Microstructural Refinement of Cast Ti48Al2W0.5Si Alloy by Static Heat Treatment

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ABSTRACT

The microstructure of the massive transformed Ti48Al2W0.5Si alloy was studied during tempering in the temperature range of 1100-1360°C. A fine fully-lamellar microstructure with the grain size of 170-220 μm was developed after tempering in the single α field. While a duplex structure comprising equiaxed γ grains and lamellar colonies was obtained at 1300-1340°C, a dual structure of fine γ grains and $\alpha_2(\beta)$ plates was observed at 1250°C. After tempering at 1100°C, fine and dense α_2 and β particles were precipitated on the massive γ matrix. Compression tests confirmed that the properties of cast Ti48Al2W0.5Si alloy are considerably improved by quenching/tempering processes.

1. INTRODUCTION

Recently, considerable studies have focused on optimizing the properties of TiAl-base alloys by microstructure control through thermo-mechanical treatments and alloy modification. Depending on the heat treatment, a duplex, a near-fully-lamellar or a fully-lamellar microstructure can be obtained [1,2]. The lamellar structure is generally tougher than the fine duplex one, while the latter is more ductile. However, the ductility of the lamellar structure can be improved by refining its colony size. A fine fully-lamellar microstructure is thus accepted as the most promising candidate, because it exhibits a good combination of

ductility, high temperature strength and creep resistance [2,3]. By appropriate thermo-mechanical treatment, a lamellar structure with a colony size of 100-300 μm can be produced.

Compared to the wrought or powder-metallurgical route, investment casting may be the most feasible and cost-effective approach for the manufacture of near-net-shape components, such as blades and vanes [4,5]. The key shortcoming of cast TiAl alloys is the residual coarse ingot microstructure, which is harmful to the performance of the final products. Therefore, it is of the utmost importance to find an approach to refine the microstructure of cast TiAl-base components.

The quenching/tempering process is a well-established heat treatment for most high-alloy steels. Upon tempering, the toughness of the as-quenched martensitic microstructure is greatly improved by the formation of various types and distribution of carbides; in this way, a wide variety of microstructure and properties can be achieved to meet industrial requirements. In a similar case, a massive transformed microstructure with the supersaturated γ phase containing a high density of defects has been observed by rapid cooling of TiAl-base alloys from the high-temperature α phase field [6,7]. Therefore, it is interesting to investigate the possibility of refining the microstructure of TiAl-base alloy by quenching/tempering processes, instead of the conventional thermo-mechanical routes. In this paper, the effect of tempering on the microstructure and ductility of a cast Ti48Al2W0.5Si alloy was investigated after massive transformation.

II. EXPERIMENTAL

The alloy used in this investigation was provided by ABB Power Generation Ltd. In cast bars with a diameter of 16 mm under US patent 5286443. The composition of the alloy was as follows: Al = 31.5-32.3, W = 8.68-8.98, Si = 0.2-0.3, O = 0.063-0.077, N = 0.0050-0.0061, H = 0.0012-0.0050, Ti = balance. The material was hipped at 1185°C/172 MPa/3 h and then heat-treated at 1302°C/20 h(Ar)/GFC + 913°C/4 h(Ar)/GFC (GFC: gas fan cooling). Samples for heat treatment (8 × φ 16 mm) were sectioned from the bars and protected by a high-temperature glass-alumina coating. The samples were first homogenized in the single α region, namely 1375°C, for 45 min, water quenched, and then tempered at 1100-1360°C, followed by controlled furnace cooling (10 K/min to 1100°C and then air cooled) to transform the high-temperature α into the lamellar structure. Examination of the microstructure was performed using optical microscopy with an image analyzer and by transmission electron microscopy (TEM). TEM foils were thinned by mechanically polishing to about 100 μm , and then by twin-jet polishing in a solution of 95% methanol and 5% perchloric acid, at 10-15 V and -35°C ~ 40°C. The observations were carried out with a Phillips CM12 TEM at an accelerating voltage of 120 kV.

Compression tests were conducted at room temperature on a MTS testing machine at an initial strain rate of $1 \times 10^{-3} \text{ s}^{-1}$, using $5 \times 5 \times 10 \text{ mm}$ specimens.

III. RESULTS

The as-received alloy exhibits a duplex microstructure with a mean grain size of about 100 μm (Fig. 1a). Holding at 1375°C/45 min developed a structure of nearly single α grains of about 450 μm in size, and less than 1 vol.% of remnant γ ($+\beta$) phases (Fig. 1b). Water quenching produces a microstructure comprising mottled or dark patchy regions and some light featureless areas (Fig. 2a), which were revealed by TEM to be massive γ (γ_m) and retained α_2 phase, respectively, in agreement with other authors [6,7]. The high density of stacking faults, dislocations and antiphase boundaries were confirmed within the γ_m grains (Fig. 2b).

The microstructure variation of the quenched samples after tempering at temperatures of 1100°C - 1360°C is shown in Fig. 3. The strong dependence of microstructure on the temperature is clearly evident. Tempering at 1100°C/8 h leads to the heterogeneous precipitation of very fine particles on prior massive γ and retained α_2 matrix, with the massive morphology

Fig. 1: Optical microstructure of the Ti48Al2W0.5Si alloy (a) as-received and (b) homogenized at 1375°C/45 min and controlled furnace cooled.

Fig. 2: Optical microstructure of the water-quenched Ti48Al2W0.5Si alloy (a) and TEM micrograph (b) showing the high density of stacking faults, dislocations and antiphase boundaries in massive γ region.

still being partially visible (Fig. 3a). The fine precipitates were identified to be α_2 and β phases, preferably formed on grain boundaries and stacking faults (fig. 4a). After 1250°C/3 h, a dual structure consisting of γ grains and about 25 vol.% of oriented dispersoids was observed (Fig. 3b). TEM observation confirmed that the dispersoids are mostly α_2 plates or needles, and again some β precipitates (Fig. 4b). Increasing the temperature up to 1300°C, a duplex structure consisting of more than 60 vol.% of lamellar colony (70 μm) and equiaxed γ grains was produced (Fig. 3c). Most importantly, a fine fully lamellar microstructure was developed after tempering in the single alpha field (Fig. 3d); the tempered lamellar grain size is shown in Fig. 5 as a function of temperature.

Since the fully-lamellar microstructure is the most promising one for engineering applications, the properties of the fine tempered lamellar structure were compared with those of the as-received and the homogenized ones by compression tests. As can be seen in Fig. 6, the tempered fully-lamellar microstructure exhibits a fracture strain (31.5%) higher than that of the homogenized (coarse) lamellar structure (22%) and even of the as-received duplex one (25%). The tempered sample also shows a yield strength comparable to that of the duplex structure. These results confirmed that the microstructure and properties of cast

TiAl-base alloy can be significantly improved by static heat treatment, namely, quenching/tempering processes.

IV. DISCUSSION

The significant finding of this investigation is the possible of refining the microstructure of cast TiAl-base alloy by a static heat treatment, instead of the costly thermo-mechanical process. As can be seen in Fig. 5, tempering the massive transformed Ti46Al2W0.5Si alloy in the single alpha field produces a fully-lamellar microstructure with a mean grain size as fine as 170-220 μm . This observation suggested that recrystallization has occurred in the water-quenched microstructure during tempering. The driving force for recrystallization is believed to be related to the high density of faults introduced by massive transformation (Fig. 2b), in analogy with the deformation-induced defects in the thermo-mechanically processed (TMP) alloy. The tempered fine fully-lamellar microstructure is expected to have a promising combination of ductility, fracture toughness, and creep resistance as obtained in the TMP alloy [2,3]. The preliminary results in Fig. 6 confirmed the improved properties of the tempered microstructure as compared to the as-received and homogenized alloys.

Fig. 3: The microstructure variation of the water-quenched Ti48Al2W0.5Si alloy during tempering at (a) 1100°C/8 h/CFC, (b) 1250°C/3 h/CFC, (c) 1300°C/1 h/CFC, and (d) slowly heating from 1320°C to 1360°C (CFC).

The strong effect of temperature on the tempered microstructure can be rationalized on the basis of the Ti-Al phase diagram [8]. Tempering at 1300 - 1360°C, a duplex microstructure comprising equiaxed γ and fine lamellar colony was developed (Fig. 3c); the lamellar structure transformed from the recrystallized high-temperature α grains during controlled furnace cooling. At 1250°C, the α phase formed as plates or spheroids due to its low volume fraction, and during cooling it transformed into single α_2 rather than the $\alpha_2+\gamma$ lamellar structure because of its low Al concentration, thereby resulting in a dual structure of equiaxed γ and α_2 plates (Fig. 3c). As temperature decreased to

1100°C, the supersaturated massive structure can only be equilibrated by the precipitation of fine dense α_2 and β particles, due to the poor diffusivity of atoms, akin to the tempered martensite in steel.

Finally, microcracks were observed in the massive transformed microstructure. For practical application, a controlled cooling technique is needed, firstly to limit the thermal residual stress induced during quenching, and secondly to ensure a near-completely transformed massive structure; the partially transformed structure, to some extent, leads to the microstructural inhomogeneity after tempering.

Fig. 4: Bright field TEM micrographs of the Ti48Al2W0.5Si alloy tempered at (a) 1100°C/h h/CFC and (b) 1250°C/3 h/CFC.

Fig. 5: The lamellar grain size developed in water-quenched Ti48Al2W0.5Si alloy on tempering at 1340 ~ 1360°C for 1 ~ 60 min.

V. SUMMARY

1. A fine fully-lamellar microstructure (170-220 μm) can be developed in cast Ti48Al2W0.5Si alloy by tempering the quenched sample at temperatures above the alpha transus, rather than by the costly thermo-mechanical or powder metallurgical process. The preliminary compression tests

Fig. 6: Room temperature compressive stress-strain curves of the various Ti48Al2W0.5Si microstructures.

As-received: duplex (100 μm) (Fig. 1a);

Homogenized: fully-lamellar (460 μm) (Fig. 1b);

Tempered: fully-lamellar (170 μm) (Fig. 3d).

confirmed that the ductility of the tempered lamellar structure is considerably improved, relative to the homogenized fully-lamellar and the as-received duplex alloys.

2. As tempered below the alpha transus, the microstructure variation is strongly dependent on temperature. A duplex structure comprising equiaxed γ and lamellar colonies was obtained at 1300 - 1340°C, whereas a dual structure of fine γ grains and $\alpha_2(\beta)$ plates was produced at 1250°C, and fine dense α_2 and β precipitates were observed on the massive γ matrix at 1100°C.

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