Archives of Materials Science and Engineering

Volume 29
Issue 1
January 2008
Pages 53-56

International Scientific Journal
published monthly as the organ of
the Committee of Materials Science
of the Polish Academy of Sciences

Orientation relationship representation in two-phase material

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Received 25.10.2007; published in revised form 01.01.2008

ABSTRACT

Purpose: Orientation characteristics determination, especially orientation relationship, in two-phase materials is important in predicting the material properties. The possible orientation relationship representations were presented and discussed in the paper.

Design/methodology/approach: Mathematical formalisms of the quantitative texture and microtexture analysis were applied.

Findings: Various orientation characteristics, especially orientation relationship representation may be used in the quantitative microtexture analysis. The choice of the orientation relationship description should relate to the research problem under discussion.

Research limitations/implications: The methods like O-lattice model should be used for orientation relationship analysis in the future research.

Practical implications: Orientation relationship determination and analysis may help in the material properties prediction.

Originality/value: The discussion of the possible orientation relationship parameters should help in the microtexture analysis in multi-phase materials.

Keywords: Multi-phase materials; Microtexture; Orientation relationship

MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

The crystallographic texture is one of the main characteristics of a polycrystalline material which determines its functional properties. The texture is defined by the orientation distribution function (ODF) – f(g), where g denotes the orienta-tion given by rotation transforming the sample coordinate system into the crystallite coordinate system [1]. ODF is a probability density distribution function. It describes the texture informing what part of the material volume (dV) is occupied by crystallites with the orientation from the interval (g, g + dg)

$$f(g)=\frac{dV}{Vdg} \tag{1}$$

The distribution function of the orientation differences F(Δg) is often also very interesting [2-4].

$$F(\Delta g)=\frac{dV}{(Vd\Delta g)} \tag{2}$$

where:

$$\Delta g = \Delta g_{12} = g_1 g_2^{-1} \tag{3}$$

In the distribution function of the orientation differences there may be taken into consideration the differences in the orientation of an arbitrary pair of crystallites with the orientations g_1, g_2 or only of neighbouring crystallites (M(Δg)) .

In order to take into consideration the effect of texture (orientation distribution) on the distribution of the orientation differences the so-called non-correlated distribution function of the orientation differences is used - N(Δg)

$$N(\Delta g) = \frac{M(\Delta g)}{F(\Delta g)} \tag{4}$$

The functions *f(g)*, *F(Δg)*, *M(Δg)*, *N(Δg)* defined for materials produced in various technological processes have the characteristic local maxima g_i, Δg_j, to which the components of the global or local texture (microtexture) are ascribed.

2. Orientation relationship and its representation

When defining the positions of the components g_i or Δg_j; various variables (parameters) are used. With reference to orientation g these are most often the Euler's angles $g = \{\varphi_1, \phi, \varphi_2\}$ or Miller's indices g = (hkl)[uvw], whereas for Δg determination it is more practical to use the so-called parameters of the axis and the rotation angle $\Delta g = \{< \upsilon,\psi >, \omega\}$; υ, ψ are the spherical coordinates of the axis about which there should be rotated by the angle ω the coordinate system of the orientation g_1 so as to make it coincide with the system of the orientation g_2 .
Another way expressing the orientation differences is to define which crystallographic planes and directions lying on these planes are – for crystallites with the orientations g_k and g_l – parallel to each other $\Delta g = \{(hkl)_k \,//\, (hkl)_l, \; [uvw]_k \,//\, [uvw]_l\}$. Such representation of Δg defines in an illustrative way the orientation relation of two crystallites and it may be useful in the analysis of the formation and development of the distributions of orientations and orientation differences, especially in multi-phase materials, then the relations of orientations between the nieghbouring crystallites of various phases are interesting.

In case of a two-phase material (containing the phases α and β) there can be distinguished, among other distributions, the following orientation characteristics:

$f_\alpha, f_\beta, F_{\alpha\alpha}, F_{\beta\beta}, F_{\alpha\beta,}, M_{\alpha\alpha}, M_{\beta\beta}, M_{\alpha\beta}, N_{\alpha\alpha}, N_{\beta\beta}, N_{\alpha\beta}$.

Analysis of the function $F_{\alpha\beta}$, $M_{\alpha\beta}$, $N_{\alpha\beta}$ provides information about the orientation relationship $\Delta g_{\alpha\beta}$ between the crystallites of the phases α and β: $\Delta g_{\alpha\beta} = \{(hkl)_\alpha \,//\, (hkl)_\beta, \; [uvw]_\alpha \,//\, [uvw]_\beta\}$.

In single-phase materials, for the interpretation of the orientation differences between the neighbouring crystallites the Coincidence Site Lattice (CSL) concept is often used. The CSL is formed as a result of the misorientation of two crystallites through rotation by a definite angle about the rotation axis common for both crystallites. In this way part of the nodal positions of the lattice of these crystallites may become placed in a common three – dimensional "super lattice" of greater dimensions of the cells and smaller (or identical) symmetry than the basic crystal lattice, from which they are formed. The degree of coincidence is expressed by the odd integer Σ defining the relation between the number of lattice points in the unit cell of a CSL and the number of lattice points in a unit cell of the basic lattice [5,6].

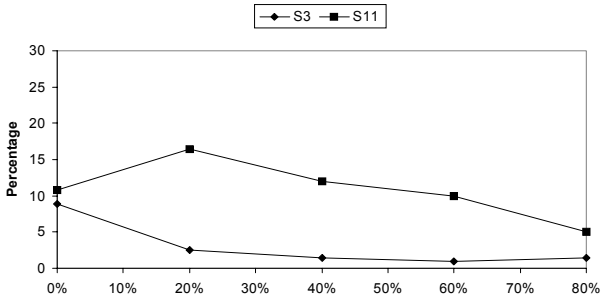
In multi-phase materials, with various symmetries of the crystal lattice of the particular phases there may be used the 0-lattice theory [7].

3. Some examples

Austeno-ferritic stainless steels of duplex structure are materials used in industry on account of their good corrosion resistance and high mechanical strength. Because of an insufficient knowledge about the relation between microstructure and texture after deformation and recrystallization, duplex steels are an interesting research area [8, 9].

The orientation relations in single phase may be characterized on the basic of the CSL model determining the parameter Σ. In Fig. 1 there has been given the percent participation of the boundaries in cold - rolled ferritic – austenitic steel of duplex structure as depending on the reduction degree – in the ferritic (1a) and the austenitic (1b) phase.

a)



b)

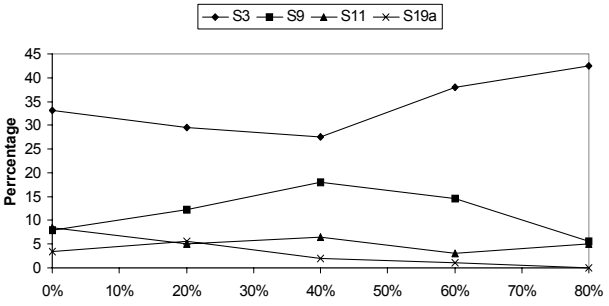


Fig. 1. Percentage of some grain boundaries between (a) ferritic grains, (b) austenitic grains as a function of the cold rolling reduction [10]

Between the orientations of the crystallites of the ferritic and austenitic phases there occur orientation relationship which are interpreted by means of the Nishiyama-Wasserman (N-W) or Kurdyumov-Sachs (K-S) models (Fig. 2).

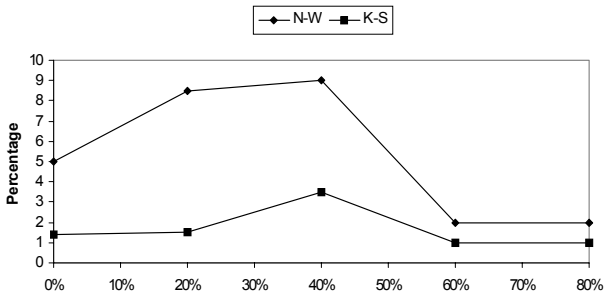


Fig. 2. Percentage of some grain boundaries between ferritic and austenitic grains according to Nishiyama-Wasserman (N-W) and Kurdyumov-Sachs (K-S),model as a function of the cold rolling reductions [10]

Table 1.
Kurdyumov-Sachs orientation relationship as a function of the annealing time [11]

Annealing time, h	K-S, %
1	7.5
10	11.8
100	16.0
1000	25.0

As it has been found in the study [11] the proportion of the orientation relationship: {110} ferrite // {111} austenite and <111> ferrite // <110> austenite according to the Kurdyumov – Sachs model increases during long time annealing (Table 1).

An interesting case of the occurrence of characteristic orientation relationships are the two – phase materials obtained by the method of directional crystallization, an example of which may be the eutectic alloy Al-$CuAl_2$ [12, 13]. In the course of such a crystallization process the lamellae of phases of Al-$CuAl_2$ alloy grow in the direction approximately parallel to the crystallization direction (direction of the greatest heat transfer) (Fig. 3). As a result a material is formed of a distinct crystallographic texture demonstrating the characteristic orientation relationship of the phases (Al) and $CuAl_2$ [14, 15].

This relation, presented by means of Miller's indices of planes parallel to the interface (Al)/$CuAl_2$ and the directions lying in these planes, can be presented as follows: {111} (Al) // {211} $CuAl_2$, <1 1 0> (Al) // <2 1 0> $CuAl_2$. There has been observed also the occurrence of the relation {1 1 2} (Al) // {2 1 2} $CuAl_2$, <110> (Al) // <120> $CuAl_2$. These relations have been defined on the basis of the analysis of single orientations (orientation mapping) measured using the scanning electron microscope and application of Electron Back Scattering Diffraction (EBSD) technique.

4. Conclusions

The distribution of orientations and orientation differences between neighbouring crystallites in polycrystalline materials determines their functional properties.

There are many methods of describing the orientation relationship and its interpretation, from strictly geometrical description of the orientation differences of two crystallites by means of three Euler's angles, through models considering the distribution of atoms on the characteristic planes and along distinguished crystallographic directions of a pair of crystallites (CSL or 0-lattice models)

Defining of the distinguished orientations and of the dominating orientation relationship that are formed during the production processes of materials allows to characterize quantitatively the microtexture of the material.

Selection of the proper description of the orientation relationship from among many possible variants should be determined by knowledge of the material structure and of the processes resulting in the production of the examined material.

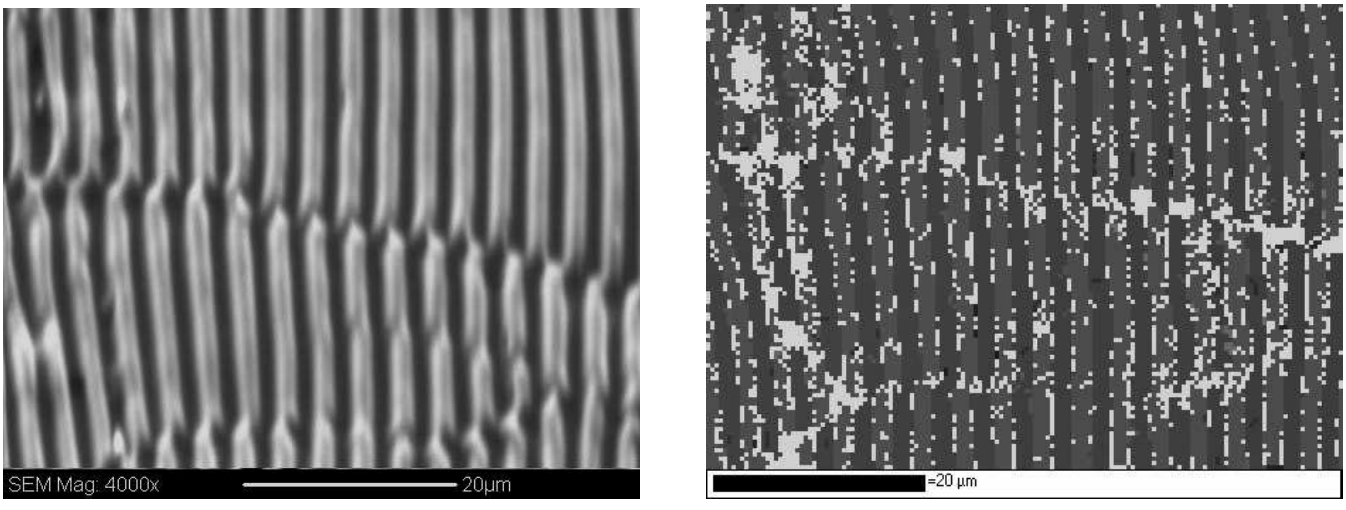


Fig. 3. The microstructure of measurement area of sample obtained in crystallization process at the rate of $85 \cdot 10^{-5}$ cm/s (in the plane perpendicular to the crystallization direction) (a) and the orientation map of (Al) and $CuAl_2$ phases (b) [15]

Acknowledgements

The work was partially sponsored by a grant of Institute of Metallurgy and Materials Science Polish Academy of Sciences 3 T08B 071 28.

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