Refining Mechanism of Ti_2AlC Particles and Improvement Mechanism of Mechanical Properties by Er Addition

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Abstract: Revealing the refinement mechanism of Er on Ti_2AlC particles and the strengthening mechanism of TiAl composites is of great significance for promoting the development prospects of TiAl composites. As-cast Ti42Al6Nb2.6CxEr alloys are prepared by vacuum non consumable arc melting. Results show that as Er increases from 0.04 to 0.08 at. %, the relative content of γ phase, α2 phase, and Ti_2AlC particle remain stable. As Er increases to 0.4 at. %, the relative content of γ phase decreases, and that of α2 phase increases. Er consumes Al to form $ErAl_3$ phase during the α2→α2+γ transformation, resulting in a decrease in Al content involved in the formation of γ lamellae. Aspect ratio of Ti2AlC particle decreases from 7.97 to 3.92 and the morphology changes from slender rod to short rod as Er increases to 0.08 at. %, which is due to the Er_2O_3 preferring to be adjacent to Ti_2AlC particle, inhibiting its growth of length and radial direction. Alloying with Er results in refinement in terms of lamellar colony size. Dispersed Er_2O_3 and refined Ti_2AlC both serve as nucleation sites, resulting in refinement of the lamellar colony. $Ti_{42}Al_6$Nb2.6C0.08Er alloy exhibits optimum compressive properties with the strength of 2057 MPa and the strain of 22.44%, which is due to the refinement of Ti_2AlC particle and lamellar colony, and the precipitation of Er_2O_3 particle.

Keywords: TiAl alloy; Er element; Refinement; Microstructure evolution; Mechanical properties

1 Introduction

The comprehensive performance of a single intermetallic compound is ill-equipped to meet the overall requirements of aircraft engines [1]. The in-situ self-generation composite technology further expands the application prospects of TiAl alloys. The segregation distribution and type of reinforcing particle have a significant effect on the mechanical properties of composite materials [2]. For carbides, uniformly distributed Ti_2AlC and Ti_3AlC are ideal reinforcement particles. Therefore, obtaining great cast microstructure is inseparable from effective control of the matrix and reinforcing particle. Rare earth (RE) element has played a valuable role in this field， which has great solid solution strengthening effect, and tends to accumulate at the front of the solid-liquid interface, increasing the undercooling and inhibiting grain growth [3]. Its characteristic of easily reacting with oxygen to form stable oxides not only improves the purity of TiAl melt, but also generates significant precipitation strengthening. Research has shown that RE elements exhibit positive regulation on the microstructure of TiAl alloys, and they also have a positive effect on the reinforcing particles [4]. Different from previous studies, we have specifically investigated the effect of RE element on the morphology and content of MAX type ceramic particles, and revealed the mechanisms of Er element promoting the refinement of Ti_2AlC particles in β-solidified TiAl alloy.

2 Experimental procedure

The vacuum non-consumable electric arc furnace was used to prepare Ti42Al6Nb2.6C*x*Er (*x*=0.04, 0.06, 0.08, 0.1, 0.4 at. %) alloys. Each ingot was solidified in a copper crucible chilled by water. Vacuum degree was maintained below 3×10^{-3} Pa until the completion of melting to prevent oxidation. All materials were remelted five times under argon environment to guarantee composition consistency. To evaluate the microstructures, the ingots were grinded, polished, and chemically etched with Kroll reagent (5 HF+10 HNO_3+85 H_2O (vol. %)) for 7s. Quanta 200F (SEM) with EDS device were used to analyze the microstructure evolution. Nanometer scale of the microstructure was observed by Talos F200X (TEM). For compressive properties, on the Instron 5569, a cylinder with the size of Ø 4mm×6 mm is deformed at a loading rate of 0.5 mm/min under a pressure head of 250kN/50kN. To assure the reliability of the experiment, the compression test requires at least three samples.

3 Result and discussion

Figure 1 shows the constituent phases are α_2, γ, Ti2AlC， Er_2O_3 with different Er contents. When Er content is below 0.08 at. %, it exists in the form of Er_2O_3 particle, the relative contents of the three constituent phases are stable. When Er content exceeds 0.08 at. %, the content of γ phase decreases, while that of α2 phase increases, which due to Er consumes Al element to form ErAl3 phase during the α_2→ α_2+γ transformation, resulting in a decrease in Al content involved in the formation of γ lamellae. It can also be seen that appropriate Er content is beneficial for reducing the aspect ratio of Ti_2AlC particles. Ti_2AlC particles exhibit the morphology with small size and uniformly distribution as Er content increases to 0.08 at. %.

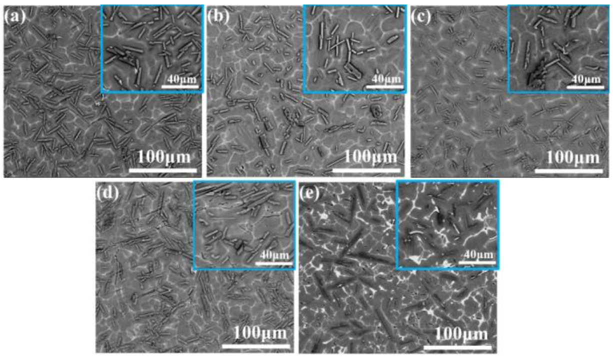

Figure 1 Microstructures of Ti42Al6Nb2.6CxEr alloys: (a) 0.04Er; (b) 0.06Er; (c) 0.08Er; (d) 0.1Er; (e) 0.4Er.

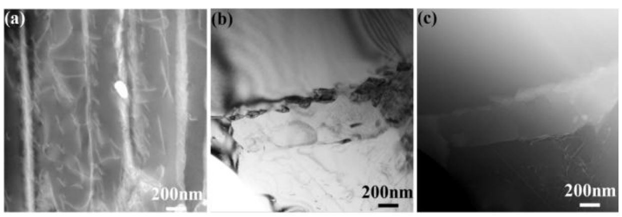

Figure 2 TEM analysis of the Er2O3/Ti_2AlC phase interface of Ti42Al6Nb2.6C0.08Er alloy.

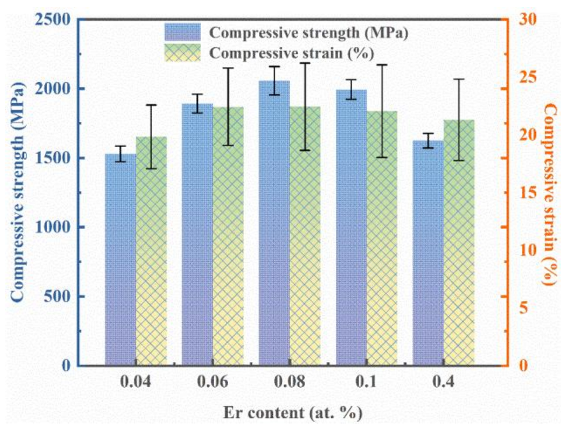

Figure 3 Compressive properties of Ti42Al6Nb2.6C*x*Er alloys.

Er_2O_3/Ti_2AlC phase interface is shown in Figure 2. Er_2O_3 particles are not only distributed inside the lamellar colony to hinder the dislocation slipping, but also prefer to be adjacent to Ti_2AlC particles. Er_2O_3 particles are connected sequentially, hindering the growth of Ti_2AlC particles in terms of length and radial direction. Therefore, Ti_2AlC particles transform from slender-needle shaped to short-rod shaped. The fine Er_2O_3 and Ti2AlC particles jointly refine the lamellar colony. Based on the refinement of Ti_2AlC particles and lamellar colony, the compressive properties at room temperature increases from 1528 to 2057 MPa without sacrificing the compressive strain (Figure 3). Therefore, Er element strengthens TiAl alloy by refining Ti_2AlC particles and the precipitation of Er_2O_3 particles.

4 Conclusion

1. The aspect ratio of Ti_2AlC particle decreases from 7.97 to 3.92 as Er content increases from 0.04 to 0.08 at. %, which is due to the Er_2O_3 preferring to be adjacent to Ti_2AlC particle, inhibiting its growth of length and radial direction.
2. The dispersed Er_2O_3 and refined Ti2AlC particles both serve as nucleation sites, resulting in significant refinement of the lamellar colony.
3. The TiAl alloy exhibits optimum compressive properties, which is due to the refinement of Ti2AlC particle and lamellar colony, and the precipitation of Er_2O_3 particle.

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