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# Damage Behavior of Micro Segregation in Al-Si Alloy by Use of Phase Contrast Imaging

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Some segregation in casting alloys are microstructural defects and degrade mechanical properties of the alloys. Therefore it is important to understand the influence of the distribution of segregation regions on fracture behavior. In this study, tensile test was carried out on an Al-Si cast alloy. Three-dimensional (3D) in-situ observation of its tensile fracture behavior was performed by means of the synchrotron X-ray computed tomography (CT) technique. Some segregation regions have similar density to that of the matrix. Phase retrieval processing, which is one of the phase contrast imaging techniques, enables us to distinguish such segregations based on X-ray CT tomographic images. Fracture path was identified by comparing unfractured and fractured 3D volumes. Grey values of each voxel in CT images correlate to the density of the material after the phase retrieval processing. Examining grey values of voxels on the extracted fracture path, it was found that fracture occurred preferably around the segregation part with high density.

***Keywords:*** *Segregation, Phase contrast imaging, Die-cast alloy, Micro tomography, In-situ study.*

## 1. Introduction

Casting alloys unlike other forged or milled alloys being heat treated, has large scattering in material properties[1]. Segregation is one of the major causes of this variation[2]. It is the deviation of the alloying elements in the material and forms very complex three-dimensional network[3]. Some segregation region region could present as defects in the material and degrade its mechanical properties. The objective of this study is to evaluate correlation of three-dimensionally distributed segregation region and the fracture behavior of an Al-Si casting alloy. In-situ observation of tensile fracture behavior was carried out by means of the synchrotron X-ray CT technique. Since the some segregation regions in the Al-Si cast alloy have similar density to that of the matrix, it is difficult to distinguish them in absorption contrast imaging. In this study, phase retrieval processing based on X-ray CT images, was employed to visualize the segregations distinctively from the matrix.

## 2. Experiment

### 2.1 Material

Al-Si casting alloy with a composition of Al-11.82%Si-2.35%Cu-0.81%Fe-0.18%Mn-0.17%Mg-0.06%Pb-0.04%Ni (mass %) was used in this study. A micro test piece for in-situ CT observation was cut by electrical discharge machining (EDM). Parallel section of the test piece had a prism shape with a cross section of 0.6×0.6mm2. Synchrotron X-ray CT imaging was performed at the undulator beam-line BL20XU of the SPring-8. In-situ observation during a tensile test was carried out at several strain levels as marked in Fig. 1. Phase contrast imaging was conducted at the third strain level just before the final fracture.

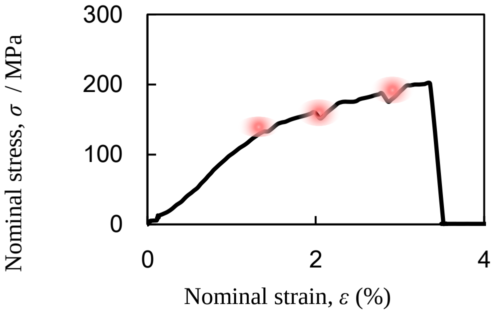

Fig. 1 Stress-strain curves in this tensile test

### 2.2 Phase retrieval processing

In order to visualize the segregation regions in the matrix, phase retrieval processing was applied in this study. It is based on Paganin’s formula shown in Eq. (1). Details of this method is described somewhere else[5];

$$\varphi(x,\ y) = \frac{1}{2} ln\left[F^{-1}\left\{\frac{F(I(x,\ y))/I_0(x,\ y)}{\beta/\delta+[\lambda L/4\pi](v^2+u^2)}\right\}\right] \qquad (1)$$

where I and $I_0$ are the intensity of transmitted and incident X-ray, respectively. λ is the wavelength and L is a camera length. δ and β are the real and the imaginary part of the complex refractive index of refraction of the X–ray, respectively. Δδ is the difference between the refractive indices of the two phases; in this study the matrix and the segregations. However, Δδ is related with the difference in densities of the two phases. Since there is scatter in the densities of the segregations in this material, Δδ was to be investigated.

## 3. Results and Disccusion

Figures 2(a) and (b) show the virtual cross sections of absorption and phase contrast images before no-loading. As seen in Fig. 2(b), difference in contrast was emphasized in the phase contrast image. The material with high density looks brighter in phase contrast images. In this material, the segregations contain heavier elements such as Cu or Fe than the matrix phase of Aluminum and look brighter in these images.

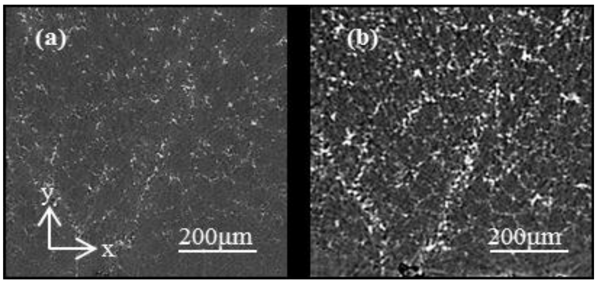

Fig. 2 (a) Absorption contrast image (b) Phase contrast image

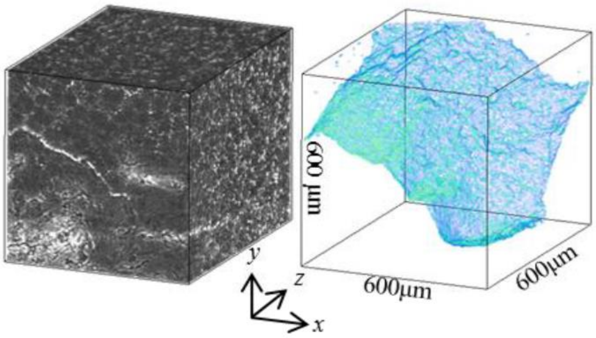

Fig. 3 (a) 3D volume and (b) extracted voxels around fracture path

Figure 3(a) shows the 3D volume observed just before the final fracture. Voxels surrounding fracture path were extracted from this volume as shown in Fig. 3(b). In Fig. 3(b), the voxels with grey values of higher part were colored in green and those with lower grey values in blue. It can be seen that most part of the fracture occurred around the high density part because of segregation. Moreover, the crack is developed complicatedly in 3D. This can be attributed to the segregation existed in this material. Figure 4 shows the grey value histogram of the voxels surrounding the fracture path (Fig. 3(b)) together with that of the full volume (Fig. 3(a)).

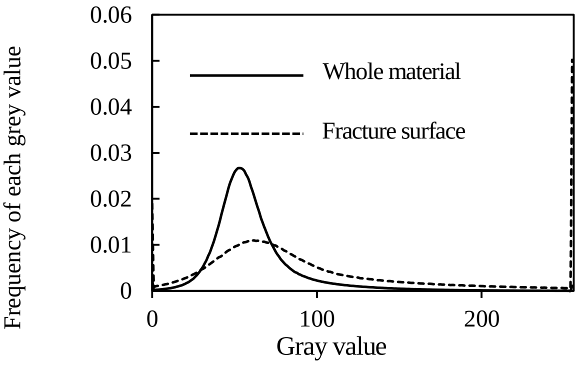

Fig. 4 histogram of grey value

It can be seen in Fig. 4 that the peak of the histogram of extracted voxels around the fracture surface was shifted to the right; i.e. they tend to have higher grey values than the whole material. From the observation results by means of phase and absorption contrast imaging technique together with X-ray CT images described above, it was found that the fractured area had higher grey values than that of the whole matrix. It suggests that fracture occurred preferably around the segregation region with high density in the Al-Si casting alloy.

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