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# Al-Cu-Co single quasicrystals obtained by the method of inclined front crystallisation

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## ABSTRACT

An Al-Cu-Co alloy was obtained by the inclined front of crystallisation method (IFC). During crystallisation the alloy delaminated into three layers, two of which were single decagonal quasicrystals of different orientations and the third one was a mixture of two phases. The first quasicrystalline layer was formed in a peritectic reaction of an earlier created single crystalline layer of an approximant (phase of the B2 structure), the second – grew directly from liquid. With the use of X-ray topography it was found that the (00001) planes of both quasicrystals are rotated of about  $1^\circ$  against each other.

**Keywords:** Al-Cu-Co single quasicrystals, decagonal quasicrystals, peritectic reaction.

## 1. INTRODUCTION

Crystal structure of decagonal quasicrystalline phases consists in periodic arrangement of planes which have non-periodic order of atoms. In result the single quasicrystals of decagonal phases may show specific anisotropy of physical properties and thus arouse wide interest. Single quasicrystals of Al-based decagonal phases have been obtained from liquid phase for many years<sup>1-3</sup>. However, the mechanism of their growth is not completely clear. The decagonal phase of the Al-Cu-Co alloy may be formed from liquid by peritectic reaction of B2 phase crystallised at higher temperatures, or it can grow directly from liquid<sup>4</sup>. Fig. 1 shows schematic pseudobinary cross-section of the Al-Cu-Co phase diagram suggested in<sup>4</sup>. At 1048°C in the L+B2+DQC three phase area there occurs a peritectic reaction  $L+B2 \rightarrow DQC$ <sup>4,5</sup>.

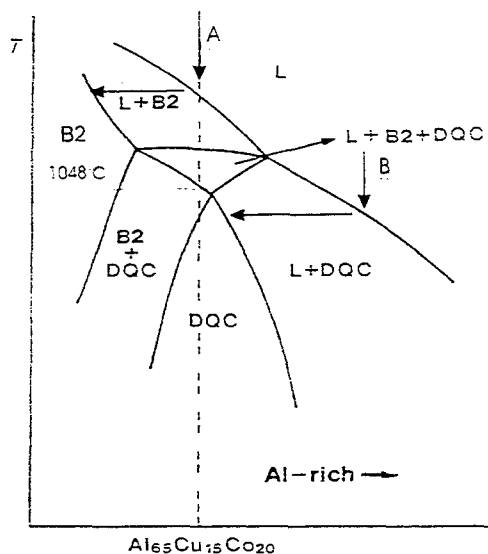


Fig.1 Schematic cross-section of the Al-Cu-Co phase diagram according to ref. [4].

If the alloy composition is close to  $Al_{65}Cu_{15}Co_{20}$  than first the B2 phase crystallises and then the phase reacts with the rest of the liquid and forms the decagonal phase (A arrows at Fig. 1). The concentration of Al in the liquid increases. At

temperatures lower than 1048°C the decagonal phase crystallises directly from the liquid in the two phase L+DQC region (B arrows at Fig.1).

The aim of this work was to obtain a single quasicrystals of the Al-Cu-Co alloy formed in both ways i.e. by peritectic reaction and directly from liquid using the method of inclined front of crystallisation. Knowledge of differences in structure and defects gives an opportunity to determine the mechanism of the phase creation.

## 2. EXPERIMENTAL

The inclined front of crystallisation method<sup>6</sup> was used to grow the material. The charge of composition of Al – 24%at.Cu – 11%atCo in form of plate of 15x4x0,5 mm was melted and than subjected to horizontal crystallisation. The shape of the charge (Fig. 2) was preserved during melting thanks to surface tension. The charge was obtained from elements of 5N purity. The metals were melted in an Al<sub>2</sub>O<sub>3</sub> crucible in induction furnace under helium atmosphere. After homogenisation the melt was cast onto a brass plate cooled with liquid nitrogen. The charge composition measured with the use of atomic absorption spectroscopy was equal to the nominal composition.

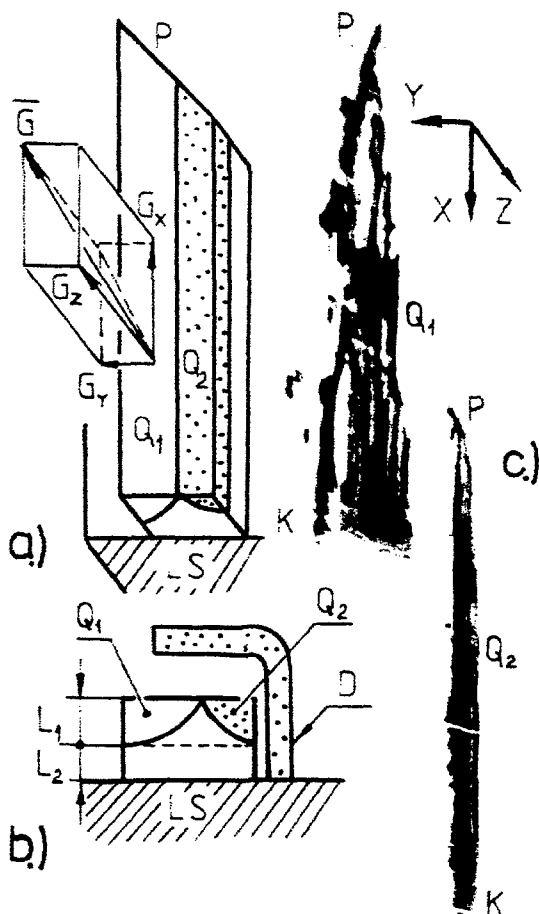


Fig.2. Diagram of the Al-Cu-Co specimen delamination after crystallisation by the IFC method (a, b) and topogram of the single crystalline L<sub>1</sub> layer (c). Radiation Cu<sub>Kα</sub>, reflex 00001.

The decagonal DQC phase created in the peritectic L+B<sub>2</sub>→DQC reaction forms in between the two phases. The speed of the DQC phase volume growth, controlled by diffusion of atoms from the liquid to the B<sub>2</sub> phase and from the B<sub>2</sub> phase to the liquid, will decrease with the DQC phase growth.

In the IFC method<sup>6</sup>, inclination of the crystallisation front versus the crystallisation direction causes that the crystallisation (in the x direction, Fig. 2a) takes place at first in the upper layer of the charge (in the L<sub>1</sub> layer, Fig.1b). According to the phase diagram shown in Fig. 1, a layer of the B<sub>2</sub> phase should be formed during this crystallisation. At lower temperatures

the lower layer ( $L_2$ , Fig.2b), being still in the liquid state, can react with the upper layer and in a peritectic reaction form the decagonal phase. Due to directional heat abstraction the temperature of the peritectic reaction is reached first at the layer interface in the primary area of the specimen (P, Fig.2a), and when the reaction proceeds it moves towards the specimen end (K, Fig.2a). Thus the speed of the decagonal phase single quasicrystal growth in the X direction is much faster than in conventional methods of single crystal growth at which the crystallisation front is perpendicular to the growth direction.

The growth was carried out in the induction furnace with a horizontal graphite heating element in helium atmosphere. The charge of a shape shown in Fig. 2a was placed on a leucosapphire plate (the LS symbol, Fig 2a). The plate was then put on a shelf milled in the graphite heating element. The charge was covered by a graphite cover (D, Fig.2b) in such a way that it

covered only one side of the charge shown in Fig. 2a and 2b by the letter  $Q_2$ . In result the temperature gradient  $\vec{G}$  was neither perpendicular nor parallel to the growth direction X i.e. none of its components  $G_x$  or  $G_y$  was equal zero (Fig. 2a). At first the temperature in the area of the specimen denominated as K (Fig. 2a) was 1430°C. Then it was decreased to 900°C with speed 100K/h. Then the specimen was kept for 3 h at stable temperature and the furnace was switched off and the helium flow was increased. In such a way the speed of temperature decrease from 900°C to room temperature was average 1800°K/h.

### 3. RESULTS AND DISCUSSION

Metallographic studies showed that after crystallisation the specimens (11 pieces) were delaminated. In the upper layer  $L_1$  (Fig.2b) there were two plates of the quasicrystalline phase denominated by  $Q_1$  and  $Q_2$ . The lower layer  $L_2$  consisted of a mixture of two phases. Fig.2c shows a typical topogram of the single crystalline layer  $L_1$  obtained with the use of Auleytner method of wide beam<sup>7</sup>. The topogram consists of two reflexes coming from the  $Q_1$  and  $Q_2$  plates. Both reflexes come from the (0001) planes of the decagonal phase. The disorientation angle between the two plate determined from the topogram is 59,4 minutes. For 11 studied specimens the angle value was from 18 to 95 minutes. The single  $L_1$  layer was obtained by polishing the lower  $L_2$  layer. The  $L_1$  layer was powdered and an X-ray diffraction pattern was taken. It showed reflexes only from the decagonal phase (Fig. 3). From the  $L_1$  layer a thin foils were also produces which were studied by TEM. These studies also show presence of the decagonal phase (Fig.4).

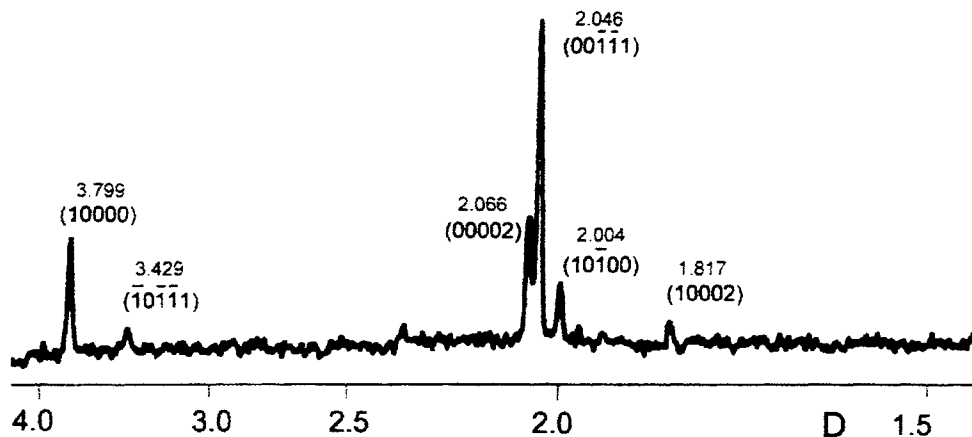


Fig.3. Powder X-ray diffraction pattern of the  $L_1$  layer of the Al-Cu-Co alloy.  
Radiation  $Cu_K\alpha$ .

The chemical composition averaged over five specimens and determined by the X-ray microanalysis was for the  $Q_1$  specimen: Al-64,2 at%, Cu-18,5at%, Co-17,3at% and for the  $Q_2$  specimen: Al-68,3at%, Cu-14,6at%, Co-17,2at%. Increased amount of Al in the  $Q_2$  means that crystallisation of the  $Q_2$  layer occurred at lower temperatures.

X-ray topograms of the both layers show contrast bands situated along the growth direction X. This is connected with a small non-homogeneity of the chemical composition occurring at the crystallisation front during the growth process as well as with internal stresses in the specimen. In the first area of the specimen  $Q_1$  (symbol P, fig.2c) the contrast was more diffused than in the last area of the specimen (symbol K, fig.2c). It may be due to less stable conditions of the beginning of crystallisation controlled by diffusion of atoms between the  $L_1$  and  $L_2$  layers. The final part of the specimen  $Q_1$

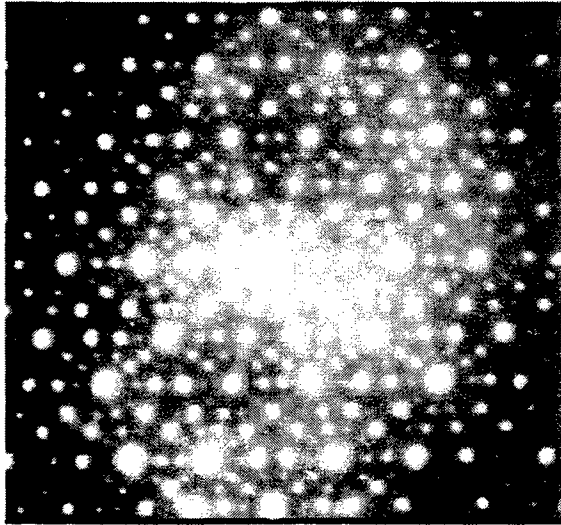


Fig.4. Electron diffraction pattern from the  $L_1$  layer of the Al-Cu-Co alloy. [00001] orientation.

(symbol K, fig.2c) is less defected and the contrast is more sharp and at the end of the specimen the contrast bands do not occur. The topogram of the single crystal  $Q_2$  layer almost do not show diffused band contrast which means that the specimen has less internal stresses than the  $Q_1$  plate.

#### 4. CONCLUSIONS

In result of IFC crystallisation with the temperature gradient asymmetric in regards to the direction of growth the single decagonal phase quasicrystals were obtained. They consisted of two plates. The disorientation angle between the plates was in average  $57^\circ$ . The first plate ( $Q_1$ , Fig.2) most probably was formed in a peritectic reaction from a earlier crystallised B2 phase (Fig.1, arrow A.) and from the liquid phase. The second plate ( $Q_2$ , Fig.2) crystallised at lower temperatures directly from the liquid phase and in result it contained more Al (arrow B, Fig.1).

#### ACKNOWLEDGEMENTS

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