOM %	EBSD %
Retained Austenite	0.8 ± 0.24	1.2 ± 1
Ferrite + Bainite		76.2 ± 1.3
Ferrite	53.9 ± 3.8	
Bainite I		22.3 ± 1.2
Martensite + Bainite	45.3 ± 3.6	
Martensite		22.5 ± 1.48
Bainite II		21.8 ± 1.5

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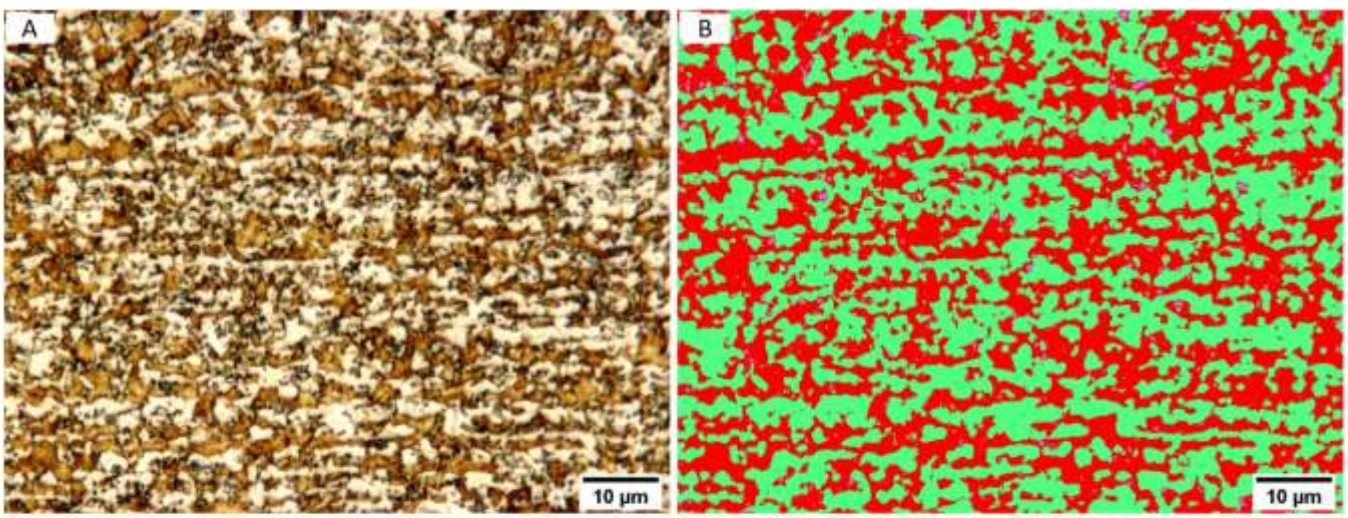

Figure 1. LOM image of the CP1100 steel and its WEKA segmentation. A) Etched surface: whitish = ferrite, brown/dark brown = martensite/bainite, black = retained austenite and B) Segmented image, green = ferrite, red = martensite/bainite, purple = retained austenite.

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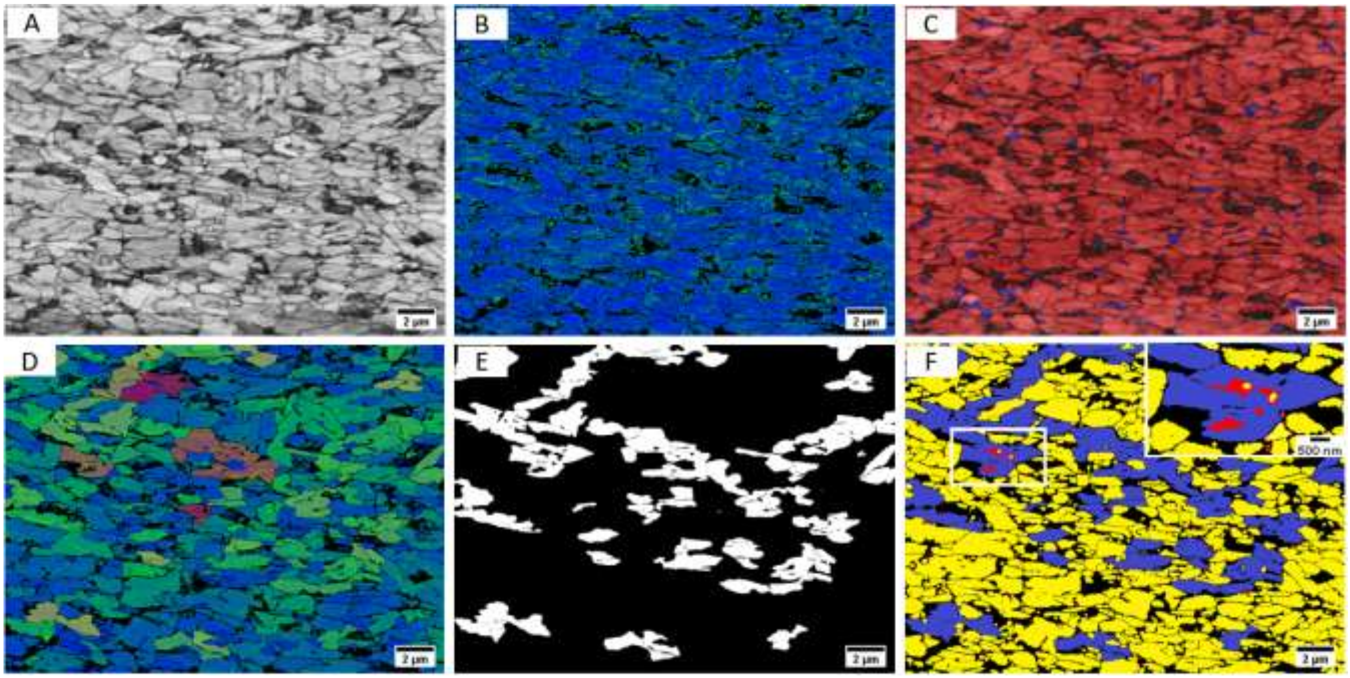

Figure 2. EBSD analysis of the CP1100. A) Image Quality map B) Kernel Average Misorientation C) Band Slop + Phase ID, red = ferrite/bainite, blue = retained austenite and black = martensite (zero solution) D) Kernel Average Misorientation + Grain Orientation Spread map E) Segmented bainitic region F) Fully segmented map with zoomed in area, yellow = ferrite (54.7%), blue = bainite (20.3%), red = retained austenite (1.8%) and black = martensite (18.3%).

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