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Preparation of particles reinforced Aluminum matrix composites by In-Situ synthesized Al-Ti intermetallics

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Abstract. Using particle reinforced aluminum matrix composites have many advantages, for example: high specific strength, good thermal conductivity, low thermal expansion coefficient, good fatigue and wear resistance and stable high temperature performance. However, there are two aspects that need further research and improvement: reasonable choice of performance difference between reinforced phase particles and matrix, reasonable design of interface structure between reinforced phase particles and matrix. Using in-situ autologous method to prepare composites. In this way, we solved the problem that the morphology of the enhanced phase was laminated with low strength, and prepared core shell structure reinforced phase. In this paper, we will demonstrate relevant studies about Ti-Al core-shell structure particles reinforced aluminum matrix composites. Studies show optimal Ti-Al ratio of the core-shell structure reinforced phase should be 1:3. Meanwhile, we will analyze mechanical properties of composites. We prepared the reinforced phase into aluminum substrate. As the result, the mechanical properties of composites were determined to be excellent when the proportion of the reinforced phase was between 5% and 10%.

1. Introduction

Metal matrix composite is a material with strong vitality that is composed of Aluminum, Nickel, Magnesium, Titanium and other metals or alloys as the matrix and fiber or particle as the reinforcement through various technological means [1]. Particle reinforced aluminum matrix composites have many advantages: high specific strength, good thermal conductivity, low thermal expansion coefficient, stable high temperature performance, good fatigue and wear resistance [2-5]. In recent years, aluminum-based composites with intermetallic compounds as particle reinforcement have become a research hotspot in the field of materials science and engineering around the world. The types, quantity, morphology, distribution and bonding strength of intermetallic compounds are the main factors affecting the mechanical properties of aluminum matrix composites. The reinforcing phase in the in-situ autogenous process is formed during the preparation process [6]. It is very important to control the morphology of in-situ reinforced aluminum matrix composites by powder preparation, solidification and sintering.

The Ti-Al core-shell enhancement phase of intermetallic compound was prepared by mechanical alloy method in this paper. The reinforced phase was put into aluminum matrix materials for vacuum hot-pressing and sintering test by in-situ method, then the aluminum matrix composites with different proportions of Ti-Al particles were analyzed and studied through micro indentation test, and the density and microstructure evolution of Ti-Al particles were analyzed quantitatively and qualitatively.



2. Experimental research

2.1. Experiment materials:

The aluminum powder used is produced by Tianjin ZhiYuan Chemical Reagent Co. The titanium powder used is provided by BLT Co. The powder specification is 15 μm -53 μm .

2.2. Experiment equipment:

The experiment adopts the WXQM-4A light horizontal planetary ball mill produced by Changsha Tianchuang Powder Technology Co. The thermal pressure sintering equipment is the YZY-40-10T vacuum thermal pressure sintering furnace produced by Shanghai Yuzhi Electromechanical Co.

2.3. Experiment program:

Three kinds of different Ti-Al powders were prepared by high-energy ball mill with different proportions of 1:1, 1:3 and 3:1 respectively. The technological parameters of high-energy ball mill are 300r/mins and 2h. Hot pressing sintering temperature is 480 $^{\circ}\text{C}$, holding time is 45 mins and the loading pressure is 9.55MPa.

3. Experiment result and analysis:

Samples with a Ti-Al ratio of 1:1 (Figure 1a) can see the core shell structure slightly, but the shell is relatively thin, while those with a Ti-Al ratio of 1:3 (Figure 1c) can see the obvious core shell structure, and the shell is relatively thick. The shinier outer shell structure shown in Figure 1a is wrapped with the darker and less spherical structure. This kind of core shell structure is distributed evenly in the matrix structure. At the time of sintering, chemical reactions on the surface of titanium and aluminum contact began to form intermetallic compounds, which formed the enhanced phase structure with Ti as the core and intermetallic compounds as the shell. With the progress of sintering, Al continuously diffuses into the Ti core, more and more Ti-Al intermetallic compounds are generated, and so, the thickness of the annular layer increases. Ti-Al ratio is 3:1 (Figure 1b), the content of Al is less. It is difficult to wrap Ti in the core shell, so there is no core shell structure.

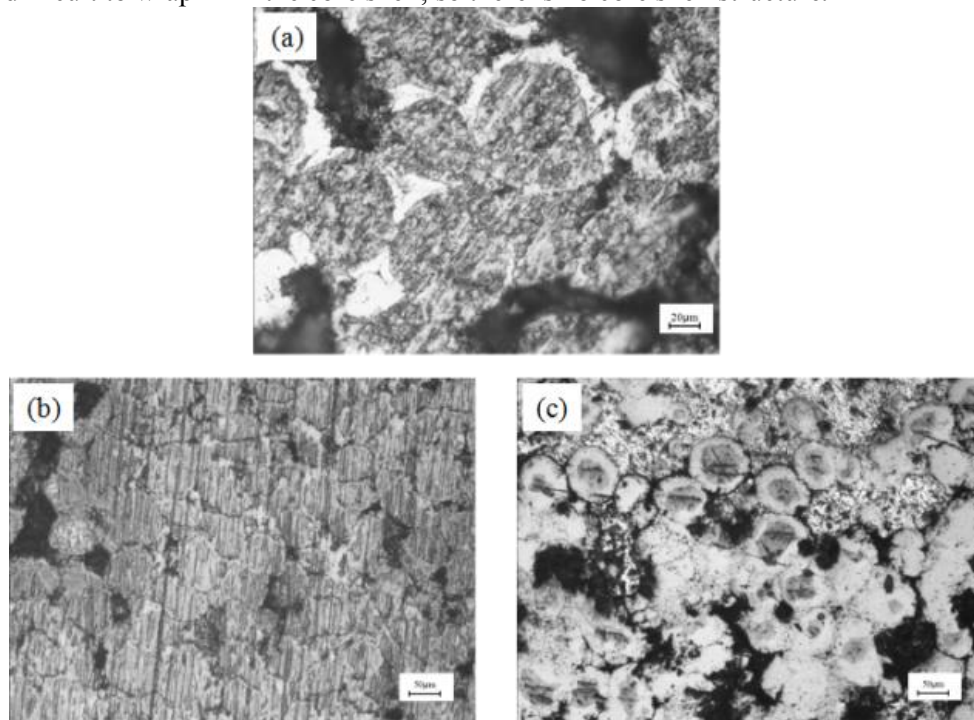


Figure 1. Microstructure of samples of vacuum heat pressure sintering samples with different titanium-aluminum ratios (a)Ti:Al=1:1; (b)Ti:Al= 3:1; (c)Ti:Al= 1:3

According to the SEM-XRD test (Figure 2), the proportion of titanium atom in position “a” and position “b” was 99.16% and 97.85% respectively, so the core position of the core-shell structure could be determined as pure titanium. The aluminum element at position “e” accounts for 99.15%, so it is a pure aluminum matrix. There are both titanium elements and aluminum elements in position “c” and “d”, forming intermetallic compounds with relatively complex components. Therefore, the core-shell structure should be formed with titanium as the core, titanium aluminum intermetallic compound as the shell, and pure aluminum as the matrix structure.

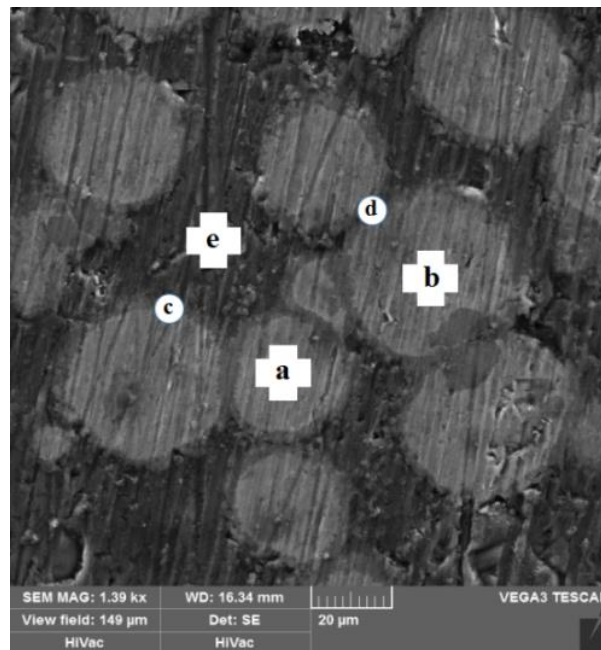


Figure 2. SEM examination of Ti-Al ratio of 1:3.

According to the compression test (Figure 3), when the molar ratio of Ti-Al is 1:3, its yield strength is the highest (Table 1), followed by that of pure aluminum and Ti-Al is 3:1 or 1:1. Compared with pure aluminum, the elastic modulus of the sample with a ratio of 1:3 was similar to that of pure aluminum but the yield strength was higher than that of pure aluminum. Because the Ti-Al ratio of 1:3 in the sample internal structure of the core-shell structure, improving the overall mechanical properties. Therefore, Ti-Al ratio of 1:3 is the reasonable proportion of the enhancement phase.

Figure 4 shows the yield strength and apparent elastic modulus of particle reinforced aluminum matrix composites with different mass fraction enhancement phases at room temperature. With the increase of the content of the enhanced phase, the apparent elastic modulus E value decreased first and then increased. The apparent elastic modulus E value of aluminum matrix composites decreases gradually from 0% to 5%, and increases significantly when the E value increases to 15% and 20%. For the yield strength, with the increase of the content of the enhanced phase, the value of the σ_s increases gradually and then decreases significantly. When the contains 5% of the enhanced phase, the value of the σ_s reaches 41.2MPa. When there are 5% and 10% reinforcement phases respectively, their distribution in the matrix is relatively uniform, with almost no agglomeration phenomenon. However, when the reinforcement phase increases further to 15%, the agglomeration phenomenon is more obvious. A large number of agglomerated core-shell structures in the matrix strengthen the phase, resulting in uneven distribution and weakened mechanical properties. Through the comparison of comprehensive mechanical properties, it is considered that the content of reinforced phase is better between 5%-10% in particle reinforced aluminum matrix composites.

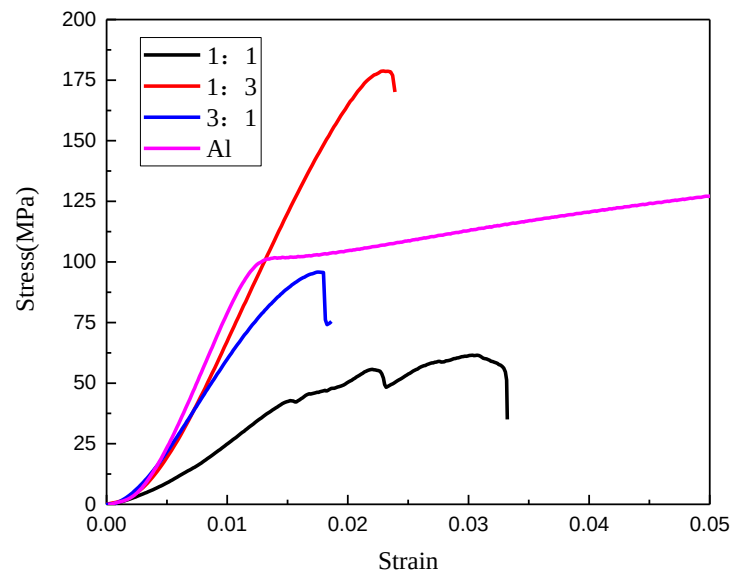


Figure 3. The compression stress-strain curves of specimens with different titanium to aluminum ratios at strain rates of $10^{-3}/s$.

Table 1. Compression experimental parameters of different titanium-aluminum ratio specimens.

Sample	Apparent elastic modulus(GPa)	Yield Strength(MPa)
Ti:Al=1:1	0.90	1.75
Ti:Al=3:1	7.69	93.05
Ti:Al=1:3	10.40	174.51
Pure Al	10.41	100.17

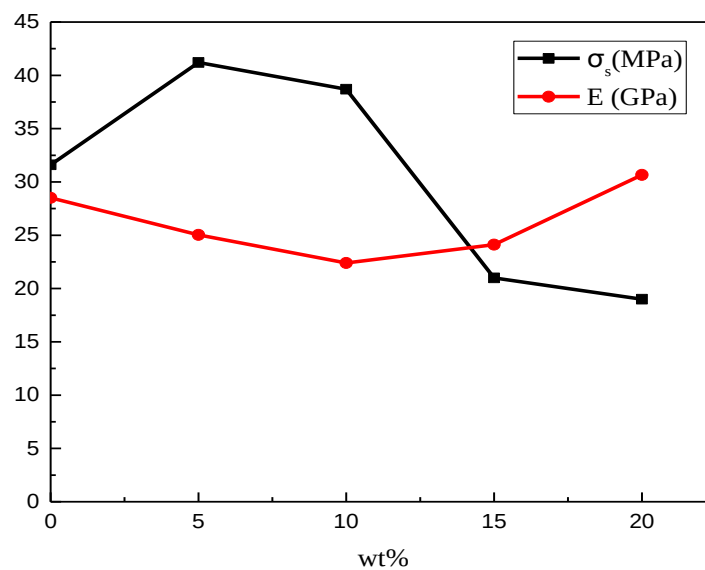


Figure 4.Yield strength and apparent Elastic modulus of loaded aluminum matrix composites with different mass fractions.

4. Conclusions

In this paper, we research the proportion, content, microstructure and mechanical properties of Ti-Al in-situ reinforced aluminum matrix composites. The technological parameters of high-energy ball mill are determined as 2h with a rotating speed of 300r/min. Hot pressing sintering process parameters for heat preservation are 480 °C and heat preservation for 45 mins. When the enhanced Ti-Al ratio is 1:3, the enhanced phase presents a core-shell structure of Ti@Al, and the mechanical properties are improved. And the mechanical properties of the enhanced phase content of 5%~10% is best.

Acknowledgments

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