Dual-Scale Near-Net Structure Design to Achieve Synergistic Enhancement of Strength and Plasticity of $(TiC+Ti_5Si_3)$/TC4 Composites

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bstract:** To solve the problem of low plasticity in homogeneous particle-reinforced composites， micro-nano dual-scale near-network (TiC+Ti5Si3)/TC4 composites were prepared by C powders+Si powders and in-situ melting-casting technology. The microstructural evolution, strengthening mechanisms of micro-nanoscale composites were systematically investigated. The results show that with the increase of the reinforced phase content, the morphology of micron-sized TiC changed significantly from the initial short plume to granular gradually, and the nano-sized Ti5Si3 particles changed from small particles to ellipsoidal gradually precipitated at the β-Ti and α/β interfaces. The (3vol.%TiC+3vol.%Ti5Si3)/TC4 (TMCs-2) sample exhibits excellent mechanical properties with hardness of 52.8HRC, compressive strength of 1774MPa and plasticity of 24.5%. The increase in strength of the composites is attributed to the synergistic effect of matrix (fine grain strengthening, solid solution strengthening) and particle strengthening.

Keywords: $(TiC+Ti_5Si_3)$/TC4 composites, Multiphase multi-scale, Mechanical properties, Strengthening mechanism,

1 Introduction

Discontinuous particle reinforced titanium matrix composites (DRTMCs) are considered to be one of the most promising candidate structural materials in high-tech fields such as automobiles and aerospace, with low density, high specific strength, good corrosion resistance and excellent high temperature performance [1,2]. TiC particles (TiCp) are considered an ideal reinforced phase for TMCs due to their excellent physical properties (high modulus, high hardness, excellent thermal stability, and good chemical compatibility) [3,4]. However, the poor interfacial bonding strength and the trade-off between strength and toughness are still the main problems in the research of TMCs [5,6]. Inspired by the concept of natural structures, many researchers have constructed various bionic structures to obtain better strength-ductility synergistic effects [7,8]. In this study, based on the design of network and multi-scale structure, the dual-scale near-network $(TiC+Ti_5Si_3)$/TC4 composites were prepared by in-situ melting-casting technology using nano-Si powder and nano-C powder. The effects of different proportions of mixed micron TiC and nano Ti_5Si_3 particles on the microstructure evolution and mechanical properties of the composites were systematically studied.

2 Experimental procedure

The experimental raw materials include commercial Ti-6Al-4V (TC4) alloy, Si powder (purity 99.9%, average particle size 800nm), and C powder (purity 99.8%, average particle size 100nm). The experimental raw materials were melted using a vacuum non consumable arc furnace, and $(TiC+Ti_5Si_3)$/TC4 composites were prepared based on in-situ self generated reactions between materials. The microstructure of the samples was characterized using a scanning electron microscope (SEM, ZEISS, Gemini 300) equipped with an energy dispersive spectrometer (EDS). The SEM samples were etched with Kroll reagent for 7-10s. The hardness of the samples was measured using HR-150A Rockwell hardness tester, and the average value was taken after 5 tests on each sample. The room temperature compression performance test was conducted using an MTS810 electronic universal testing machine with a strain rate of $1.38\times10^{-4}s^{-1}$.

3 Result and discussion

3.1 Analysis of microstructure and mechanical properties

When a small amount of reinforced phase content is added, TiC is rod-like and uniformly distributed in the matrix grains or grain boundaries, and a small amount of spherical Ti_5Si_3 particles are precipitated in the β-Ti phase and the α/β interface. With the increase of the content of the reinforced phase, the morphology of TiC changed significantly. The TiC phase gradually evolved from rod-like to short pinnate distribution, and the number of Ti_5Si_3 particles increased significantly. When excessive reinforced phase content is added, a large number of equiaxed TiC particles are distributed at the grain boundaries of the matrix, and a small amount of spherical Ti_5Si_3 particles are precipitated at the β-Ti grain boundaries. More spherical

Ti_5Si_3 particles are attached to the TiC particles, showing obvious aggregation of the reinforced phases. The coarse Ti_5Si_3 particles are easily connected to each other at the interface (TiC interface, grain boundary, etc.) to produce local aggregation, which adversely affects the mechanical properties of the TMCs [9]. The TMCs-2 sample exhibits excellent mechanical properties with hardness of 52.8HRC, compressive strength of 1774MPa and plasticity of 24.5%.

3.2 Strengthening mechanism

During the deformation process, with the continuous loading of stress, cracks begin to form and propagate along the interface between the reinforced phase and the matrix. The reinforced phase can interact with dislocations and inhibit dislocation motion. When the crack propagates along the interface between the reinforced phase and the matrix, the reinforced phase strongly hinders the crack propagation, effectively passivates the crack tip and hinders the further propagation of the crack. In addition, the deflection due to the near-network structure during crack propagation effectively consumes the propagation energy of the crack. The fine α-Ti grain sheets with high strength in ductile β-Ti grains inhibit the deformation of β-Ti grains, which is the reason for the enhancement of TMCs [10]. In addition, due to the multi-scale structure of TMCs. Micron-sized TiC particles can be used as an additional heterogeneous nucleation site to promote the formation of equiaxed α-Ti particles to refine grains and strengthen grain boundaries, which is conducive to improving the mechanical properties of TMCs. Due to the special distribution and size characteristics of Ti_5Si_3 reinforcement, sufficient space can be provided for dislocation movement to ensure the ductility of TMCs. Therefore, the design of dual-scale near-net structure can effectively improve the deformation coordination of the composites.

4 Conclusion

The in-situ formation of TiC and Ti_5Si_3 phases have a significant influence on the growth of grains. The designed dual-scale near-net structure ($TiC+Ti_5Si_3$)/TC4 composites have excellent strength and plasticity. The increase of strength is attributed to the synergistic effect of solid solution strengthening, fine grain strengthening and reinforced phase strengthening. The improvement of plasticity is attributed to the design of the two-scale near-net structure, which can effectively hinder the crack propagation, resulting in crack deflection and passivation, thereby increasing the energy required for crack propagation and delaying the fracture of the composite.

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