Synthesis of the Single Phase i-AlCuFe Bulk Quasicrystal by Spray Forming

V.C.Srivastava[1,2], V. Uhlenwinkel[1], A. Schulz[1], H.-W. Zoch[1], N.K. Mukhopadhyay[3], S.G. Chowdhury[2]

[1]Institut für Werkstofftechnik, Universität Bremen, D-28359 Bremen, Germany
[2]National Metallurgical Laboratory, Jamshedpur-831 004, India
[3]Department of Metallurgical Engineering, Banaras Hindu University, Varanasi-221 005, India
Email: srivastava@iwt.uni-bremen.de OR vcsrivas@nmlindia.org

Introduction

The Al-Cu-Fe alloy system in the composition range of 58-70 at.% Al and 20-28 at.% Cu and 10-14 at.% Fe, containing stable quasicrystalline (QC) phases, has been extensively studied. However, no single phase icosahedral structure is obtainable in $Al_{62}Cu_{25.5}Fe_{12.5}$ (at.%) system without further heat treatments. The synthesis of a single phase bulk quasicrytsalline material is still a challenge.

In view of the above and to address the need of bulk single phase quasicrystal synthesis, spray forming process is envisaged here as an alternative route. The spray forming process combines two distinct but integral processes of melt disintegration, with high velocity inert gas jet, into a spray of micron size droplets and its subsequent deposition onto a substrate (fig. 1). The melt disintegration with high velocity gas jet gives rise to rapid solidification effect in the droplets. Therefore, the aim of the present work is to explore the spray forming route for the production of bulk and dense single-phase icosahedral quasicrystalline $Al_{62}Cu_{25.5}Fe_{12.5}$ alloy.

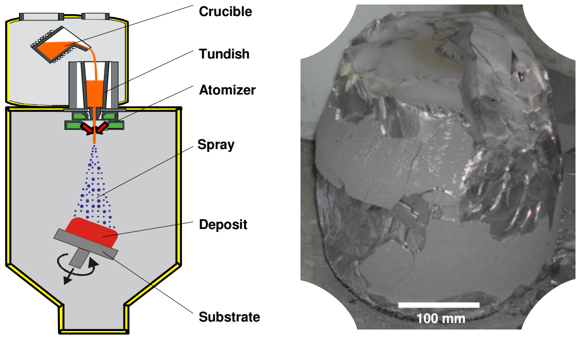

Fig. 1 : Spray forming process (left) and spray formed $Al_{62}Cu_{25.5}Fe_{12.5}$ billet (right)

Experimental Details

The spray casting experiment was carried out at the spray forming plant (SK-2) at the University of Bremen, Bremen, Germany. The elemental materials for the given composition were melted together in an induction furnace under argon atmosphere. The spray forming was carried out using the process parameters shown in Table 1.

The spray deposit as well as oversprayed powders were characterized in terms of x-ray diffraction, optical and scanning electron microscopy, hardness and crack length measurement etc.

Table 1: Spray forming parameters used for the processing

Composition	Melt flow rate (kg/h)	GMR*	Scan angle (°)	Scan frequency (Hz)	Pouring temperature (°C)	Substrate material	Deposition distance (mm)
$Al_{62}Cu_{25.5}Fe_{12.5}$	361	2.81	± 4	15	1176	Low C. Steel	430

*Gas to Melt mass flow ratio

Results and Discussion

The x-ray diffraction results are shown in fig. 2. The oversprayed powders, which experience high cooling rate compared to deposit, show strong peak of β-phase along with i-phase. Whereas, the spray deposited material shows single phase icosahedral quasicrystalline material. The x-ray patterns from five different locations (randomly chosen) of the deposit indicates single phase bulk characteristic of the billet.

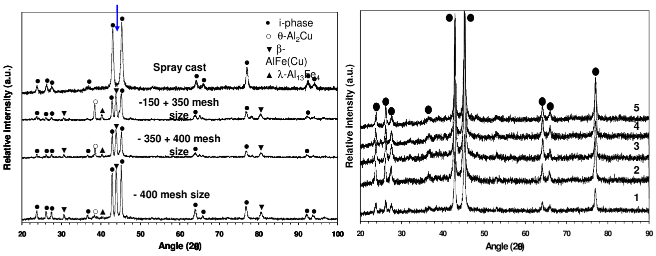

Fig. 2 : Comparison of x-ray patterns of oversprayed powders with deposit (left) x-ray patterns of randomly chosen samples (right)

The optical micrographs of the bulk deposit is shown in fig 3 (left). The average grains size is 10 μm. This show the refinement of grains as well as the single phase structure. The compositional homogeneity of the structure is observed by x-ray element mapping, as shown in fig. 3 (right). This also confirms the microscale homogeneity of the billet.

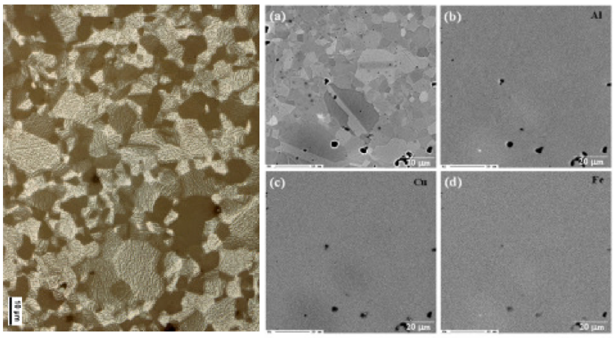

Fig. 3 : Optical micrographs (left) x-ray element mapping of Al, Cu and Fe (right)

Fig. 4 shows the hardness values measured at different loads and the fracture toughness calculated from the measurements of indentation crack legths. For the calculation of fracture toughness, following relationship has been used:

$$K_{IC} = 0.035 \cdot \Phi^{-\frac{3}{5}} \cdot H \cdot \left(\frac{H}{E}\right)^{-\frac{2}{5}} \cdot \left(\frac{d/2}{\sqrt{l}}\right)$$

Where l is the crack length, d is the indentation diagonal length, H is the hardness, E is the elastic modulus, is a constraint factor. The values of Φ and E has been taken to be as 3 and 167 GPa, respectively. The characteristics of the indentation cracks at two different loads are shown in fig. 5

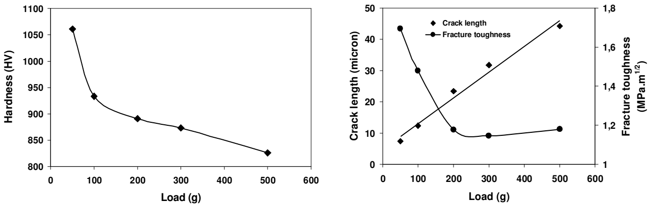

Fig. 4 : Variation in harness values (left) and crack length and fracture toughness(right)

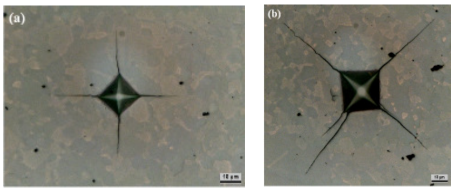

Fig. 5 : Indentation cracks at 200 g (left) and 500 g (right) loads

The bulk single phase icosahedral phase formation by spray forming is attributed to the unique mechanism of microstructural evolution during deposition leading to refined structural features and in-situ annealing of the deposited material at relatively high temperature during billet cooling.

Conclusions

A bulk single phase icosahedral quasicrystalline material, based on $Al_{62}Cu_{25.5}Fe_{12.5}$ alloy, could be successfully synthesized by spray casting route, in a single step. Although high cooling rate in atomized particles could not result in single i-phase, spray-cast deposit has given rise to single phase. The hardness and fracture toughness (8.7 GPa and 1.2 MPa.m1/2 at the load of 200g) values lie within the regime of already reported values for this alloy system.

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