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Use of Time Resolved X-Ray Radiography to Measure Interdiffusion in Liquid Metals

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1. Introduction

Chemical diffusion (also named interdiffusion), originating from the fluctuations among different elements, is a common phenomenon in multicomponent liquid metals. The interdiffusion coefficients in liquid alloys control the liquid-solid transformation and are thus basic parameters for materials design from the melt. In this work, a novel X-ray radiography (XRR) technique (Fig.1) is developed to *in situ* measure interdiffusion in liquid alloys[1, 2]. With this *in-situ* method, we can accurately measure liquid diffusion coefficients directly in the liquid state without knowing the absolute diffusion time and without considering the solidification effect [2]. Particularly, XRR can also allow us to check for the buoyancy-driven convention effect in the liquid diffusion process. With this method, reliable interdiffusion data in Al-Cu and Al-Ni melts have been measured systematically [2, 3].

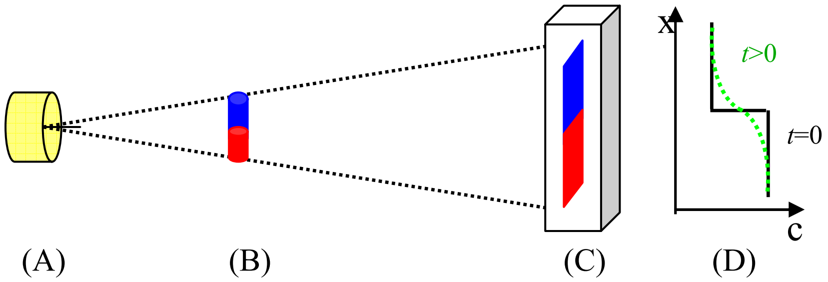

Fig.1: Sketch of the X-ray radiography measurement technique of diffusion in liquid alloys. (A), (B) and (C) show the X-ray source, diffusion couple and panel detector, respectively. (D) represents the concentration profile calculated from the image grayscale at times $t = 0$ (solid line) and $t > 0$ (dashed line).

2. Experimental

In each diffusion experiment, a diffusion couple (i.e., two diffusion rod samples with 1.5 mm in diameter and 15 mm in length) with about 5 at.-% composition difference is used (Fig.2). The diffusion couple was installed vertically inside a graphite tube furnace. Series of X-ray images (gray scale) of the diffusion couple covering from the heating, isothermal annealing and cooling processes are recorded by the XRR facility. Based on Beer's law the concentration profile of the diffusion couple in each image can be calculated from the corresponding X-ray intensity profile of the diffusion couple. An error function as a solution of the Fick's diffusion law was utilized to fit each

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concentration profile. Assuming that the diffusion coefficient is constant at a constant temperature, the diffusion coefficient can be derived from the slope of the time dependent penetration depth X^2 (= $4Dt$, as one of the error function fitting parameters, where D is the diffusion coefficient and t diffusion time) at the isothermal diffusion process [2]. Moreover, by checking the time resolved concentration profile and the linear relation of the time dependent X^2, the disturbance of the convective flow in the diffusion process can be examined [2,3].

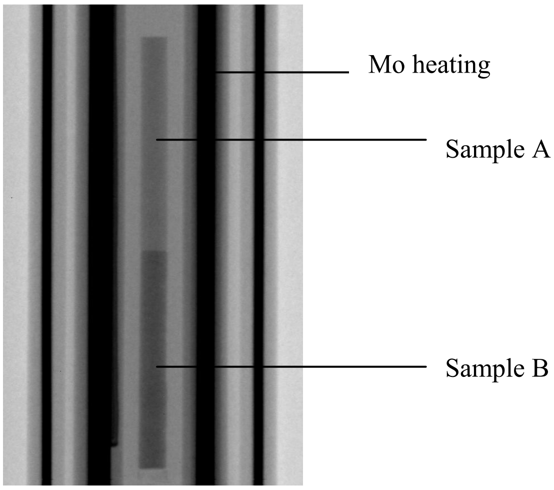

Fig.2 A typical X-ray image for the diffusion couple in solid state. Two diffusion samples (A and B) are installed inside a graphite tube, which is heated by Mo wires.

3. Conclusions

For the first time, interdiffusion efficients in liquid metals are directly measured in the liquid state. The relative error of the measured interdiffusion coefficients can be down to 10 %, which is much better than that (~ 50 %) of results measured by the *ex-situ* long capillary method [1]. No obvious convective effect was found in the diffusion process of Al-Cu and Al-Ni melts using the present diffusion device. Compared with the self-diffusion coefficients of Cu measured by quasielastic neutron scattering (QNS) [4], the measured interdiffusion coefficients are ~3 times as large as the self-diffusion coefficients of Cu in a similar composition of Al-Cu melt [3]. Furthermore, the calculated interdiffusion coefficient from the Darken equation using the QNS self-diffusion data is only a half of the measured value, which means that the diffusion mechanism in Al-Cu is more complicated than expected [3]. As a result, such an enhancement of interdiffusion should be taken into account when simulating the solidification process and solidified microstructure.

References

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