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Fractal Analysis of the Pores in Annealed Al-V_2O_5 Mechanically Alloyed Composite

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Abstract: Fractal analysis was used to observe the size, shape and distribution of pores in Al-V_2O_5 mechanically alloyed composite. The analysis reveals that the pores are of irregular shapes, i.e shrinkage pores, with sphericity $\beta < 0.3$.The "worst" of the shapes is the pore with β = 1.0254e-009 and D = 1.8541, while the "best" shape is the pore with β = 4.8309e-004 and D = 1.6521. Also, the graph of β against D shows that as β decreases the D values increases. This is in agreement with the theoretical background.

Key words: Fractal analysis, microstructures, composites, fractal dimension, pores

INTRODUCTION

The use of fractals to study surfaces of different materials has been done by different researchers and it is still receiving increasing attention. Scientists who study or try to describe natural phenomena have to consider the use of fractal geometry. From the theory of chaos to land surface description, from sea surface synthesis to stock market analysis, fractal concepts are used in more and more research field (Giuseppe *et al*., 2006). Chung-Kung (1998) used the fractal analysis and observed the effect of heat treatment on the well measured nitrogen isotherms on alumina and aluminum borate samples. He observed that heat treatment, for the two methods used may decrease fractal dimension, D, of the four examined porous samples. From analysis carried out, fractured surfaces were discovered to be fractal in nature (Alexander, 1990).

For alloys and composite materials containing regular microstructures a prediction of mechanical properties can be made by a quantitative measurement of features such as grain size, particle sizes and spacing etc. This however, is not the case where an irregular microstructure is involved because of the difficulty in a numerical characterization of the structure. For each microstructure, the application of fractal geometry offers a method by which both the individual particle shapes and the mode of the distribution of the particles can be fully described in a numerical manner (Shu-Zu and Hellawell, 1994).

The measurement of the porosity in aluminum cast alloys using fractal analysis was done by Huang and Lu (2002). They found that fractal analysis can be applied to the porosity measurement to describe the shapes of the pores in the aluminum silicon cast alloys using two dimensionless parameters, roughness, D and sphericity, β. They further observed that the tensile strength of the samples is related to the shapes of the pores in the microstructure. The higher the sphericity, β, the higher the tensile strength.

Blaz *et al*. (2004) while working on Al-V_2O_5 Mechanically Alloyed (MA) composite (Fig. 1) observed that intermetallic grains coarsening and increased porosity of long aged samples result in a reduction of the metallic hardness.

This research is an improvement on the work done by (Blaz *et al*., 2004). The intention is to use fractal analysis to numerically characterize the shape, size and the distribution of the pores formed in the microstructure of mechanically alloyed Al-V_2O_5 composite initially subjected to heat treatment method of annealing at 873K for 6 h.

MATERIALS AND METHODS

Fractal geometry was developed (Mandelbort, 1983) about two decades ago. Its principle is universal in any measurement and has been previously used to numerically describe complex microstructures including graphite flakes and nodules (Lu and Hellewell, 1994, 1995, 1999). The mathematical basis for measuring chaotic objects with the power law modified shall be adopted in this research. The basic equation is as follows:

$$P = P_E \delta^{D-1} \ldots\ldots (1 < D < 2 \text{ and } \delta_m < \delta < \delta_M) \qquad (1)$$

Where P_E is the measured perimeter, P is the true perimeter, δ is the yardstick, δ_m and δ_M are upper and lower limits respectively, for any shape and D is defined as the fractal dimension ($1 < D < 2$). From the above

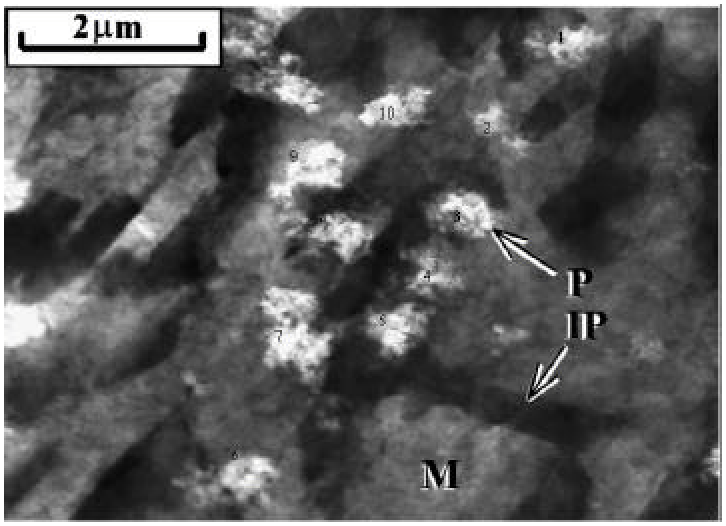

Fig. 1: Structure of Al-V_2O_5 MA composite annealed at 873 K/6 h (STEM) (P: Pores; IP: Intermetallic Particle; M: Matrix)

expression, it can be deduced that the true perimeter is actually a function of the yardstick for measurement. The smaller the yardstick used, the more accurate the measurement. This study intends to use the average of four different yardsticks for better accuracy.

The fractal dimension, D, therefore describes, the complexity of the contour of an object. It can be more practically called the roughness (Huang and Lu, 2002).

When $\delta < \delta_m$, the measurement is not sensitive to the yardstick chosen, therefore giving a smaller value of the slope, while $\delta > \delta_M$, the size of the yardstick exceeds that of the individual feature being measured so that the measurement loses meaning because the object falls below the resolution limit of the yardstick used for measurement (Lu and Hellawell, 1994).

Sphericity, β, another dimensionless number, is used together with roughness, D, to describe the shape of the pores formed. It can be expressed as

$$\beta = 4\pi A_T/P^2 \quad (0<\beta<1 \quad \text{and} \quad 1<D<2) \qquad (2)$$

Substituting Eq. (1) in (2) gives

$$\beta = \left(4\pi A_T/P_c^2\right)\delta^{2(1-D)} \quad (0<\beta<1 \quad \text{and} \quad 1<D<2) \qquad (3)$$

Where A_T is the total pore area. When β = 1 and D = 1, a perfect circular shape is formed by the pore in the microstructure. For shrinkage pore β<0.3 and for gaseous pores β>0.3. As β decreases, the shapes become more elongated showing a departure from perfect sphere (Huang and Lu, 2003).

The locations of 1 < D < 2 represents less regular shapes.

It was also discovered that the larger the roughness, the more irregular a pore and thus more stress concentration.

Area of a pixel or yardstick = L× B

Area of the total pore A_T = Area of yardstick×Number of yardsticks

To calculate the perimeter P of the pore, the Slit Island Method (SIM) (Bigeralle and Lost, 2006) introduced (Mandelbort, 1983) was used. It is expressed as:

$$\log_e P = 0.5 D \log_e A_T \qquad (4)$$

$$P = e^{0.5D\log_e A_T} \qquad (5)$$

Using the Eq. (1), (2) and (5) above, an interactive software in Matlab programming language is developed to obtain the numerical values of the fractal dimension D and the sphericity β for the microstructures Fig.1.

RESULTS AND DISCUSSION

The extrusion of the mechanically alloyed composite to produce rods gives a microstructure as shown in Fig.1. Some large oxide particles remains, ~300 nm in size, which are accompanied by large number of very fine V-rich particles refined by milling process. Fine Vanadium oxide particles of 0.6±0.5µm in size are uniformly distributed within the Al-matrix. Cavities are not observed within the area tested and highly recovered Aluminium grains within the matrix are 0.18±0.07µm in size (Blaz *et al.*, 2004).

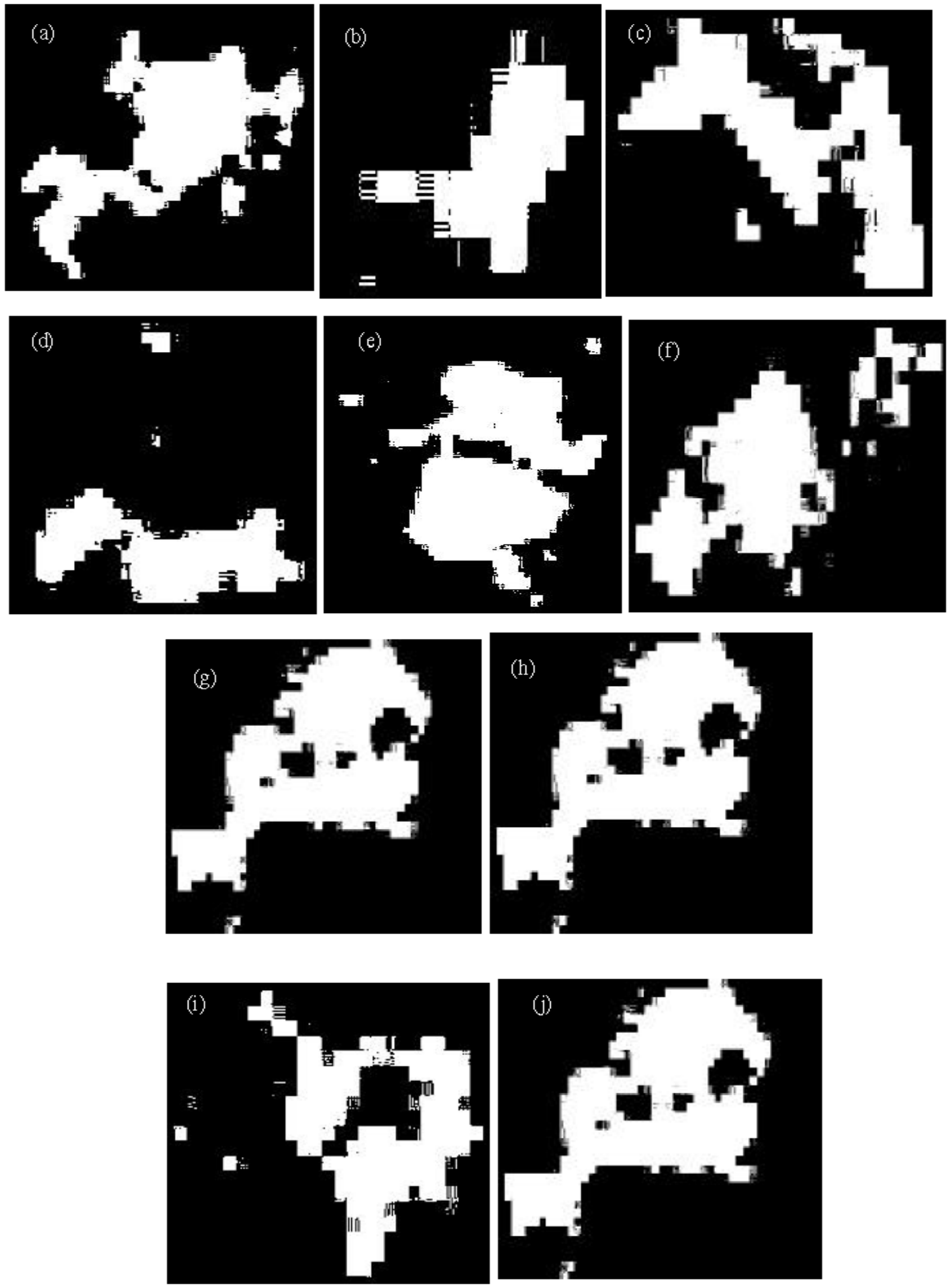

Fig. 2: Graph of sphericity against fractal dimention

Cavity growth and coarsening of new intermetallic grains is observed for samples annealed at 873K for 6h revealing intermetallic grains of 1±0.4 μm in length and 0.3±0.08 μm in width are observed in the structure Fig. 2. The pores are of different sizes and shapes and their distribution are as shown in Fig 3.

Fractal analysis reveals that the pores are of irregular shapes, i.e shrinkage pores, with β approaching zero and the fractal dimension D approaching 2.0 (note: For a perfect sphere $\beta = 1$ and $D = 1$ where $0 < \beta < 1$ and $1 < D < 2$. For shrinkage pore, $\beta < 0.3$ and for gaseous pores, $\beta > 0.3$ (Huang and Lu, 2002).

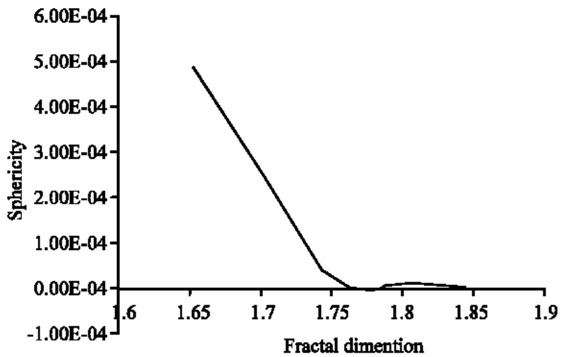

Fig. 3: Isolation of the pores 1-10 in the microstructure

Table 1: Measured result for view field in Fig. 1

D	β
1.7450	3.6585e-005
1.7103	2.0611e-004
1.7872	8.6501e-006
1.6521	4.8309e-004
1.8129	1.1118e-005
1.7413	5.2065e-005
1.7855	5.5648e-009
1.7641	1.3835e-008
1.8541	1.0254e-009
1.7828	5.5154e-009

The "worst" of the shapes is the pore with β = 1.0254e-009 and D = 1.8541, while the "best" shape is the pore with β = 4.8309e-004 and D = 1.6521. Also the Fig. 3. shows that as the sphericity β decreases the fractal dimension D increases Table 1. This is in agreement with the theoretical background Eq. (3).

CONCLUSION

- Annealing of the composite was found to result in the intermetallic grains growth and an increase of the material porosity due to chemical reaction between components.
- The resulting pores, in the microstructure of Al-V_2O_5 mechanically alloyed composite annealed at 873K for 6hrs, are shrinkage pores.
- The "worst" pore is characterized by β = 1.0254e-009 and D = 1.8541, while the "best" pore is characterized by β = 4.8309e-004 and D = 1.6521.
- Also, the graph of β against D shows that as β decreases the D values increases. This is in agreement with the theoretical background.

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