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Fractal dimension of grain boundary in CuAu alloys refined by platinum addition

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Irregularity of the grain boundaries in CuAu alloys refined by platinum addition was estimated by fractal analysis. The fractal dimension increased with decreasing the grain size, which introduced by platinum addition. The grain refinement produced more complexity in microstructure.

1. Introduction

The study of morphology gives us many interesting and realistic informations. Various techniques such as microscopes and X-ray facilities have been employed for inspecting the shapes and forms in natural science. Mandelbrot [1] introduced the concept of fractal dimension for the quantitative analysis in morphology. This method was welcomed in many fields, namely, biology [2], medicine [3, 4], engineering [5], economics [6] and so on. Fractal analysis has yielded very useful results.

It is well known that addition of platinum group elements to an alloy is effective is refining the grain size, resulting in hardening. Although many researchers have been interested in the morphology of grain boundaries in terms of size, there is little information on the complexity or ruggedness themselves. Recently, self-similarity was observed in a wide range of magnification for highly deformed grain boundaries. Hornbogen in Cu–Zn–Al alloy [7], Nishihara [8] and Tanaka [9] in pure iron have reported that the fractal dimension of grain boundaries increased in the value of $1 < D < 2$ with the amount of plastic deformation.

The purpose of the present work is to make a quantitative estimation on the grain boundaries of CuAu alloys refined by platinum addition using a fractal analysis.

2. Materials and methods

$(CuAu)_{1-X}Pt_X$ alloys were prepared by melting pure metals in an induction furnace. The specimens were homogenized by repeated cold-working and annealing at 1073 K. The chemical compositions of these alloys are shown in Table I. Although the composition of equiatomic CuAu alloy was not analysed chemically, the lattice parameter estimated by X-ray diffraction has already proved the composition [10, 11]. The alloys were solution-treated at 1073 K for 3.6 ks followed by ice brine quench to obtain a single phase with face-centred cubic lattice. Then, the specimens were polished using a standard metallographic technique and finally etched by a freshly prepared aqueous solution of 20% potassium cyanide and 20% ammonium persulphate. The microstructures were observed with an optical microscope (OM). Fractal dimension was obtained by the box-counting method [12] on the OM images (100 × 100 mm) with a magnification of 1000×. The box size was in a range of 2–10 mm (2–10 μm). Complexities of the grain boundary were quantitatively estimated by fractal dimension.

3. Results and discussion

Fig. 1 shows optical microstructures of the specimens solution-treated at 1073 K and quenched. It is obvious that addition of platinum to the equiatomic CuAu alloy produced remarkable grain refinement. Each grain size was determined by a linear analysis, as shown in Table I. It is noticed that the grain size decreases with increasing amount of platinum. The platinum addition reduced the average grain size from 39.5 to 9.5 μm.

Fig. 2 shows box-counting plots for $(CuAu)_{1-X}Pt_X$ alloys. Straight lines were obtained and the fractal analysis is possible. It is noticed that the slope becomes larger with increasing the amount of platinum addition. The fractal dimension could be calculated from each slope using a least-square method. Variation of the fractal dimension with platinum content of the alloys is shown by sold circle with standard deviation in Fig. 3. Larger standard deviation may suggest that each alloy has considerable scatter in grain size. The fractal dimension increases remarkably till about 1 mol % Pt, followed by slow one. One has to take account of effect of grain size on the fractal dimension, because Nishihara [8] reported that the dimension increases with decreasing the grain size. Therefore, it is considered that the fractal dimensions in Fig. 3 are influenced by the grain size. In order to substitute the effect of grain size itself, we estimated the fractal dimension of the specimens with different grain size and self-similarity using standard grain size patterns, as shown in Fig. 4. The fractal dimensions obtained are plotted by open circles in Fig. 5 with the data for the grain boundary by solid circles. The variation of fractal dimension obtained from the standard patterns is small comparing

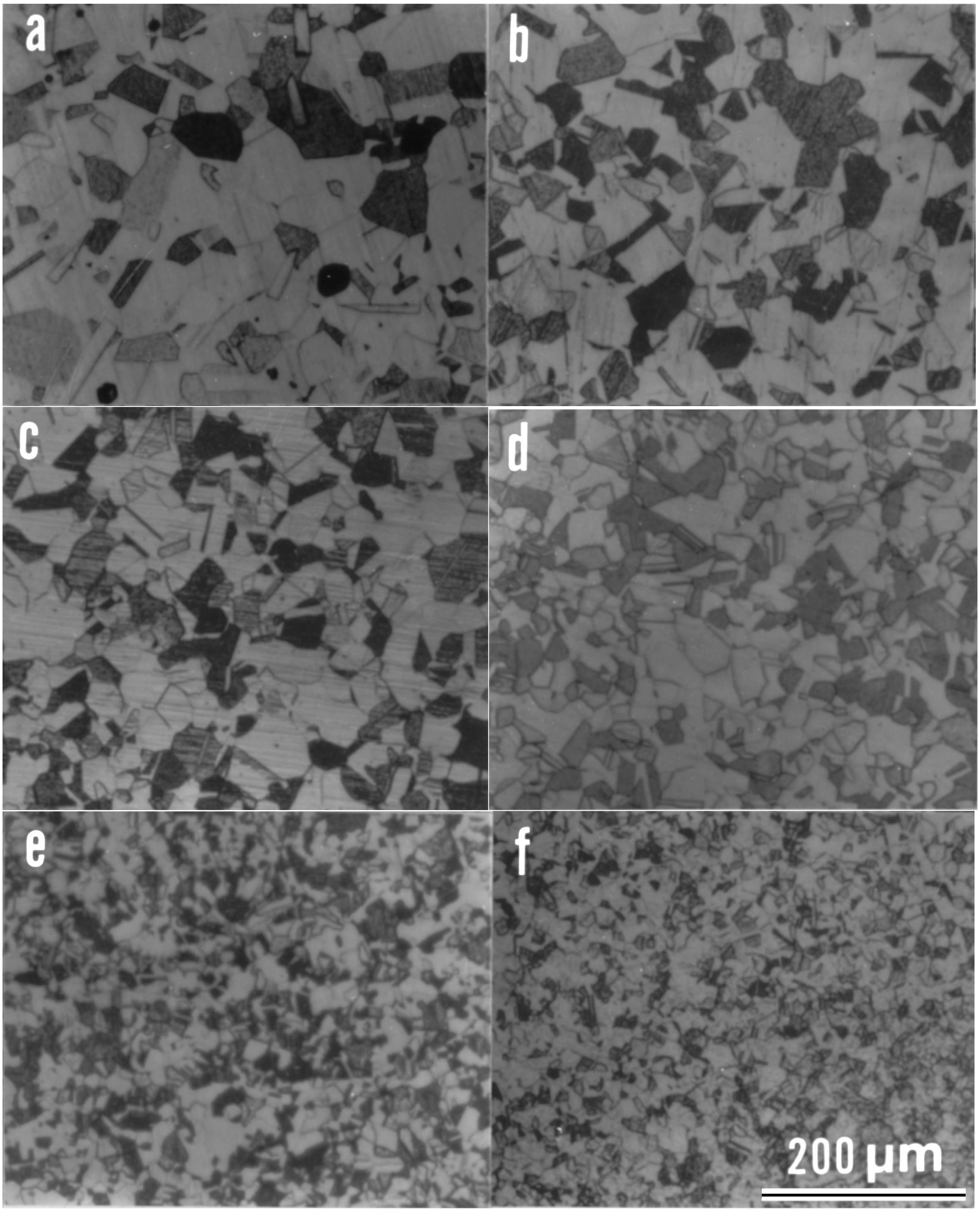

Figure 1 Optical microstructures of: (a) CuAu; (b) CuAu–0.26 mol %Pt; (c) CuAu–0.76 mol %Pt; (d) CuAu–0.97 mol %Pt; (e) CuAu–2.48 mol %Pt; (f) CuAu–6.92 mol %Pt annealed at 1073 K for 3.6 ks followed by ice brine quench.

TABLE I Chemical composition (mol %) and average grain size (μm) of ternary alloys used

Alloy no.	Cu	Au	Pt	Grain size (SD)
1	50.0	50.0	0	39.5 (7.3)
2	49.89	49.85	0.26	36.8 (3.2)
3	49.73	49.76	0.51	26.3 (3.4)
4	49.60	49.64	0.76	25.7 (2.5)
5	49.56	49.47	0.97	22.8 (3.4)
6	48.67	48.85	2.48	13.7 (2.4)
7	46.58	46.50	6.92	9.5 (1.3)

to those of $(CuAu)_{1-X}Pt_X$ alloys. Furthermore, it is noticed that the standard deviations are small because of better similarregularity. Fig. 6 shows variation of the fractal dimension with the grain size. Solid and open circles indicate the fractal dimensions of $(CuAu)_{1-X}Pt_X$ alloys and the standard patterns, respectively. The differences between both data in Fig. 6 suggest the physical meaning of the true fractal dimension which was reflected on the grain boundaries by the refinement of platinum addition. Unfortunately, we cannot estimate precise fractal dimension for only the refinement

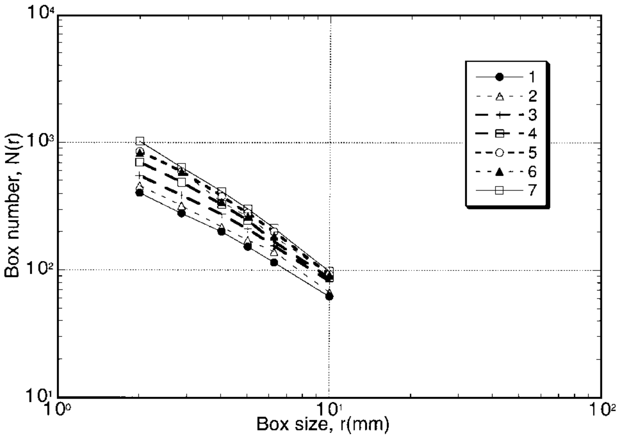

Figure 2 Box-counting plots for $(CuAu)_{1-X}Pt_X$ alloys.

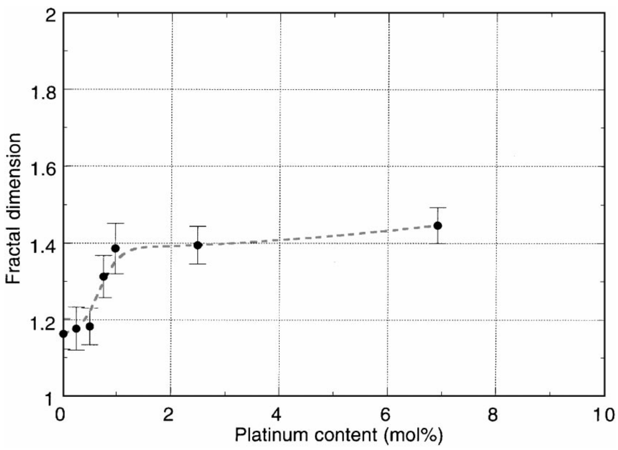

Figure 3 Variation of the fractal dimensions with platinum addition in CuAu alloy.

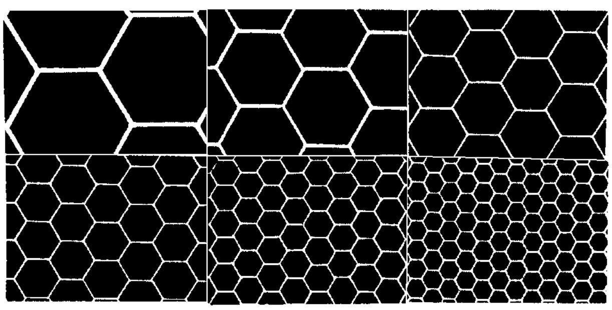

Figure 4 Standard patterns of the grain boundary with different size.

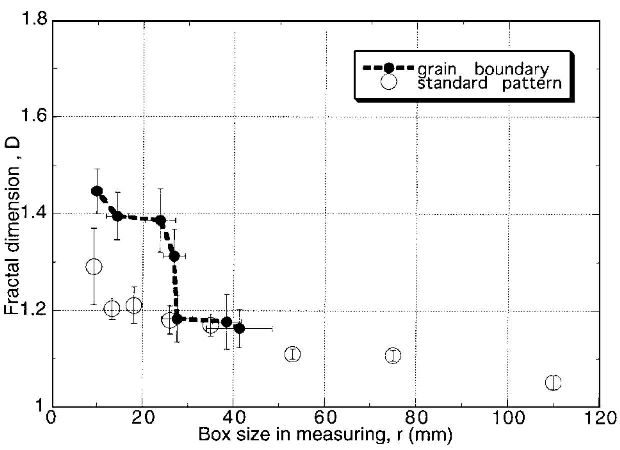

Figure 5 Variations of the fractal dimension with box scale used.

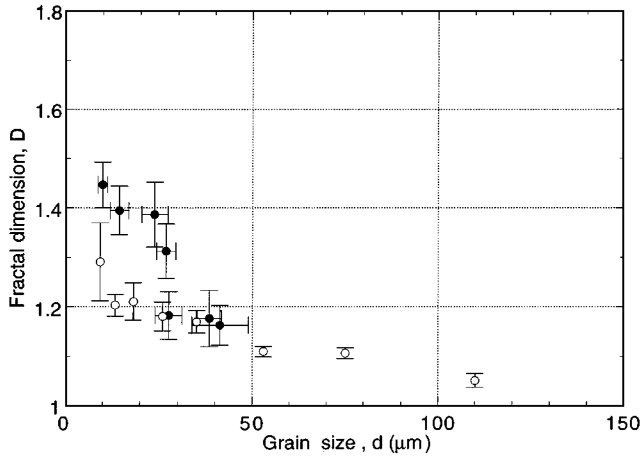

Figure 6 Variation of the fractal dimension with grain size.

at present. It is obvious that the fractal dimension increases with decreasing the grain size. According to Hornbogen [13], increase in fractal dimension D value proves that the microstructure contains more irregularity. In fact, grain refinement by platinum addition to CuAu alloy produces more complexity in microstructure. The complexity of the grain boundaries in the alloys refined by platinum addition may produce the hardening. To get a direct evidence of the complexity in grain boundary morphology, transmission electron microscopic observations are demanded.

4. Conclusions

A fractal analysis using the box-counting method was performed in the optical microstructures of the CuAu alloys refined by platinum addition. The fractal dimension increased with decreasing the grain size. It was revealed that the grain refinement produced more complexity in microstructure.

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