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FRACTAL RESEARCH APPROACH ON THE FRACTURE SEM IMAGE OF Ti_2AlC/TiAl COMPOUND MATERIALS

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Abstract. The Ti_2AlC/TiAl compound materials have the finer mechanics performance under the normal temperature compared to the TiAl alloy. The author will use the computer simulation to establish the model. The article explores that the fracture theory is used to deal with the interface topography's SEM image of the materials' heat treatment process. At last through the linear regression analysis, the curve fitting equation is obtained. The results show that the quantitative relationship between the fractal dimensions and the heating temperature, as well as the quantitative relationship between different heat treatment ways and bending strength, fracture toughness. This research indicates that the SEM images of Ti_2AlC/TiAl materials with different temperature in rapid heating heat treatment have different fractal dimension. The fractal dimension of the fracture images of the samples with element B decreases with the increase of the fracture toughness. While that of the samples without element B shows the characteristics of brittle materials, namely, the fracture toughness increases with the increase of the fractal dimension.

1. INTRODUCTION

Conventional TiAl alloys are enjoying significant engineering importance and applications in the aerospace industry [1]. Their use is justice by their increased properties compared with traditional materials, such as iron and nickel-based super alloys [1]. TiAl compound materials are important classes of titanium alloys for the aerospace and automobile industries. Titanium aluminum compound materials are classified as either alpha TiAl or gamma TiAl-based alloys according to their microstructure [2-4].

At present, the application of γ-TiAl alloys is limited by their poor ductility at low to intermediate temperatures. This shortage of γ-TiAl alloys leads to the reduced fracture toughness, bending strength, thermal shock property, and ultimately, a shorter working life [5-7].

Recently, much effort have been made to improve the ductility of γ-TiAl composites, through the addition of alloying elements and the novel processing procedures, which have met with limited success. Single-phase alloys usually contain a third alloying element such as Nb, B, and Ni. It is found that the presence of B in single-phase gamma alloys gives the increased strength and the enhanced oxidation resistance [8]. It have proved that, the simultaneously joined Nb and Cr could enhance the TiAl alloy toughness effectively [9]; When the B is contained at 0.8 wt.%, the cast structure is refinement remarkable; Mei *et al.* synthesized the TiAl/Ti2AlC compound materials through the electric discharge plasma sintering process (SPS) method [10], when the TiAl/Ti_2AlC composites available contain 7% TiC(vol) the maximum bending strength reached 900MPa. More and more articles of TiAl alloy are published, but the research in Ti_2AlC/TiAl compound materials is neglected [11-13].

With the materials science development, more and more methods have been developed to research

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the mechanical properties. In all of these methods, the computer simulation has become one of the most important components of saluting the practical problems in materials science [13].

In this work, we tried to carry out computer simulation to confirm our further conclusion on the mechanical properties of the Ti_2AlC/TiAl composites. Based on the fractal theory [14], a set of models has been successfully built to explore the reasonable relationship between the structure and mechanical behavior of the Ti_2AlC/TiAl composites. To the best of our knowledge, there are few reports about the simulation of mechanical properties of composite materials via the fractal theory. Based on our research, more Macro mechanical properties can be obtained though the analysis of the SEM images of Ti_2AlC/TiAl samples.

2. EXPERIMENTAL

The compound materials samples (TB1, TB2, TB3, and TB4) were prepared as follows: powder Ti (size < 50 μm), powder Al (size < 45 μm) , powder Nb (average size for 18 μm), powder B (average size for 5 μm), and powder TiC (average size for 0.8 μm) were weighed in stoichiometric ratio. Ti-48.30Al-2.25Nb and Ti-47.66Al-2.22-Nb-1.34B were synthesized through thermal explosion reaction, then the obtained composites and 7 vol.% TiC were grounded and milling-mixed thoroughly, and the Ti_2AlC/Ti-48.30Al-2.25Nb and Ti_2AlC/Ti-47.66Al-2.22Nb-1.34B are synthesized through in situ reaction with SPS-1050 sintering furnace (Sumitomo Company of Japan).

The prepared TB1 was heated with room temperature to 1323K and calcined for 24 h in the oven, and then cooled to room temperature. The prepared TB2 was firstly treated by the same procedures with Sample 1.then heated to 1523K, calcined for 24 h in the oven, and cooled to room temperature; at last it was heated to 1123K, calcined for 24 h in the oven, and cooled to room temperature. The prepared sample TB3 were firstly treated by the same procedures with Sample 1, too, and then it was heated to 1593K, calcined for 45 min in the oven, and cooled to room temperature, at last heated to 1173K, calcined for 6 h, and cooled to room temperature. The prepared sample TB4 were firstly treated by the same procedures with T1 and TB1, too, then heated to 1663K, calcined for 5 min in the oven, and cooled to room temperature, at last heated to 1173K, calcined for 6 h, cooled to room temperature.

3. COMPUTATIONAL

The MATLAB can analyze the fine structure in handing of the chaotic phenomenon in virtue of the similar principle [15]. It has been widely applied in the quantitative investigation and the analysis of material surface characteristic [15].

The fractal dimension is the quantitative characteristic of fractal theory. The definition of the fractal dimension comes from the Hausdorff dimension definition. The most commonly used method is box counting, compared with other methods such as variance method and structure function method. Box of dimension is also called the Kolmogorov entropy [16]. Because of the easy mathematical computation and the experience estimates, it is applied widespread in computer simulation. In this work, we design computational procedures to calculate the fractal dimension via the box-counting dimension.

The definition of the box-counting is that assumed that F expresses the random, bounded and non-null subset of R^n. Limit is the request of fractal dimension. The formula is

$$Dim_B F = \lim_{x \to 0} \frac{\log N_\delta(F)}{-\log \delta}. \quad (1)$$

In order to calculate the box dimension of plane aggregate F, square of lengths of d is conformant. Then we will count the intersect number between F and different box.

In the MATLAB program, such works as follows have been carried out. Calculated by the fractal dimension with box-counting, the concerned region of the image is also needed to be extracted. The image is treated in turns to discrete cosine transform, histogram enhancement (histogram equalization), wiener filter, image threshold segmentation, edge detection and edge extraction. Then the discussed SEM images have been transformed into 256´256 binary images successfully.

The author discovers that the initial side length of fractal box is 1, pixel value is 256, and then the box is established. Halve the box successively, then the box is divided into 4n little boxes.. When the pixel value turned to 1 (because $2^8 = 256$), the image can only halve 8 times. When $n = 1$, $\delta = 0.5$, box is divided into other four little boxes, and each box will be judged to whether the matrix is 0; if the matrix is null matrix, then the matrix is recorded 0; if not, it is recorded 1, at last the number of 1 will be statisticalized and summed, next the number to the formula will be gained. When n = 2, 3, 4….8, we

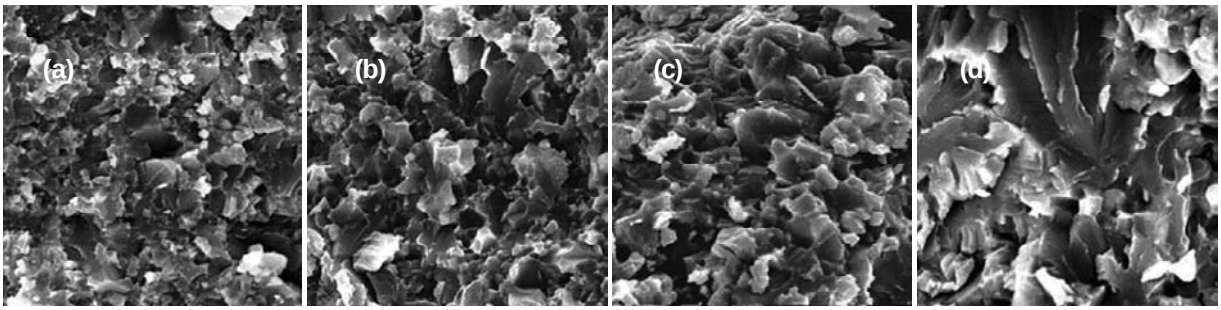


Fig. 1. SEM images of TB1 (a), SEM images of TB2 (b), SEM images of TB3(c), and SEM images of TB4 (d).

Table 1. The bending strength and the fracture toughness of the compound materials (TB1, TB2, TB3, and TB4).

Sample	TB1	TB2	TB3	TB4
Bending strength /MPa	882.29	869.66	889.21	957.91
Fracture toughness /MPa·m$^{1/2}$	19.61	19.45	19.89	20.73

Table 2. The fractal dimension of the compound materials (TB1, TB2, TB3, and TB4).

Sample	TB1	TB2	TB3	TB4
BW	1.8595	1.8551	1.8485	1.8433

can get different *D*. Then *D* is put into the formulation.

4. RESULTS AND DISCUSSION

Through the work mentioned above, we have obtained the SEM images (Fig. 1) of the four samples (TB1, TB2, TB3, and TB4).

For TB1 and TB2, the mixed mode of intergranular fracture and transgranular fracture could be observed obviously, while in the SEM image of TB3 and TB4, only transgranular cleavage fracture could be found. For compensating the deformation work of formation new surface and the plastic deformation in material fracture, the crack is inhibited extending along the main cleavage plane [17].

We test the fracture toughness and bending strength, and the results were shown in Table 1. From Table 1, we could find that the bending strength of TB4 is larger than that of TB3; meanwhile, the bending strength of TB3 is larger than that of TB1. The bending strength of TB2 is the smallest one among them. The fracture toughness also follows this role.

The obtained bi-logarithm coordinates of δ and *D* of fracture dimension were displayed in Fig. 2. From Fig. 2, we also found that when the box is divided smally, the value of N would increase correspondingly. However, the slope of the curve, which means the fracture dimension of the samples, has become smaller.

From Fig. 2 we could discover that the fractal dimension keeping constant with the lager mesh is used. The differences of the fractal dimension of different samples could be observed obviously, with the smaller mesh used, which shows that the smaller fractal is meshed and the finer fractal dimension is obtained.

We count the fracture dimension of the fracture with above-mentioned formula. The results were summarized in the Table 2. From Table 2, we could find that different fractal dimension was obtained with different ways of heat treatment. For the convenience of further research, the relationship of the fracture toughness, bending strength and the fractal dimension is established (Fig. 3).

As we know, transgranular fracture presents to not only ductility but also brittle, which mainly depends on the ability of the plastic deformation and the external environmental conditions of the crystal material itself. Ace-centered cubic Al-based alloys have good ductility, the occurrence of plastic deformation make the top cracks passive, the stress

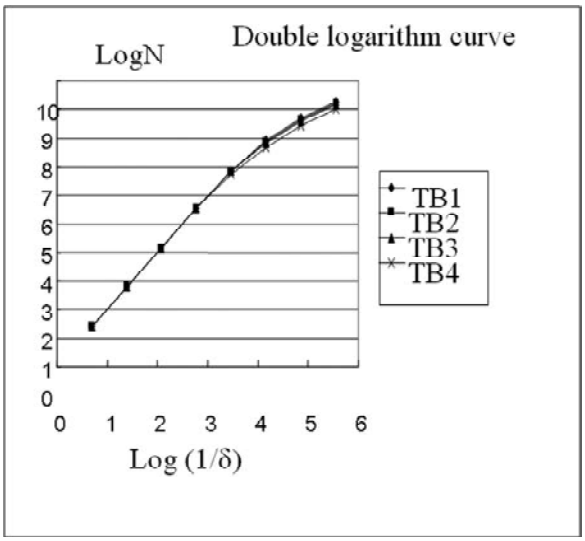


Fig. 2. Relationship between log (1/δ) and log*N.*

concentration decreased, thus crack propagation result in fracture.

In Fig.3, similar trend of the relationship of the fractal dimensions and the bending strength, fracture toughness was observed. Actually we can understand different heat treatment would cause different internal structure, and then the fractal dimension would also be changed.

For the plastic material, the smaller the fracture toughness is, the larger the Fractal dimension of the fracture would be obtained. Fracture toughness of the materials become larger with the increase of the fractal dimension of the fracture for brittle materials. The fractal dimension of TB3 and TB4 decreases with the increment of the fracture toughness, which was in good accordance with the characteristics of plastic materials. While TB1 and TB2 show the characteristics of brittle materials, namely, the fracture toughness increases with the increase of the fractal dimension.

Based on the results discussed above, we obtained a quality relationship of the fracture toughness, bending strength and the fractal dimension. Via the curve fitting of least square method in Matlab package, two equations were fitted successfully, and the results were shown as below.

$$Bs = \left(0.718Fd^2 - 2.663Fd + 2.4702\right) \times 10^6, \quad (2)$$

$$Ft = \left(0.863Fd^2 - 3.2027Fd + 2.9731\right) \times 10^4, \quad (3)$$

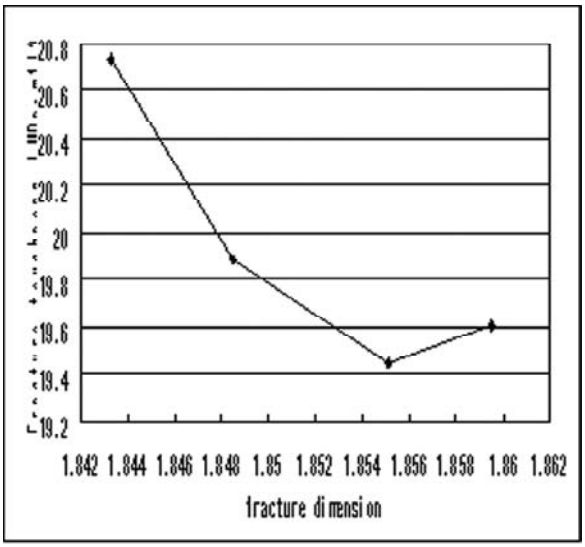
where *Bs* - Bending strength/MPa, *Ft* - Fracture toughness/MPa·$m^{1/2}$, *Fd* - fracture dimension.

5. CONCLUSIONS

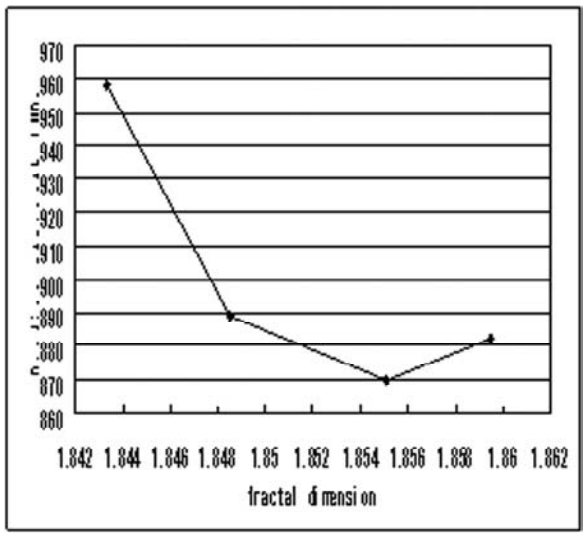
(1) For different Ti_2AlC composite materials with different treatment, different fractal dimension of the fracture images would be obtained from their SEM images.

(2) The Ti_2AlC composite materials show the characteristics of ductility at high temperatures with heat treatment.

(3) A quality relationship has been obtained between the fractal dimension and fracture toughness, bending strength with multi-step heat treatment.



(b)



(a)

Fig. 3. Relationship between fractal dimension and bending strength (a) and relationship between fractal dimension and fracture toughness (b).

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