Structural Properties of Levitated Liquid Aluminum-based Alloys

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Introduction

Transition-metal aluminides are a technologically important class of alloys that combine high strength and resistance to environmental attack at elevated temperatures with low weight and low material cost. Due to the complexity of the binary phase diagrams, there is an open question about the structure of the liquid phase, in particular, the possibility of existence of the intermetallic clusters in the liquid. A hybrid aerodynamic-electromagnetic levitator has been recently developed and successfully tested [1]. With this new device, it was possible to study the local structure of Al-based liquid alloys, including compositions with low melting points, which would not have been accessible with standard electromagnetic levitation techniques. Here we report on x-ray diffraction measurements of molten aluminium-transition metal alloys carried out on the ID15b beamline at ESRF (Grenoble, France).

Methods and Materials

The Al-4.22at%Fe; Al-7.5at%Fe; Al-0.5at%Ti; Al-1.0at%Ti; Al-2.7at%Ni (eutectic); Al-25at%Ni (Al_3Ni); Al-17at%Cu (eutectic); Al-33at%Cu (Al_2Cu) samples were prepared by arc melting in water-cooled Cu crucible under Ar atmosphere. Samples weighting approximately 25-40 mg (2.7-3 mm diameter spheres) were used for the experiments. The Al-Fe and Al-Ti samples were studied at room temperature by scanning electron microscopy (SEM) using backscattered electron (BSE) imaging together with quantitative chemical analysis using energy dispersive x-ray (EDX) spectroscopy. Measurements were performed using two accelerating voltages: 10 and 20kV.

Diffraction measurements were performed using the levitation chamber specially designed for the ID15b beamline [1]. The monochromatic beam of 88.54 keV (λ = 0.14 Å) was used. The detection system was the MAR 345 online image plate scanner (2300x2300 pixels, pixel size 0.15 μm), and the usable Q-range was 0.8 - 14 Å-1. The one-dimensional diffraction patterns were obtained by integrating the rings of the two-dimensional patterns using MATLAB© and FIT2D software packages.

Results

The average structure factors S(Q) have been determined for various temperatures and compositions in the stable liquid state. From S(Q), the pair correlation functions g(r), have been calculated. The first interatomic distance is nearly temperature-independent, whereas the first-shell coordination number decreases with increasing temperature for all the alloys investigated. On the other hand, the differences in S(Q) and g(r) between eutectic and intermetallic compositions, both for Al-Cu and Al-Ni, are remarkable (Fig. 1,2). Only the melts corresponding to the intermetallic compositions Al_2Cu and Al_3Ni, respectively, show a prepeak, indicative of medium-range order. For the Al-Fe alloys, room-temperature SEM studies show the formation of a microstructure, namely, the existence of $Al_{13}Fe_4$ inclusions in the Al matrix.

Discussion

The most prominent effect in the pair distribution functions of alloys is the shift of the maxima to smaller distances as compared to pure aluminium. For the same alloy, Al-Cu or Al-Ni, the nearest neighbour distance is smaller for the intermetallic composition, indicating a more compact structure. In contrary, the liquid Al-Fe and Al-Ti alloys appear to be homogeneous liquids. The microstructure formed in dilute Al-Fe alloys can play a crucial role in the high specific strength since intermetallic particles dispersed homogeneously through the Al matrix can enhance its strength by impeding dislocation motion.

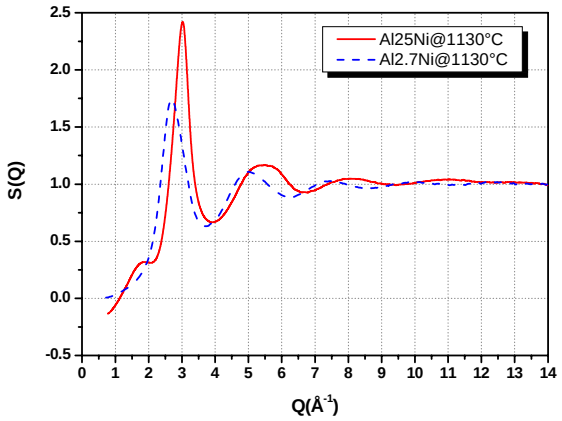

Fig. 1. Structure factor S(Q) for liquid Al-Ni at intermetallic and eutectic compositions.

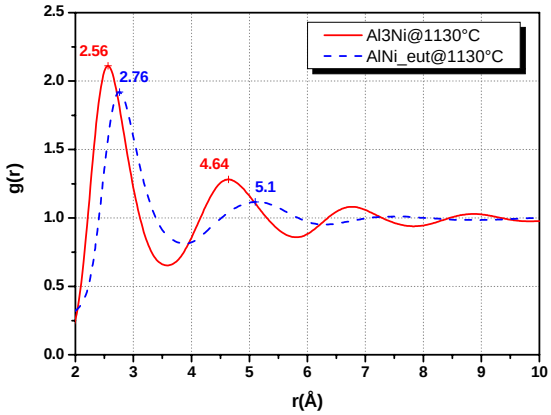

Fig. 2. Pair correlation function g(r) for liquid Al-Ni at intermetallic and eutectic compositions.

[1] G. Mathiak, I. Egry, L. Hennet, D. Thiaudière, I. Pozdnyakova, D. L. Price, Int. J. Thermophys. 26, 1151 (2005).