A R C H I V E S   O F   M E T A L L U R G Y   A N D   M A T E R I A L S
Volume 50 2005 Issue 2

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ANALYSIS OF THE PREFERRED CRYSTALLOGRAPHIC ORIENTATIONS IN AL-CUAL2 EUTECTIC ALLOY OBTAINED BY DIRECTIONAL CRYSTALLIZATION

ANALIZA UPRZYWILEJOWANYCH ORIENTACJI KRYSTALOGRAFICZNYCH W EUTEKTYCZNYM STOPIE AL-CUAL2 PO KIERUNKOWEJ KRYSTALIZACJI

The microstructure of directionally solidified eutectic Al-$CuAl_2$ alloy has been analysed by optical microscopy and electron microscopy. The microstructure of this alloy consists of parallel arrangement of alternating lamellae of (Al) and $CuAl_2$. The orientation microscopy has been applied to determine the crystallographic orientations and the orientation relationship of phases.

Keywords: texture, eutectic alloy, directional crystallization, orientation relationship.

Mikrostruktura stopu eutektycznego Al-$CuAl_2$, uzyskanego w procesie kierunkowej krystalizacji, analizowana była przy wykorzystaniu mikroskopu optycznego oraz elektronowego. Charakteryzuje ją układ równoległych naprzemiennych płytek faz (Al) i $CuAl_2$. Zastosowanie mikroskopii orientacji umożliwiło określenie orientacji krystalograficznych oraz wzajemnej relacji orientacji faz.

1. Introduction

Two-phase materials are at present an object of intensive investigations on account of their advantageous properties and various applications. Formalisms of the quantitative description of the microtexture — interpreted as the determination and the analysis of local crystallographic orientation and orientation difference distributions of neighbouring grains in case when the phases have different symmetries of their crystallographic lattice — are not yet sufficiently developed and they are an interesting area of investigations.

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An important group of two-phase materials are composites in situ obtained by directional solidification of eutectic alloys. They are characterized by a good bonding between phases, strength retention at temperatures close to the eutectic melting point and excellent high-temperature phase stability [1].

The representative of this group of composites is the analysed Al-$CuAl_2$ eutectic alloy containing 33.2 wt %Cu and 66.8 wt %Al, obtained in a directional crystallization process by the Bridgman method. This material shows a distinct crystallographic texture.

The use of the orientation microscopy based on the Kikuchi diffraction patterns obtained by transmission electron microscopy enabled the determination of the orientation of (Al) and $CuAl_2$ phases.

2. Results

The directional crystallization of eutectic alloy was conducted by the Bridgman method. Crucibles with the liquid alloy were moved down at a constant rate of $84*10^{-5}$ cm/sec and at a constant temperature gradient of 100°C/cm. These conditions made the process of crystallization stationary. The rate of crystallization was equal to the rate of pulling out the crucible from the furnace. In order to select the optimal measurement conditions (high temperature gradient and low rate of growth) and to obtain a structure with suitable size of the lamellae, it was necessary to determine the temperature gradient at the crystallization front by investigating the dependence of the distance between the thermocouple and the front of the radiator as a function of temperature [2, 3]. In the course of the crystallization there has been observed the phenomenon of competitive growth, which consists in that the grains containing the lamellae of phases parallel to the direction of heat flow and having a distinct crystallographic orientation eliminate grains with less privileged growth directions [4, 5]. A rod 150 mm in length and the diameter of 2.7 mm has been received as a result of crystallization. It was submitted to a thorough analysis of its microstructure and crystallographic texture.

The microstructures of the transverse sections of the sample consist of alternating parallel lamellae of (Al) (α) phase and $CuAl_2$ (θ) crystallizing in the tetragonal system (C16) with the parameters of a unit cell: $a = 0.6067$ nm, $c = 0.4877$ nm. The lamellae have grown in a direction approximately parallel to the direction of crystallization. It was also observed that the parallelism in the transverse direction was partially destroyed by the presence of discontinuous lamellae and the disturbance of the parallel lamellar structure, resulted in the mutual displacement of the lamellae and the appearance of extra lamella, which distort the lamellar structure in their direct neighbourhood.

The measurement of individual orientations in the transverse section of the rod (Fig.1) was carried out by orientation microscopy. It enables quick automatic indexing of the diffraction patterns and creation of the orientation maps. These maps contain information about the orientation distribution in the studied areas and permit identification of the phases and of the boundaries of grains. They make also possible the statistical analysis of the results.

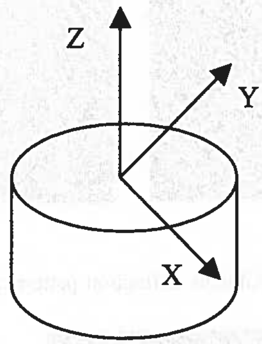


Fig. 1. Sample coordinate system; z axis is parallel to the crystallization direction, x axis is chosen arbitrarily

3. Discussion

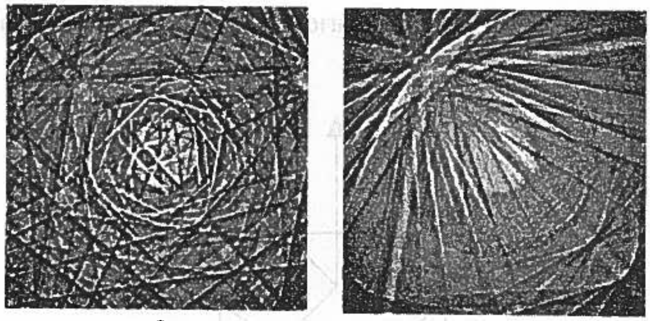
Formation of the Al-$CuAl_2$ eutectic alloy has already been studied by K r a f t and A l b r i g h t [6, 7] using X-ray diffraction techniques. They determined the orientation relationship between phases as: (2 1 -1) $CuAl_2$ // (1 1 -1) (Al), [1 -2 0] $CuAl_2$ // [1 -1 0] (Al).

The presented results of investigations conducted at the crystallization rate, which guaranteed obtaining the lamellar structure, have confirmed the occurrence of the distinguished orientations of lamellae of both phases and the relationship between them as indicated in literature [6, 7, 8, 9]. The applied method permitted to distinguish some more orientation relationships between the crystallographic phases in the characteristic areas of a cross section perpendicular to the crystallization direction.

3.1. The diffraction pattern analysis and the description of a map of phases and orientations

On the basis of the K i k u c h i diffraction patterns (Fig. 2), obtained in a transmission electron microscope, the crystallographic orientations of the phases of an alloy were determined. The measuring step was equal to 0.4 μm.

They were used to determine the orientation relationship of the alloy phases in areas with ordered lamellar structure where the lamellae were arranged parallel side by side and in areas where the structure was distorted. The observed inhomogeneity of structure is resulted in presence the extra lamella in studied area and shift of lamellae lying in its neighbourhood. Figure 3 represents the phase orientation map of the analysed area.



a b

Fig. 2. Exemplary Kikuchi diffraction patterns: a) $CuAl_2$, b) (Al)

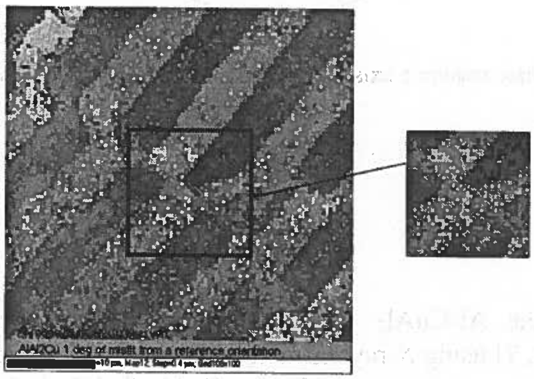


Fig. 3. The phase orientation map with the marked subregion including the analysed inhomogeneities: $CuAl_2$ (black), (Al) (grey) Step = 0.4 μm

3.2. Determination of the orientation relationship of phases and orientation in relation to the direction of crystallization

The selected subregion (Fig. 3) was analysed in detail. The disturbances in the microstructure have been distinguished as follows:

- additional lamella of $CuAl_2$ phase and the accompanying displacement of the neighbouring lamellae and irregularity of their shape,
- intrusion of $CuAl_2$ phase in (Al) phase lamellae or (Al) in $CuAl_2$ (less often).

The orientation relationship of the phases was determined and recorded in the form of M i l l e r indices of the planes and the crystallographic directions depending on the examined area of the cross section. The orientation relationship of the phases on both sides of the interface and the orientation of each phase in relation to the sample system (italic type) were analysed in the following areas (Fig. 4):

a) the regular alternatively arranged lamellae of (Al) and $CuAl_2$ phases
(-1 1 -1) Al // (-2 1 -1) $CuAl_2$ [1 1 0] Al // [1 2 0] $CuAl_2$
(0 1 1) Al (-1 3 4) $CuAl_2$

b) area in the neighbourhood of the end of an extra lamella
(-1 1 -1) Al // (-2 2 -1) $CuAl_2$ [0 1 1] Al // [1 1 0] $CuAl_2$
(0 1 1) Al (1 1 0) $CuAl_2$
(-1 -1 1) Al // (-2 -2 1) $CuAl_2$ [0 1 1] Al // [0 1 2] $CuAl_2$
(0 1 1) Al (0 1 1) $CuAl_2$
(-1 1 -1) Al // (-1 0 0) $CuAl_2$ [0 1 1] Al // [0 -2 1] $CuAl_2$
(0 1 1) Al (0 -4 1) $CuAl_2$

c) intrusions of $CuAl_2$ phase in the (Al) lamellae
(-1 -1 1) Al // (-1 -2 -1) $CuAl_2$ [-1 1 0] Al // [0 -1 2] $CuAl_2$
(0 1 1) Al (3 -20) $CuAl_2$
(-1 -1 1) Al // (2 1 -1) $CuAl_2$ [0 1 -1] Al // [-1 1 -1] $CuAl_2$
(0 1 1) Al (1 1 0) $CuAl_2$
(-1 1 -1) Al // (-1 0 0) $CuAl_2$ [0 1 1] Al // [0 2 1] $CuAl_2$
(0 1 1) Al (0 3 1) $CuAl_2$

d) intrusion of (Al) phase in the lamella of $CuAl_2$ phase
(2 -1 -2) Al // (2 -1 1) $CuAl_2$ [-1 -2 0] Al // [-1 -2 0] $CuAl_2$
(1 0 1) Al (-1 3 4) $CuAl_2$

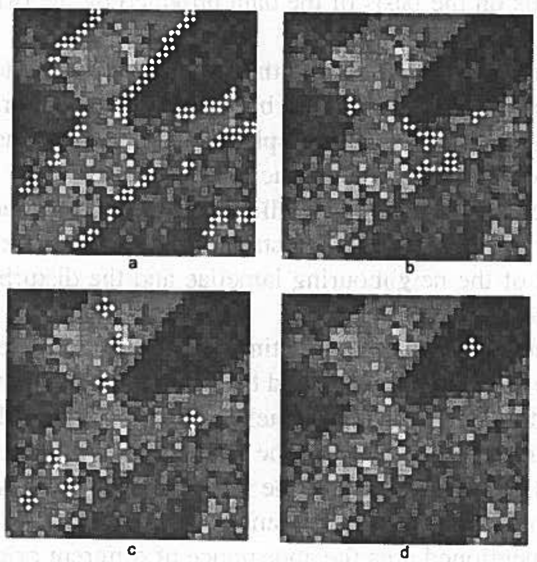


Fig. 4. The orientation relationships between (Al) and $CuAl_2$ phases in the four analysed cases: a) the regular alternately arranged lamellae of (Al) and $CuAl_2$ phases, b) the area in the neighbourhood of the end extra lamella, c) the intrusions of $CuAl_2$ phase in the lamellae of (Al) phase, d) the intrusion of (Al) phase in the lamella of $CuAl_2$ phase

From the above listed relationships it follows that the orientation of (Al) phase in relation to the sample system remains constant in the measurement areas defined at the points (a), (b), (c) and it is described by (0 1 1). It changes however to (1 0 1) in the case (d) when the phase of (Al) occurs in the form of intrusion in the lamella $CuAl_2$. The orientation of the phase $CuAl_2$ remains constant at points (a) and (d) and it is defined as (-1 3 4) and changes into (b) and (c).

In the areas comprising the regular, alternately arranged lamellae of (Al) and $CuAl_2$ phases the orientation relationship of the phases on both sides of the interface plane can be defined in an unambiguous way as (-1 1 -1) (Al) // (-2 1 -1) $CuAl_2$, [1 1 0] (Al) // [1 2 0] $CuAl_2$. It occurs in the greater part of the analysed area and it is analogous to that cited in literature. This characteristic misorientation of phases results from similar configuration of atoms on the planes (111) (Al) and (211) $CuAl_2$ and the approximate atomic thickness at the interfacial surface.

4. Conclusions

1. Composites in situ obtained during directional crystallization exhibit clearly defined orientation relationship of the crystallographic lattice of the component phases. It is necessary, however, to develop the formalisms of the analysis of the microtexture of two-phase materials on the basis of the data provided by the orientation microscopy method.

2. The diffraction pattern analysis and the orientation maps allowed us to define the orientations of phases and the relationship between the crystallographic orientations of (Al) and $CuAl_2$ phases depending on the place of the measurement in relation to the inhomogeneities observed in the microstructure.

3. The local fluctuations of the crystallization process parameters are responsible for the formation of defects of the microstructure such as: the extra lamella causing mutual displacement of the neighbouring lamellae and the disturbance of the shape of the interfacial surface.

4. In the analysed sample we have distinguished four characteristic areas in which we have analysed the phase orientations and the orientation relationships between them:

a) the regular alternately arranged lamellae of (Al) and $CuAl_2$ phases,

b) the area in the neighbourhood of the end of extra lamella,

c) the intrusions of $CuAl_2$ phase in the lamellae of (Al) phase,

d) the intrusion of (Al) phase in the lamella of $CuAl_2$ phase.

5. In the above mentioned area the appearance of different orientation relationships between the phases of the alloy has been found.

6. The (Al) phase orientation in relation to the sample system was stable as (0 1 1) in each analysed area, whereas the $CuAl_2$ phase orientation was changing.

Acknowledgements

The authors would like to thank A. Morawiec, E. Bouzy, J. J. Fundenberger for help in the experimental work.

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Received: 21 March 2005.