# Analytical TEM of an Al-Mn-Be-Cu alloy

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Quasicrystals form an additional state of matter to those of crystalline and glassy. The atoms positions are ordered but with non-crystallographic rotational symmetry and without three-dimensional periodicity [1]. Icosahedral quasicrystal (i-phase) in Al-Mn system is metastable. It was not formed by casting into metallic dies. However, by using different methods of conventional casting, i-phase was found in some ternary and quaternary alloys based on the Al-Mn system. Yet, considerable amounts of crystalline intermetallic phases were also observed [2].

During the last year an Al-Mn-Be-Cu was developed consisting mainly of i-phase in Al-rich solid solution matrix (α-Al), with only small amount of in-equilibrium $\Theta$-$Al_2Cu$ phase in the interdendritic regions. The i-phase formed at moderate cooling rates typical for the conventional die casting. This indicates that the developed alloy possessed very low tendency to form intermetallic compounds reflected itself in as low liquidus temperature as ≈ 650 °C (DSC analysis with 10 °C/s heating and cooling rates) [3].

In order to understand such strong quasicrystalline forming ability it is of utmost interest to determine the composition and structure of all phases. With this in mind the alloy with the nominal composition of $Al_{94}Mn_2Be_2Cu_2$ was vacuum induction melted and cast into a copper die.

Transmission electron microscopy (TEM) was carried out on a Philips CM20. The TEM specimens were cut out at specific sites using a focussed ion beam (FIB) in a FEI Nova 200 Nanolab. Energy dispersive spectroscopy (EDS) was carried out both in SEM and TEM. Electron energy loss spectroscopy (EELS), energy-filtering TEM (EFTEM) and high-resolution transmission electron microscopy (HRTEM) was done on an FEI Technai F20.

Fig 1a shows the bright field TEM image of the investigated alloy in the as-cast condition. It consisted mainly of three phases: α-Al, *i*-phase and $Al_2Cu$. The matrix phase was α-Al that dissolved approximately 2 at. % Cu and around 1 at. % Mn. The solubility of Be in α-Al is very small. The lattice parameter of α-Al determined from the positions of the diffraction spots (Fig. 1b) was almost the same as in pure Al. SAED-pattern in Fig. 1c confirmed the presence of $\Theta$-$Al_2Cu$ phase.

Fig. 1d shows a twofold diffraction pattern of i-phase. It is clear, that the diffraction pattern is not periodic, but that the distances between the most important spots increase with $\tau = (1+\sqrt{5})/2$. The position of the most important diffraction spot (211111) in the Elser's indexing scheme indicated that the quasicrystalline phase possessed primitive icosahedral structure. It can be also seen that the diffraction spots, especially the weaker ones, are deflected from their ideal positions. This is a strong indication for the presence of phason strains. The EDS-analysis confirmed that i-phase contained Al, Mn, and only around 2.5 at. % Cu, which is slightly more than the average Cu content in the alloy. The Al/Mn ratio was

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≈3.5, which is almost the same as in the ternary Al-Mn-Be alloys [11]. On the other hand, the ratio Al/Cu was approximately 30 indicating an important content of Cu in the *i*-phase. Using EELS also a presence of Be in the i-phase was confirmed.

Increased quasicrystalline forming ability can be attributed to the stabilizing effect of both Be in Cu because of their incorporation into the i-phase.

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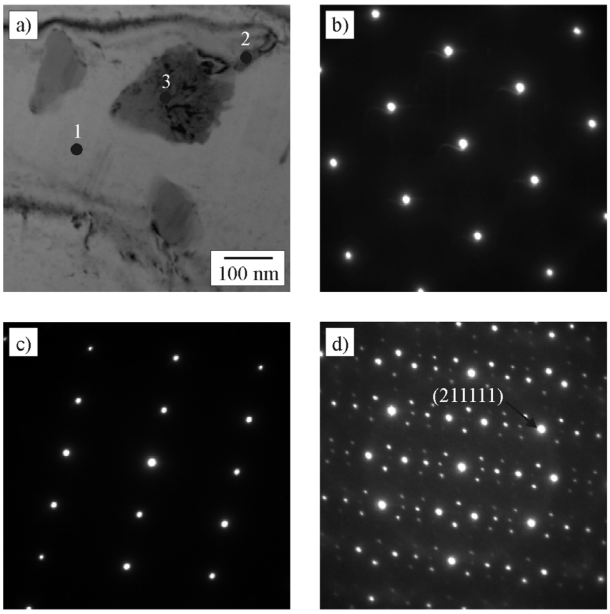


**Figure 1.** The $Al_{94}Mn_2Be_2Cu_2$ alloy in the as-cast condition. a) Bright-field TEM micrograph, b) SAED-pattern in spot 1 (α-Al matrix – [011] zone axis), c) SAED-pattern in spot 2 (Θ-$Al_2Cu$ particle). d) SAED-pattern of an icosahedral quasicrystalline particle (twofold zone axis)

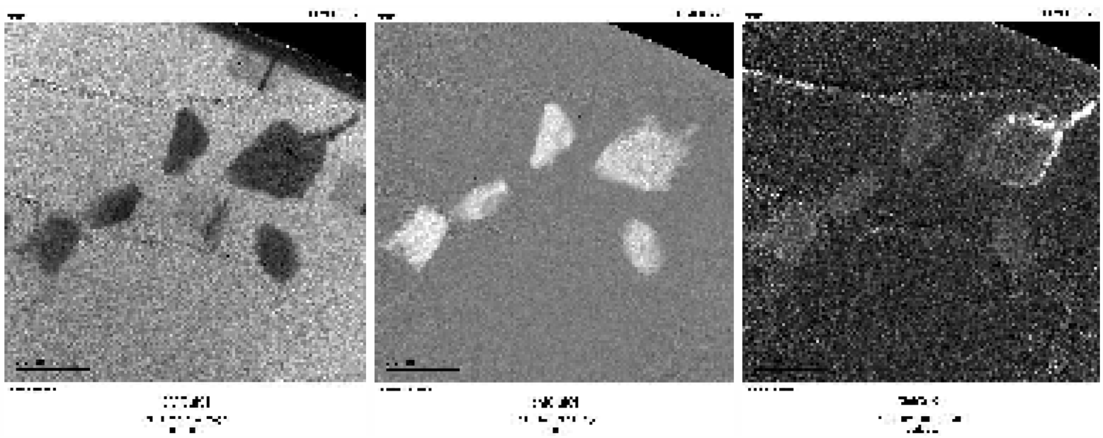

**Figure 2.** Distribution of elements using EFTEM in alloy Al94Mn2Be2Al2. The same region as in the Fig. 1: a) elemental distribution of Al, elemental distribution of Mn and c) elemental distribution of Cu (jump ratio images).


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