Ultramicroscopy 137 (2014) 40–47

Contents lists available at ScienceDirect

Ultramicroscopy

journal homepage: www.elsevier.com/locate/ultramic

An automated method of quantifying ferrite microstructures using electron backscatter diffraction (EBSD) data

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ARTICLE INFO

Article history:
Received 4 October 2013
Received in revised form
8 November 2013
Accepted 12 November 2013
Available online 21 November 2013

Keywords:
Electron backscatter diffraction
Data analysis
HSLA steel
Niobium

ABSTRACT

The identification and quantification of the different ferrite microconstituents in steels has long been a major challenge for metallurgists. Manual point counting from images obtained by optical and scanning electron microscopy (SEM) is commonly used for this purpose. While classification systems exist, the complexity of steel microstructures means that identifying and quantifying these phases is still a great challenge. Moreover, point counting is extremely tedious, time consuming, and subject to operator bias. This paper presents a new automated identification and quantification technique for the characterisation of complex ferrite microstructures by electron backscatter diffraction (EBSD). This technique takes advantage of the fact that different classes of ferrite exhibit preferential grain boundary misorientations, aspect ratios and mean misorientation, all of which can be detected using current EBSD software. These characteristics are set as criteria for identification and linked to grain size to determine the area fractions. The results of this method were evaluated by comparing the new automated technique with point counting results. The technique could easily be applied to a range of other steel microstructures.

1. Introduction

The characterisation and quantification of the different types of ferrite in steels is of great importance in materials engineering as the proportion and distribution of these 'microconstituents' strongly influence the steel's mechanical properties. Steel microstructures are extremely complex, and often consist of mixtures of different types of ferrite, such as acicular ferrite, polygonal ferrite and bainite. These structures have long been investigated using optical microscopy and scanning electron microscopy (SEM) and these studies have led to classification systems for the differentiation of steel microstructures, such as Dubé classification [1–3], but these systems do not allow for quantification. To truly understand the microstructure-property relationships for the complex microstructures of steels, quantitative measurements of the proportions of phases in the microstructures is required. The standard test method for determining volume fraction by systematic manual point counting (ASTM E562) [4,5] can be used to determine ferrite volume fractions, but this procedure is tedious, time consuming, and subject to operator bias and errors such as improper grid selection, sample quality, and incorrect measurements of fine ferrite microconstituents that are difficult to detect [6,7]. For these reasons, the identification and quantification of ferrite microconstituents in steels still remain a major challenge for researchers studying ferrous alloys.

Electron backscatter diffraction (EBSD) has been proven to be beneficial to the microstructural analysis of steels [8–10]. This technique uses crystallographic orientation mapping and crystallographic/lattice structural differences to provide information such as grain size measurements and distribution, boundary characteristics, crystallographic orientations and their distributions (or texture), and phase identification. EBSD is often used to obtain crystallographic information that is combined with optical microscopy or X-ray diffraction to better identify constituent phases [11]. However the shortfall of EBSD for the quantification of steel microstructures is that many morphologies of ferrite have the same crystallographic structure. Indexing alone cannot then differentiate between different microconstituents of ferrite and thus their accurate identification and quantification remain difficult.

In order to overcome this problem, previous studies have used diffraction pattern quality or index confidence to distinguish between different microconstituents [12–14]. The use of diffraction pattern quality for this purpose is based on the fact that different types of ferrite produced at different transformation temperatures have varying amounts of lattice defects. The diffraction pattern quality index is used to distinguish the degree of lattice imperfections and thus characterise the microstructure of selected high strength low alloy (HSLA) steels. Wu et al. [14] used diffraction pattern quality (referred as image

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http://dx.doi.org/10.1016/j.ultramic.2013.11.003

quality (IQ)) to separate different microconstituents and quantify them through a multi-peak model with reasonable results. Zaefferer et al. [15] used index confidence, which is similar to the image quality method but uses the fit between the diffraction pattern and indexing pattern to differentiate between ferrite microstructures. These techniques have been used on steels with fairly simple microstructures. However, a limitation is that more complex processing parameters will influence the amount of dislocations, and can distort the results obtained [13]. Another issue is that diffraction pattern quality is dependent on sample contamination and preparation and grain orientation [16,17], making comparisons between samples a challenge. Fractions of the microconstituents present obtained via these methods will also be different if obtained from different systems due to differences between the EBSD detectors' phosphorus screens, cameras, SEMs and software, on top of all the sample and operator variables.

The technique presented in this paper employs the fact that different microstructures of ferrite exhibit preferential grain boundary misorientations, aspect ratios and mean misorientation, all of which can be detected using current EBSD systems. This combination of characteristics allows for automatic, quantitative measurement of the area fraction of each microconstituent. In this study the new method is applied to the ferrite microstructures of ultra thin strip cast (USC) steels produced by the CASTRIP® process [18–21]. These steels have an intricate microstructure consisting of acicular, polygonal, and bainitic ferrite [22,23]. Each of these ferrite microconstituents has distinctive characteristics in terms of grain size, different degrees of lattice imperfections (i.e. dislocation or subgrain boundary density), grain boundary misorientation, and grain morphology. The proportion and distribution of each microconstituent influence the steel's mechanical properties; it is therefore important to obtain accurate and reliable data regarding the microstructure to be able to predict the mechanical properties.

Polygonal ferrite is characterised by mainly equi-axed grains containing few low angle grain boundaries [2,24,25]. The presence of polygonal ferrite increases the ductility of steels, but if the grain size is unrefined it can result in lower strengths. Acicular ferrite consists of thin, lenticular plates that nucleate heterogeneously from non-metallic inclusions [2,26,27]. Their small grain size and high angle grain boundaries inhibit cleavage propagation and can increase toughness and strength. Bainite is in the form of very fine lenticular plates or laths that manifest as sheaves of ferrite plates that are usually separated by low-angle grain boundaries [2,26,28,29]. Bainitic microstructures contain a high density of dislocations that result in higher strength and lower ductility.

With this new method, three distinctive characteristics (grain boundary misorientation, aspect ratio, and mean misorientation) are exploited to develop criteria for the identification of each ferrite grain. The grain size is then used to determine the area fraction of each ferrite microconstituent. The underlying Matlab code for this technique is freely available from the authors of this article under the working title 'Ferrite Microstructure Quantifier'.

Table 1
Chemical composition (wt%) and processing parameters of the CASTRIP steels investigated.

Specimen	Hot rolling reduction (%)	Hot rolling temperature (°C)	Coiling temperature (°C)	Nb	C	Mn	Si	N
Nb-free steel	12	879	544	< 0.001	0.034	0.93	0.2	0.008
04 Nb steel	12	895	547	0.041	0.036	0.87	0.21	0.007
08 Nb steel	38	897	567	0.084	0.031	0.83	0.2	0.006

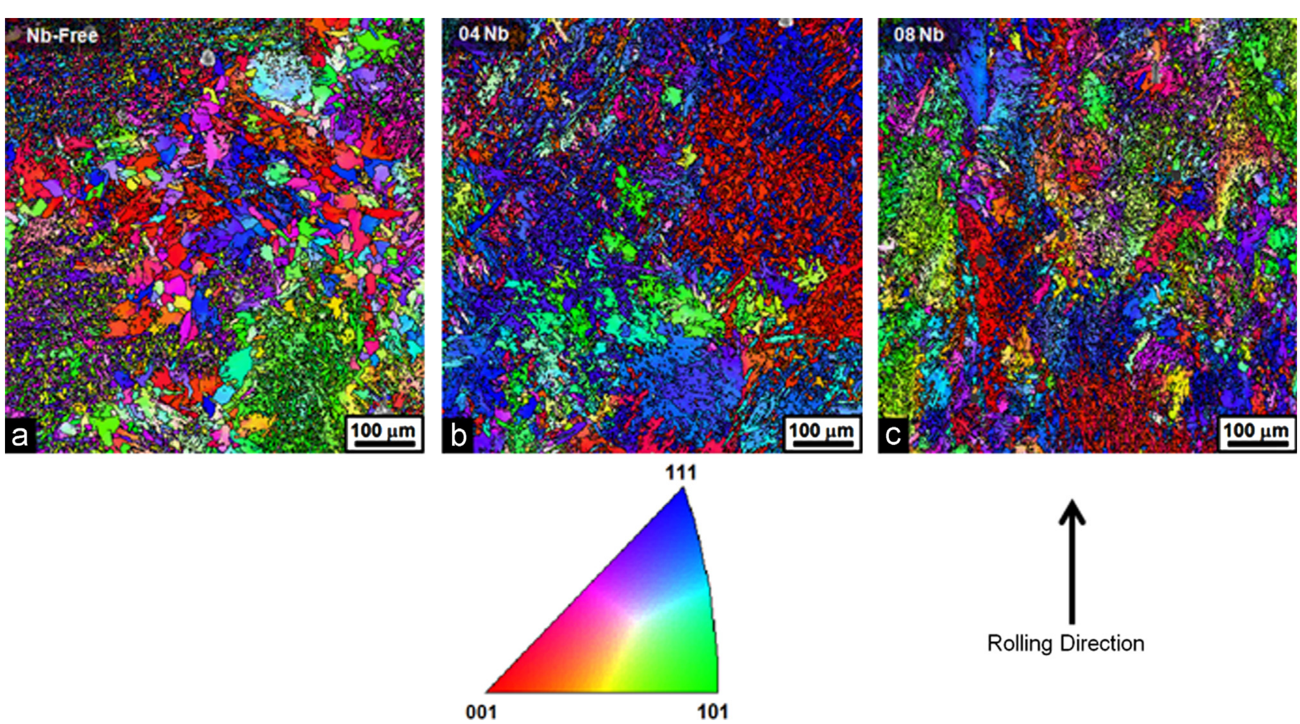

Fig. 1. EBSD inverse pole figure maps of the microstructures of (a) Nb-free, (b) 04 Nb, and (c) 08 Nb steel hot rolled specimen along the rolling direction. Note these images represent a small portion of the actual dataset used.