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Fabrication of Double-Layer 2024Al-2024Al/B_4C Composite by Plasma Activated Sintering and Its Mechanical Properties

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Abstract: The properties of particle reinforced composites are often limited due to the interface between reinforcements and matrix materials. In this study, double-layer structure 2024Al-2024Al/B_4C composites were fabricated by plasma activated sintering (PAS) under the condition of 530°C, 3 min, 20 MPa. Effect of B_4C content on the mechanical behavior of the composites was investigated. When the B_4C content in the higher layer is 17.5 wt.%, the bending strength of the composite is 1099.68 MPa. In addition, the hardness of the substrate surface is 136.58 HV, and the composite surface is 198.68 HV. This kind of material introduces the design idea of the function gradient material and the microstructure control, which makes the effective transition of the interface between the reinforcements and matrix materials, meeting the special need of works.

Keywords: Plasma Activated Sintering, 2024Al-2024Al/B_4C, Function Gradient Material, Microstructure, Mechanical Property

1. Introduction

Function gradient material (FGM) applies to various fields such as aerospace, armor, biomedical, nuclear and so on [1-2]. However, studies performed on it are so limited, and few of them have been put into practice so far. Aluminum matrix composites (AMCs) emerged as excellent candidates in particle reinforcement for the sake of its unique characteristics in high-strength and lightweight [3-5, 13]. Among the AMCs, Al-2024/B_4C composite has ascendant properties. Zheng [6] characterized high volume fraction of B_4C particles (> 20%) on Al-2024 alloy based composites, and the composite exhibited high compression strength of 950 MPa, which is almost twice as high as that of the matrix alloy (~450MPa) made from milled powder. His later paper [7] also reported an engineering yield strength and ultimate tensile strength of the 2024 alloy, about 529.6 MPa and 583.1 MPa, respectively.

B_4C is chosen as a superior reinforcement among ceramics because of good chemical inertness, high hardness (2900-3580 kg/mm^2), high elastic modulus, and high melting point [8-10]. The bending strength of the FGM (AA7075/B_4C) was investigated by Bertan Sarikan [11]. They obtained that the FGM showed remarkable performance of high bending strength (527MPa). Zhang [12] reported the functionally graded material B_4C/C composite produced by a powder stacking method and hot-pressing with a bending strength of 138 MPa. Thus B_4C could be a potential material in the field of aluminum matrix composites, and more attention should be paid to it.

In the current study, samples with two layers, in which the chemical changes from the bottom (Al-2024) to the top (Al-2024/B_4C composite with different weight fraction of B_4C), were fabricated by PAS, one of the powder metallurgy techniques. This process can consolidate AMCs efficiently in a short time at a low temperature [13, 14], and finish the consolidation in just one step with high density, which makes it much more convenient than many other processing methods. The micro-structure of the resultant FGMs were examined by field-emission scanning electron microscopy (FESEM) and optical microscope.

2. Method

The 2024Al powder and B_4C (Aesar Alfa) powder are in spherical and irregular shape, and Figure 1 shows the micro morphology and particle size of them with 21.986 μm and

4.162 μm in D_{50}, respectively. We conducted experiments with different weight fraction of B_4C (2.5wt.%, 7.5wt.% and 12.5wt%) in the top layer. Figure 2 presents the structure of the double-layer function gradient composites as-synthesized in this paper. The purchased 2024 aluminum alloy powder and composite powder were prepared by a shaker mixer for 24 h, with ball to powder weight ratio of 10:1. Subsequently, the powder was poured into a high strength graphite carbon mold (32 mm in diameter) without additives, binders, but pre-pressed to prevent it leaking from the mold during the sintering process. Then bulk samples were synthesized via PAS at 530°C, holding for 3 min, and the applied pressure was 20 MPa. Temperature was controlled by a K-type thermocouple inserted into the graphite die from the side. After consolidation, the specimens were then heat treated at 493°C [7] for 3h and quenched in the water at room temperature.

We characterize the micro-structure, fracture morphology by Field-emission scanning electron microscopy (FESEM, quanta-250). SHIMADZUSALD-23000 laser diffraction particle size analyzer was used to evaluate the power size distribution. The thickness of the two-layer 2024Al-2024Al/B_4C samples was calculated from the Metallurgical Microscopy. Vickers micro-hardness was tested on a load of 1kg dwelling for 15s. Three point bending test (20×6.25×5.25mm bars, the layers of 2024Al matrix and 2024Al/B_4C are in the same thickness) was performed on a ceramic system (USMT810).

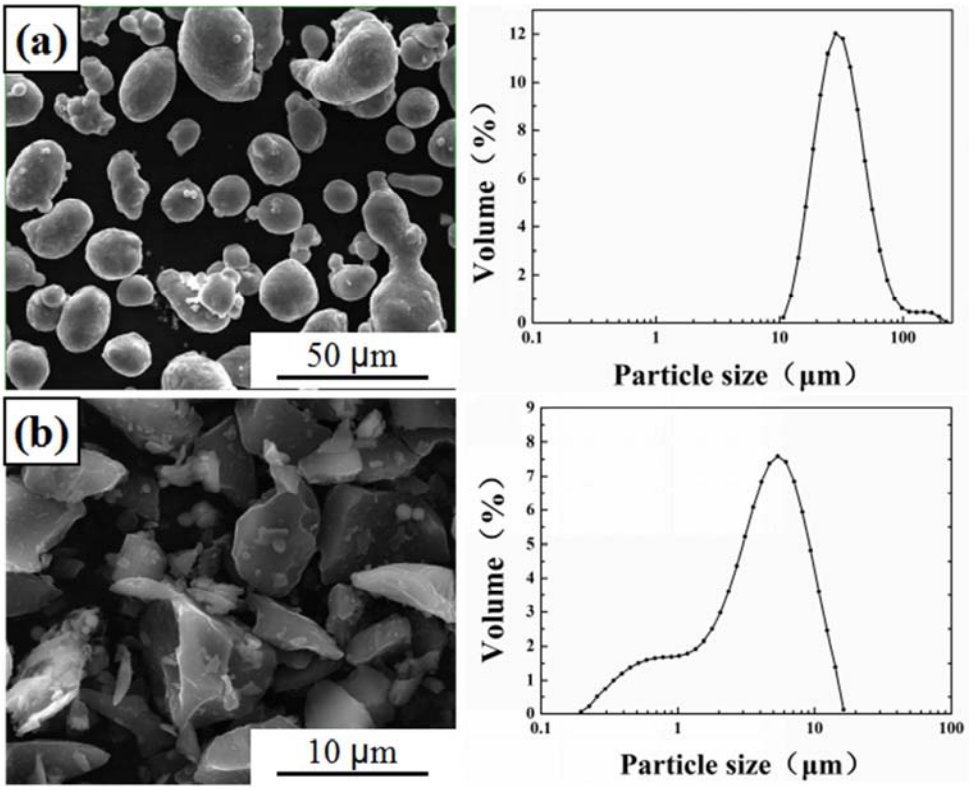

Figure 1. *Microstructure and particle size of 2024Al powder and B_4C powder: (a) 2024Al; (b) B_4C powder.*

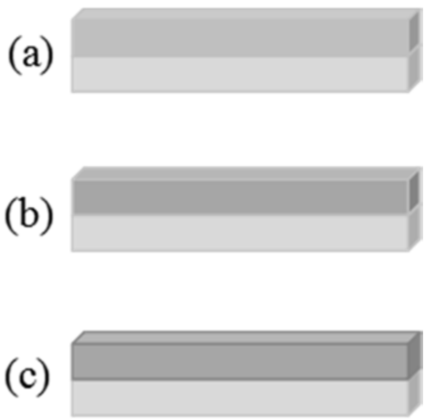

Figure 2. *Design of gradient composite: (a) 2024Al-2024Al/7.5 wt.%B_4C;(b) 2024Al-2024Al/17.5 wt.%B_4C; (c) 2024Al-2024Al/27.5 wt.%B_4C.*

3. Result

To better evaluate the mechanical properties, the hardness and bending strength of the FGMs synthesized by PAS are presented in Table 1. As shown in the table, with the increase of the content of B_4C, the hardness of 2024Al/B_4C side increased gradually. when the B_4C content reached 27.5 wt.%, the vickers hardness is 218.34 HV, but its bending strength does not change in this way. When the content of B_4C increased from 7.5 wt.% to 17.5 wt.%, the bending strength increased from 995 MPa to 1099.68 MPa. Ubeyli [15] prepared three layer-structural SiC-AA7075 functionally gradient material by traditional hot pressing method but with only 510 MPa in bending strength, further prove that the PAS sintering process is of high efficiency. However, when the B_4C content continued to increase (27.5

wt.%), its bending strength decreased to 917.58 MPa, even lower than that with 7.5 wt.% B_4C in the top layer. The main reason is that when the content of B_4C is too high, it is not uniformly dispersed in the 2024Al matrix, and the aggregation of them is also increased, which causes the source of cracks around the aggregation and clustering of B_4C particles. So we observed the decrease in mechanical properties of 2024Al -2024Al/27.5wt.%B_4C.

***Table 1.** Hardness and bending strength of 2024Al-2024Al/B_4C gradient composites.*

Sample	Side	Vickers Hardness (HV)	Bending strength (MPa)
a	2024Al/7.5wt.%B_4C	158.83	995.01
	Al-2024	139.4	
b	2024Al/17.5wt.%B_4C	198.68	1099.68
	Al-2024	136.58	
c	2024Al/27.5wt.%B_4C	218.34	917.58
	Al-2024	126.31	

4. Discussion

Figure 3 demonstrates the micro interface between the two layers of 2024Al-2024Al/B_4C gradient composites. We can see that the composition in the left of each image is 2024Al/B_4C and the right is 2024Al. No obvious boundary was found in the pictures, and each layer was homogeneous in its composition. In addition, no significant micro cracks or pores were detected in the cross section of the interfaces, and this means a very good bonding was obtained between the layers [15]. The continuous connection of the 2024Al matrix may contribute to the strong bonding between the two layers. There weren't strong reactions in the process of sintering, showing a good chemical stability of this method. It illustrates that the compositionally graded layer of the gradient composite resulted in a well-bonded composite structure. When the content of B_4C in the top layer is 7.5 wt.% (Figure 3a) and 17.5 wt.% (Figure 3b), B_4C particles in the matrix were well dispersed, randomly distributed, and no obvious aggregation occurred between B_4C particles. When the content of B_4C increased to 27.5 wt.% (Figure 3c), the B_4C formed a continuous network in the 2024Al matrix, and was seriously aggregated in the image, which resulted in the decrease of bending strength.

Figure 4 is the fracture surface morphology of the gradient materials. In Figure 4a and 4b, the B_4C content in the composite layer were 7.5 wt.% and 17.5 wt.%, and no obvious bare B_4C particles was found in the figures. When the content of B_4C composite layer is 27.5 wt.%, as shown in Figure 4c, the matrix layer and the composite layer was broken off at the interface. Figure 4d is the high magnification of 4c, and it can be seen that the B_4C particles are surrounded by the matrix 2024Al, but some cracks are observed between the interface of each other. The agglomeration B_4C gave rise to high stress concentration and material hardening under the effect of external stress. The region first appeared cracks, then extended to grow up until the occurrence of fracture [16].

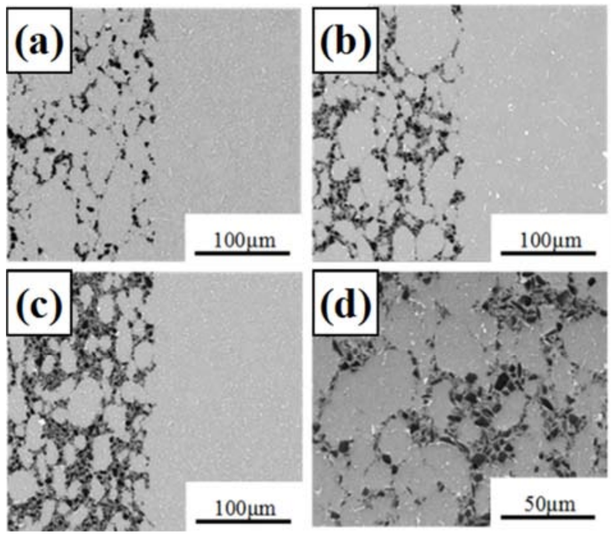

***Figure 3.** Micro morphology of gradient composites: (a) 2024Al-2024Al/7.5 wt.% B_4C; (b) 2024Al-2024Al/17.5 wt.% B_4C; (c) 2024Al-2024Al/27.5 wt.% B_4C; (d) high magnification of c.*

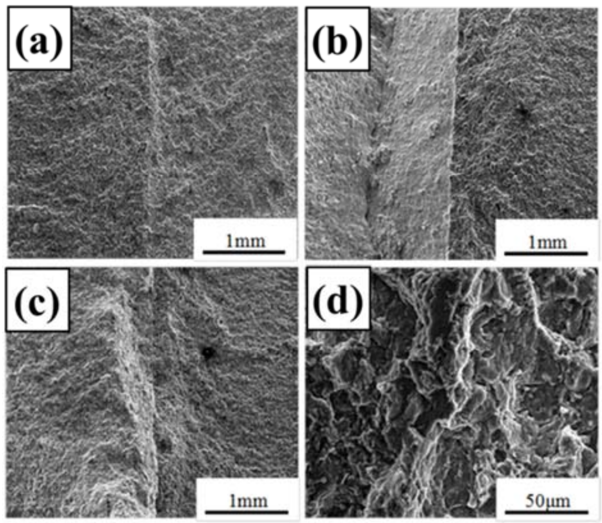

***Figure 4.** Fracture morphology of the gradient composites: (a) 2024Al-2024Al/7.5 wt.%B_4C; (b) 2024Al-2024Al/17.5 wt.%B_4C; (c) 2024Al-2024Al/27.5 wt.%B_4C; (d) high magnification of c.*

5. Conclusion

Plasma activated sintering process (PAS) was able to successfully prepare the double-layer structural 2024Al-2024Al/B_4C gradient material with high density, no cavity cracks and pores. Due to the continuous connection of the 2024Al matrix, the composition in the interface was efficiently transited, which makes the bonding between the 2024Al layer and 2024Al/B_4C layer was strong enough.

The vickers hardness increases with the increase of the B_4C in the composite layer at first. And when the B_4C content reaches 27.5 wt.%, it is as high as 218.34 HV. On the other hand, the bending strength of the gradient materials increases from 995.0 MPa to 1099.68 MPa when the B_4C content increase from 7.5 wt.% to 17.5 wt.%. But when the B_4C content continued to increase (27.5 wt.%), it decreased to

917.58 MPa. We attributed the reason to the aggregation and clustering of B_4C particles within 2024Al matrix, forming the crack source and resulting in a decline in mechanical properties.

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