Multi-Scale Microstructure Regulation and High-Temperature Strengthening Mechanism of Ti_2AlC/TiAl Composites Prepared by Vacuum Melting

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Abstract: TiAl alloy is an ideal lightweight high temperature structural material in the aerospace field, however, it could not meet the urgent need of the new generation high thrust-to-weight ratio aero engine blade to withstand the 800℃ high temperature for a long time. In this study, the multi-scale Ti2AlC/TiAl composite is fabricated. The in-situ micro-Ti2AlC is obtained at the grain boundaries of the full lamellar TiAl matrix by vacuum melting, the targeted precipitation of submicro-Ti2AlC at the lamellar TiAl/Ti3Al phase boundary and directional precipitation of nano-Ti2AlC within TiAl crystals are achieved by heat treatment. The composite showed excellent high-temperature strength (the tensile strength of the composite at 850℃ is comparable to that of the TiAl alloy at 750℃). The results show that the micro-Ti2AlC inhibits grain boundary softening and hinders dislocation motion, the submicro-Ti2AlC prevents twin propagation, the nano-Ti2AlC obstructs dislocation motion and refines lamellar microstructure, and the full lamellar TiAl matrix microstructure changes the propagation paths of twins/stacking fault at high temperatures. This study provides theoretical basis and technical support for the preparation technology and application of a new generation of light high temperature resistant TiAl alloy for aeroengines.

Keywords: TiAl Matrix Composite, Multi-scale Ti_2AlC, high-temperature strengthening mechanism

1 Introduction

With the rapid advancement in the aerospace field, the development of a high-temperature, lightweight structural material with exceptional mechanical properties has become an undeniably formidable challenge. TiAl alloy stands as an exemplary lightweight, high-temperature structural material in the aerospace industry, yet it falls short of meeting the stringent demands posed by the next-generation aero engine blades. Multi-scale Ti_2AlC/TiAl composite can effectively improve the high-temperature properties of TiAl alloys. In this study, by optimizing composite components and heat treatment techniques to achieve multi-scale Ti_2AlC/TiAl composite tissue modulation, lightweight and high-strength multi-scale Ti_2AlC/TiAl composite materials can be developed to meet national needs.

2 Experimental procedure

The composite used in this paper are all prepared by vacuum arc melting (VAR) technique. Subsequently, a heat treatment procedure (underwent a 24h solid solution treatment at 1573K, followed by a 0.5h aging treatment at 1173K.) was employed to modulate the microstructural characteristics of the material. The raw materials used for vacuum arc melting were sponge titanium (99.7%), aluminum rod (99.99%), chromium particles (99.98%), aluminum-niobium master alloy (with Nb content of 55%) and graphite powder (99.98%).
Test for tensile properties using the MTS 370.10 hydraulic servo test system. At least three tensile experiments were carried out on each sample to ensure the accuracy of the experimental results. The high-temperature tensile experiments were conducted at 800 °C with a tensile rate of 0.0001 S^{-1}. In order to preserve the microstructure after high temperature tensile deformation, the samples were quenched immediately after the tensile experiments. The microstructure and morphology of the samples were analyzed by SEM. The fracture surface was extensively characterized using a TEM to gain a more detailed understanding of the morphology following the stretching process.

3 Result and discussion

3.1 Effect of graphite powder content on the microstructure of composite

For multi-scale Ti_2AlC/TiAl composites, by controlling the graphite powder content, the micro-Ti_2AlC phase length-diameter ratio can be controlled. Adopting a suitable heat treatment process (1573K solid solution for 24 hours and 1173K aging for 0.5 hours) can precipitate multi-scale Ti_2AlC.

3.2 Effect of micro-Ti2AlC on the high temperature mechanical properties of composite

For multi-scale Ti_2AlC composites, the in-situ micro-Ti_2AlC is obtained at the grain boundaries of the full lamellar TiAl matrix. The micro-Ti_2AlC effectively inhibits grain boundary softening and hinders dislocation motion to enhance the high-temperature performance of composites.

3.3 Effect of submicro-Ti2AlC on the high temperature mechanical properties of composite

The targeted precipitation of submicro-Ti_2AlC at the lamellae TiAl/Ti_3Al phase boundary is achieved by heat treatment. When the multi-scale Ti_2AlC/TiAl composite is subjected to an external tensile load, a large number of deformation twins would be generated along the γ-TiAl movable slip system, and the submicro-Ti_2AlC could hinder the deformation twins further propagation, which is beneficial to improve the strength of the composite.

3.4 Effect of nano-Ti2AlC on the high temperature mechanical properties of composite

The directional precipitation of nano-Ti_2AlC within TiAl crystals are achieved by heat treatment. During high-temperature tensile, the nano-Ti_2 AlC exerts a dual beneficial effect on mechanical properties. Firstly, it acts as an effective barrier, hindering the motion of dislocations. Secondly, the nano-Ti_2 AlC refines the lamellar microstructure, leading to a more homogeneous that further bolsters the mechanical attributes.

3.5 Effect of the full lamellar microstructure on the high temperature mechanical properties of composite

The multi-scale Ti_2AlC/TiAl composite prepared by vacuum arc melting furnace and heat-treated have a full lamellar microstructure. When the multi-scale Ti_2AlC/TiAl composite is subjected to an external tensile load, the full lamellar TiAl matrix microstructure can change the propagation paths of twins/stacking fault at high temperatures and thus impede the further extension of the deformation twins, which is conducive to the enhancement of the strength of the composite.

4 Conclusion

(1)The multi-scale Ti_2AlC/TiAl composite with a full lamellar microstructure can be obtained by vacuum arc melting furnace and heat treatment. It can effectively improve the high-temperature performance of TiAl alloy.

(2)The micro Ti_2AlC is precipitated at grain boundaries in a fully lamellar TiAl matrix. It inhibits the softening of grain boundaries and hinders dislocation motion. The Submicro-Ti_2AlC precipitates on the boundary of the lamellar TiAl/Ti_3Al phase, effectively hindering the propagation of twins during high-temperature stretching.

(3)The nano Ti_2AlC, directedly precipitated within TiAl crystals, effectively hinders dislocation motion and refines lamellar microstructure. Additionally the full lamellar TiAl matrix microstructure changes the propagation paths of twins/stacking fault at high temperatures.

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References

[1] Wang Z B, Liu P, Hou B, Ye F, Wang A Q and Xie J P. Investigation on the in-situ reaction mechanism of Ti_2AlC/TiAl composite prepared by spark plasma sintering. Mater. Charact, 2022, 194: 112417.

[2] Liu P, Liu Z W, Wang Z B, Wang A Q, Xie J P and Hou B. Investigation on the effect of alloying elements on the Ti_2AlC/TiAl interfacial properties: First-principles prediction and experimental verification. Mater. Today. Commun, 2023, 35: 106314.

[3] Liu P, Liu Z W, Hou B, Wang A Q, Xie J P and Wang Z B. A systematic investigation on the surface properties of Ti_2AlC via first-principles calculations. Surf. Sci, 2023, 735:122337.

[4] Hou B, Wang A Q, Liu P and Xie J P. Investigation of the nucleation and growth behavior of Ti_2AlC and Ti_3AlC nano-precipitates in TiAl alloys. Nanotechnol. Rev, 2023, 12(1): 20220510.

[5] Liu P, Hou B, Wang A Q, Xie J P and Wang Z B. Balancing the strength and ductility of Ti_2AlC/TiAl composite with a bioinspired micro-nano laminated architecture. Mater. Design, 2022, 220: 110851.

[6] Liu P, Hou B, Wang A Q, Xie J P, Wang Z B and Ye F. Superior strength-plasticity synergy in a heterogeneous lamellar Ti_2AlC/TiAl composite with unique interfacial microstructure. J. Mater. Sci. Technol, 2023, 159: 21-32.

[7] Wang Z B, Liu P, Wang A Q, Xie J P and Hou B. Effect of spark plasma sintering temperature on the multi-scale microstructure evolution and mechanical properties of Ti_2AlC/TiAl composites with network architecture. J. Mater. Res. Technol, 2023, 25: 6209-6223.

[8] Wang Z B, Liu P, Wang A Q, Xie J P and Hou B. Fabrication, microstructure and mechanical properties of TiAl matrix composite reinforced by submicro/nano-Ti_2AlC. Mater. Charact, 2023, 203: 113141.

[9] Liu P, Wang Z B, Ye F, Hou B, Wang A Q and Xie J P. Hierarchically heterogeneous strategy for Ti_2AlC/TiAl composite with superior mechanical properties. Compos. Part. B-Eng, 2024, 273: 111259.