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
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MULTISCALE TEXTURE AND ORIENTATION RELATIONSHIP INVESTIGATION IN Al-CuAl$_2$ EUTECTIC ALLOY

WIELOSKALOWE BADANIA TEKSTURY I RELACJI ORIENTACJI W EUTEKTYCZNYM STOPIE Al-CuAl$_2$

The paper presents the analysis of the crystallographic texture of Al-CuAl$_2$ eutectic alloy, carried out in some scales with the application of various measuring methods: in the macroscale – the X-ray diffraction; in the mesoscale – the scanning electron microscopy (SEM – FEG) and EBSD technique; in the microscale – the transmission electron microscopy. The applied measuring methods enabled to describe the microstructure of the examined alloy in the aspect of the occurrence of the preferred crystallographic orientations of the phases and the orientation relationship of phases on both sides of the interface.
***Keywords*: two-phase eutectic alloy, texture, orientation relationship**

W pracy została przedstawiona analiza tekstury krystalograficznej stopu eutektycznego Al-CuAl$_2$ wykonana w kilku umownych skalach przy zastosowaniu różnych metod pomiarowych: w skali „makro" – dyfrakcji rentgenowskiej; w skali „mezo" – skaningowego mikroskopu elektronowego (SEM – FEG) i techniki EBSD; w skali „micro" – transmisyjnego mikroskopu elektronowego. Zastosowane metody pomiarowe umożliwiły opis mikrostruktury badanego stopu w aspekcie występowania wyróżnionych orientacji krystalograficznych faz oraz związku orientacji faz po obu stronach powierzchni międzyfazowej.

1. Introduction

The object of the investigations was the texture formed during directional crystallization of Al-CuAl$_2$ eutectic alloy, interpreted as a crystallographic texture with consideration given to its dependence on the place of measurement (inhomogeneity) and the relation between the orientations of the neighbouring areas of measurement. The microstructure of the examined alloy was composed of alternately arranged lamellae of (Al) phase with regular symmetry and of CuAl$_2$ phase with tetragonal symmetry of the crystallographic lattice, situated parallel to the crystallization direction.

During directional crystallization there appears the phenomenon of competitive growth which consists in the fact that the grains containing the lamellae of phases, parallel to the direction of heat flow and having the crystallographic orientations favouring their growth, eliminate grains of other orientations. At the initial stage of crystallization it was observed the occurrence of a few grains containing subgrains with alternately arranged lamellae of both phases parallel to the crystallization direction. The difference in the orientation of the grains can be macroscopically described as a rotation (by some tens of degrees) about the direction of crystallization. After longer duration of crystallization the domination of a single grain was observed. Figure 1 shows the area formed at the initial stage of the process (in a section perpendicular to the crystallization direction), comprising fragments of three grains in which the lamellae are arranged in different directions. These grains are composed of many subgrains with clearly marked boundaries, containing lamellae of (Al) and CuAl$_2$ phases. The subgrains are separated from each other due to distortions occurring in the regular arrangement of the lamellae. They disturb the lamellar structure in their immediate neighbourhood [1-3]. The boundaries between the subgrains run more or less perpendicular to the lamellae. Orientations of subgrains described by the rotation about the crystallization direction differ within the range from a few to some ten to twenty degrees. Inside the subgrains the orientation of the arrangement of lamellae is more or less preserved.

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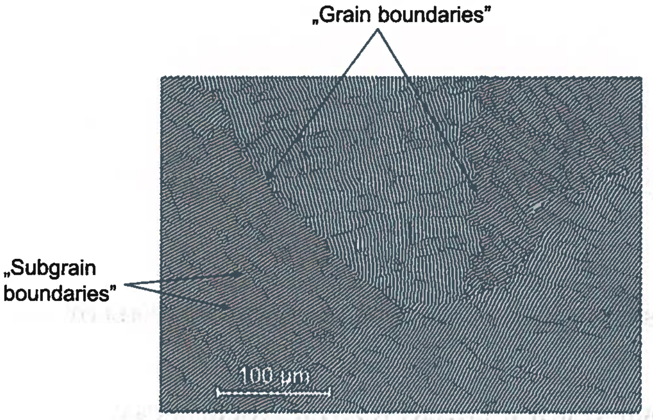

Fig. 1. Microstructure of three grains characterized by different arrangement of lamellae with visible boundaries of subgrains (SEM)

2. Experimental techniques

The mutual orientation relationship of (Al) and $CuAl_2$ phases occurring on both sides of the interface and their orientations with respect to the crystallization direction are presented. The analysis was carried out using various measuring techniques. It allowed to carry out the investigations in a scale, assumed to be called: macroscale (X-ray diffraction), mesoscale (scanning microscope with field emission gun SEM – FEG) and microscale (transmission electron microscopy).

In the macroscale – the pole figures measured by the X-ray reflection technique enabled to determine the orientation distribution function and the global texture. In turn, observations carried out using the scanning electron microscope have revealed the morphological features of the microstructure.

In the mesoscale – the measurements realized by means of SEM – FEG have revealed differentiation of orientations and allowed to define the relations between orientations of the neighbouring areas of measurement.

In the microscale – the observations by means of a transmission electron microscope enabled the analysis of the orientation relationship near the occurring inhomogeneities of the microstructure.

3. Macroscale global texture

Texture analysis is a description of the orientation distribution in a polycrystalline material. The orientation distribution is a characteristic of a polycrystalline material which is defined by the three-dimensional orientation distribution function (ODF) – f(g) [4, 5]. ODF was determined [6, 7] from experimental data such as the two-dimensional pole figures (111) and (100) for (Al) phase and (211), (110), (112), (310) and (101) for $CuAl_2$ phase, measured in a plane perpendicular to the crystallization direction. The measurement was carried out by means of X-ray diffractometer Philips X'Pert system, using CoK_α radiation with the wavelength 1.7903 Å, the measurement area was 1.5 mm by 1.5 mm. Figure 2 shows exemplary pole figures for (Al) and $CuAl_2$ phases, measured and calculated from ODF.

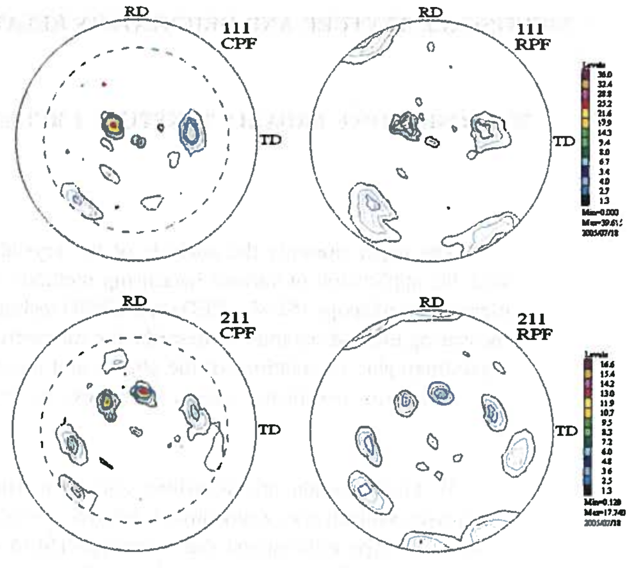

Fig. 2. Pole figures 111 for (Al) phase and 211 for $CuAl_2$ phase, measured on the plane perpendicular to the crystallization direction. Denotations of CPF and RPF figures refer to the measured figure and that calculated from ODF, respectively

Analysis of pole figures allowed to state that both phases have clearly identified orientations. On the basis of ODF the characteristic orientation of each of the phases was defined, in the case under consideration determined by the planes {hkl} perpendicular to the direction of crystallization. For the (Al) phase it was the $(\bar{2}\ 3\ \bar{1})$ plane, whereas for $CuAl_2$ it was the plane $(1\ \bar{1}\ \bar{2})$. The sharpness of texture was estimated by defining the scattering width around the identified orientations in the both phases. It has been found that the half scattering width for $CuAl_2$ phase is about two times greater than that for (Al) phase, and it amounts to ~ 10° and ~ 5°, respectively.

4. Mesoscale local texture – orientation relationship

In the mesoscale the texture was analysed by the EBSD (Electron Back Scattering Diffraction) technique by means of a scanning electron microscope (SEM – FEG). The investigations covered a measurements area 200 μm by 90 μm (Fig. 3). The obtained information about the orientation distribution in the analysed area has confirmed the occurrence of orientations identified on the basis of ODF determined from the pole figures measured by X-ray technique.

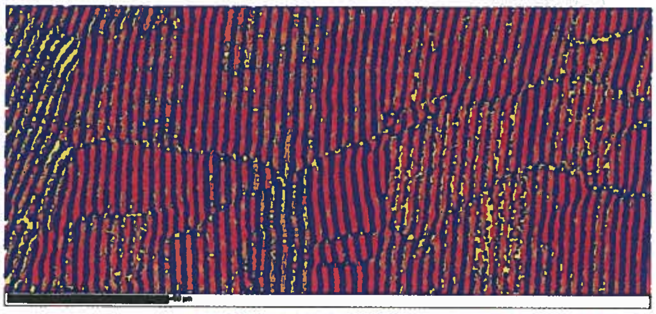

Fig. 3. Orientation map prepared using EBSD technique (SEM – FEG)

The analysis has additionally revealed the existence of the following phase orientations in the plane perpendicular to the crystallization direction (2 1 4) and (3 1 6) for (Al) and $(1\ 1\ \bar{3})$ for $CuAl_2$. The relation of the orientations of phases on both sides of the interface has also been determined, which is as follows: $(\bar{1}\bar{1}\ 1)\ [1\ \bar{1}\ 0]$ (Al) // $(\bar{2}\bar{1}\bar{1})\ [\bar{1}\ 20]$ $CuAl_2$. This characteristic orientation relationship is due to similar configuration of atoms on the planes {111} of (Al) phase and {211} of $CuAl_2$ and similar atomic density at the interface. It is analogous to that cited in literature [2, 8].

5. Microscale local texture – texture inhomogeneities

In the microscale the texture was determined using the electron transmission microscope (TEM). Applying the manual scan there have been determined the orientations in the area comprising two (Al) and one $CuAl_2$ lamellae (Fig. 4).

a) b)

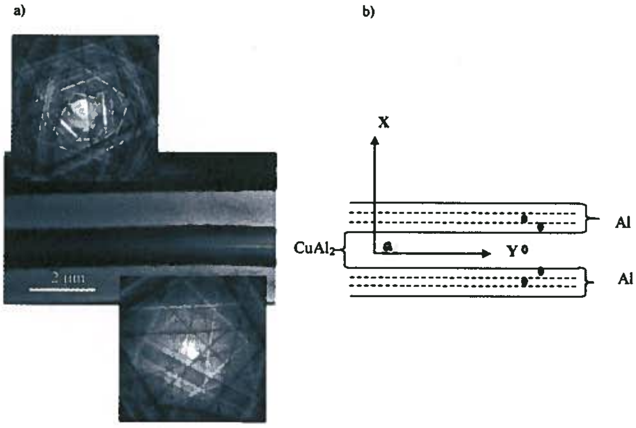

Fig. 4. The exemplary microstructure (a) and localization of the measurement points (b)

Also in this case the obtained orientation of phases in the plane perpendicular to the crystallization direction was $(2\ \bar{1}\ 3)$ for (Al) and (112) for $CuAl_2$, and the orientation relationship of the phases on both sides of the interphase surface remained in the form $(\bar{1}\bar{1}1)\ [1\bar{1}0]$ (Al) // $(\bar{2}\bar{1}\bar{1})\ [\bar{1}20]$ $CuAl_2$. The deviations from this orientation relationship occurring near the microstructure inhomogeneities were analysed in [3]. The manual measurement has also shown that the difference in the orientation (defined by the angle of misorientation) between the boundaries and the centre of (Al) lamella is about 2°. This is an indication of the inhomogeneity of the microstructure occurring inside the lamellae.

6. Summary and conclusions

The texture occurring in Al-$CuAl_2$ eutectic alloy after directional crystallization can be analysed in macro-, meso- and microscales. In the macroscale, in the initial period of crystallization, on the section perpendicular to the crystallization direction there can be observed grains composed of many subgrains. These subgrains in the mesoscale reveal a structure containing parallel lamellae of both phases. In turn, in the microscale there are visible numerous distortions in the regular arrangement of the lamellae, which result in the inhomogeneity of microtexture.

In the later stages of crystallization there takes place the domination of a single grain and the number of disturbances in the arrangement of the lamellae is reduced.

The determined dominating orientation relationship between the neighbouring lamellae of the phases $(\bar{1}\bar{1}1)$ $[1\bar{1}0]$ (Al) // $(\bar{2}\bar{1}\bar{1})$ $[\bar{1}20]$ $CuAl_2$ is identified by each of the applied measuring technique. However, near the microstructure inhomogeneities there have been observed deviations from the above mentioned orientation relationship [3].

The occurring identified orientations of phases can be attributed to high packing density of atoms in the respective planes, whereas the orientation relationship between the lamellae of the phases is due to similar configuration of atoms on the planes $(\bar{1}\bar{1}1)$ of (Al) phase and $(\bar{2}\bar{1}\bar{1})$ of $CuAl_2$ when the direction $[1\bar{1}0]$ of (Al) is parallel to $[\bar{1}20]$ of $CuAl_2$ phase.

REFERENCES

[1] R. W. Kraft, D. L. Albright, Microstructure of Unidirectionally Solidified Al-$CuAl_2$ Eutectic, Transactions of the Metallurgical Society of Aime **221**, 95-102 (1961).

[2] R. W. Kraft, D. L. Albright, Crystallography of Equilibrium Phase Interfaces in Al-$CuAl_2$ Eutectic Al-

loys, Transactions of the Metallurgical Society of Aime **224**, 65-74 (1962).
[3] A. G ó r a l, J. J u r a, K. S z t w i e r t n i a, G. L i t a w a, Analysis of the preferred crystallographic orientations in Al-$CuAl_2$ eutectic alloy obtained by directional crystallization. Archives of Metallurgy and Materials **50**, 341-347 (2005).
[4] H. J. B u n g e, Texture Analysis in Materials Science, Butterworths Publishers London (1982).
[5] J. H a n s e n, J. P o s p i e c h, K. L u c k e, Tables for Texture Analysis of Cubic Crystals, Springer – Verlag, New York 1978.
[6] LaboTex v. 2000: The Texture Analysis Software, by LaboSoft s.c.
[7] K. P a w l i k, Determination of the Orientation Distribution Function from Pole Figures in Arbitrarily Defined Cells. Physica Status Solidi B **134**, 477 (1986).
[8] G. G a r m o n g, Structure and Crystallography of Curred Al-Al_3Ni and Al-$CuAl_2$ Directionally Solidified Eutectic Alloys. Metallurgical Transactions A **6A**, 1335-1343 (1975).

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