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Microstructure Homogeneity of Wrought TiAl

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The effects of hot forging to various height reductions on microstructure homogeneity in two wrought TiAl based alloys were investigated. It was shown that increasing the accumulative height reduction to 85% considerably expanded the uniform flow zone and produced an almost entirely homogeneous microstructure. It was also found that minor addition of Gd resulted in complete spheroidization and recrystallization even in the stagnant zone. In addition, Gd-containing particles appeared to be beneficial in bringing about a better refined and homogenized near fully lamellar microstructure in wrought TiAl.

Keyword: microstructure homogeneity, wrought titanium aluminide (TiA1), hot die forging

1. Introduction

Titanium aluminide is a candidate substitution for both nickel and titanium based alloys because of its lower density and higher temperature tolerance. The long-range ordered structure makes it having good strength retention at high temperatures but causes its brittleness at room temperature and also the limited hot workability[1)]. Thermal mechanical processing has been considered as the most effective technology to get trade-offs of the mechanical properties at room and elevated temperatures[2,3)]. In the recent decades, the primary objective of the thermomechanically processing is to produce a chemically and microstructurally homogeneous, fine grained product of gamma titanium—aluminide alloys[4,5)]. The current challenge in ingot break-down is to convert the segregated, polyphase, multiconstituent, textured microstructure resulting from ingot melting, into a more workable and homogeneous microstructure. Multi-step hot working has been employed to accomplish this conversion efficiently[6)]. But, the lamellar structure still remained anyhow in the forged ingots since those lamellar structures were in the hard orientation towards to the load direction and therefore received less deformation[7)]. This non-uniformity is very difficult to be removed in the following heat treatments and therefore detrimental to the mechanical reliability of wrought TiAl alloys[8)].

Recent experiments showed that minor additions of Ni have significant effects in improving the steady-state flow behavior and to enlarging the process windows of TiAl[9)]. This made it possible to conduct a more severe deformation on the ingot metallurgy TiAl. Moreover, there was plenty of evidence showing that scattered precipitates could help to homogenize and refine the microstructures[10,11)]. The present research investigated the effects of increased height reduction in two-step forging, as well as the contribution of minor Gd additions, on the deformed microstructures of Ti-46.3Al-2.5V-1.0Cr-0.3Ni alloy. The duplex and near fully lamellar microstructures were also produced to further demonstrate the improved microstructural homogeneity and grain refinement in wrought TiAl.

2. Experiments

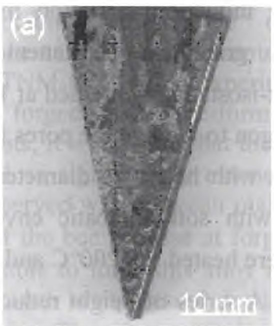
The alloys, Ti-46.3Al-2.5V-1.0Cr-0.3Ni and Ti-46.3Al-2.5V-1.0Cr-0.3Ni-0.15Gd (at.%), were prepared by cold crucible induction levitation melting, cast into 85mm-diameter graphite permanent mould and subsequently heat-isostatically pressed at 1240 — 1320°C in 120 — 150MPa argon to remove the pores from casting. The cylindrical ingots with height to diameter ratio of around 1.8 and coated with soft adiabatic envelope containing glass lubricant were heated to 1200°C and put into a pair of 1050°C hot dies. A series of height reductions as listed in **Table 1.** were chosen to evaluate their effects on the deformed microstructures. Heat treatments at 1280 and 1310°C were also conducted to further estimate the homogeneity of transformed duplex and near fully lamellar microstructures. Microstructure examinations were carried out by optical microscopy and back scattered electron images in scanning electron microscopy. Metallographic specimens were mechanically polished and those for optical observations were dip-etched in a hydro-solution containing 2%HF and 10%HNO_3 (by volume).

Table 1. Height reductions of the hot-die forging tests.

Number	Step 1	Step 2	Total
1	60%		60%
2	70%		70%
3	50%	60%	80%
4	60%	63%	85%

3. Results and discussion

Qualitatively, both the macrostructures and microstructures in the as-cast ingots of these two alloys were similar, presenting the same challenges in thermomechanical processing. The solidification and solid-state transformation processes resulted in typical structures as shown in **Figure l.** They were apparently both macroscopically and crystallographically textured as a result of the heat flow during solidification and of the crystallographic constraints on the solid-state $\alpha \rightarrow \alpha + \gamma$ transformation[11]. The Gd-rich particles (white contrast in **Figure 1c))** were found scattering both inside the lamellar colonies and at the boundaries and were qualitatively identified as either a Gd oxide or a Gd-Al intermetallic phase based on EDS analyses.



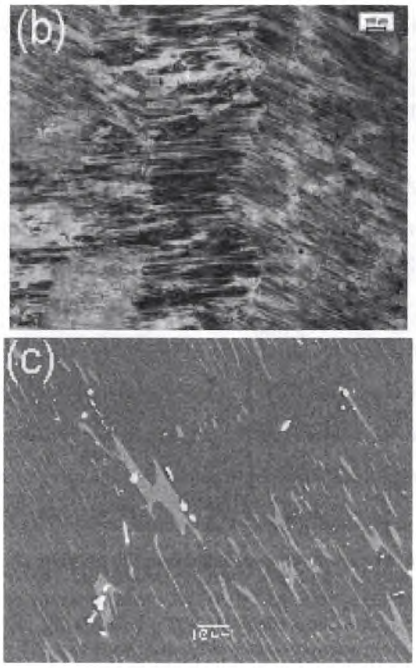


Figure 1. (a) Macrostructure and (b) microstructure of the transverse section in the as-cast Ti-46.3Al-2.5V-1.0Cr-0.3Ni ingot; and (c) back-scattered electron microstructure in the as-cast Ti-46.3A1-2.5V-1.0Cr-0.3Ni-0.15Gd ingot. Note the small white Gd-containing particles identified as either Gd oxide or Gd-Al intermetallic in (c).

Optical observation showed that the unidirectional forging produced three kinds of deformation characteristics in all the pancakes obtained, especially in those with height reduction lower than 80% as shown in **Figure 2.** The stagnant zone near the top and bottom surfaces still contained a large amount of the remnant lamellar structure. The microstructure near the free side surface exhibited insufficient recrystallization. Lamellar structures remained although some lamellae were bent by the intense deformation **(Figure 2c))**. The uniform flow occurred in the central part of the pancakes. The microstructure in this part mostly consisted of the completely spheroidized or recrystallized grains **(Figure 2.b))**.

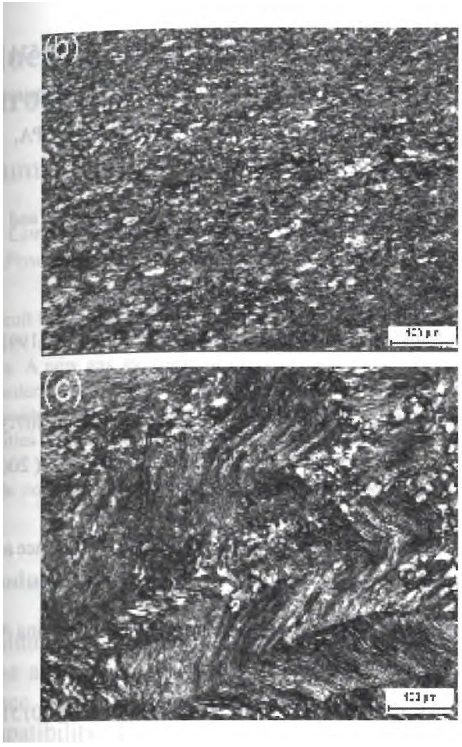


Figure 2. (a) Typical macrostructure after forging to a height reduction of 70% in Ti-46.3A1-2.5V-1.0Cr-0.3Ni, showing the stagnant zone near the top and bottom surfaces, the insufficiently recrystallized zone at the free side surface and the uniform flow zone in the middle; (b) microstructure in the uniform flow zone showing well recrystallized and spheroidized grains, and (c) microstructure in the stagnant zone showing remaining lamellae which were bent due to severe deformation.

It has been proved that the as-cast lamellar structure of TiAl exhibits significant locally-anisotropic plastic properties because of its heterogeneous and textured characteristic[12)]. Consequently, there exists a local grain-to-grain variation in the threshold strain required to induce recrystallization. It is thus desirable that a minimum macroscopic strain should be achieved throughout the material. This study indicated that increasing height reduction to 85% could expand the uniform flow zone to almost the entire volume and produce improved homogeneity of the deformed microstructure, as shown in **Figure 3.a)**. Two-step forging was employed to achieve higher accumulative macroscopic strain (>80%) without generating strain-induced defects or cracking. In addition, mi crostructure examination revealed that the alloy containing Gd displayed better homogeneity as spheroidization and recrystallization occurred completely even in the stagnant zone **(Figure3.c))** in contrast to that for the alloy without Gd in **Figure3.b).** The Gd-rich particles were distributed preferentially along the deformation bands.

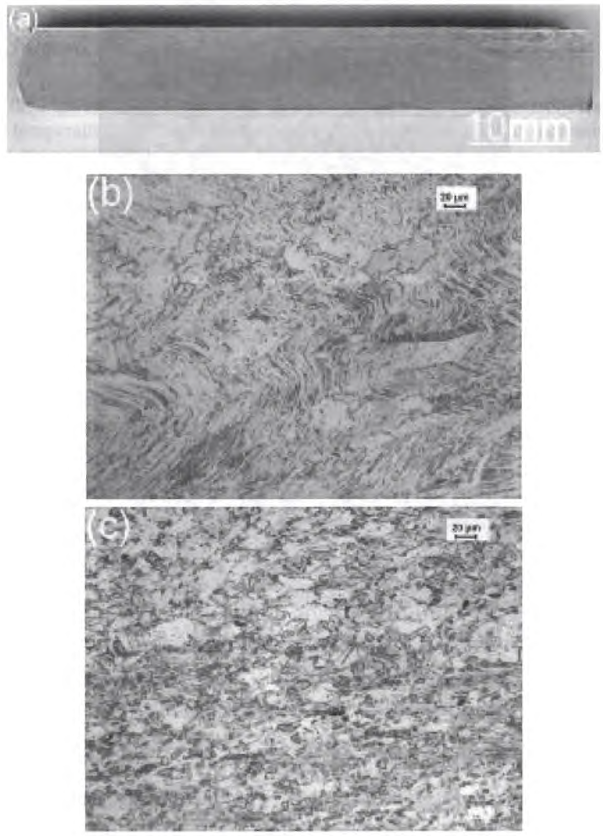


Figure 3. (a) Macrostructure of a Ti-46.3A1-2.5V-1.0Cr-0.3Ni pancake forged to 85% height reduction, and the microstructures in the stagnant zones of (b) Ti-46.3A-2.5V-1.0Cr-0.3Ni and (c)Ti-46.3A-2.5V-1.0Cr-0.3Ni-0. 15Gd, respectively.

The duplex and near fully lamellar microstructures were obtained by annealing the Ti-46.3Al-2.5V-1.0Cr-0.3Ni and Ti-46.3Al-2.5V-1.0Cr-0.3Ni-0.15Gd alloys after 85% forging. It was found that the near fully lamellar microstructure in the Gd-containing alloy consisted of better refined and homogenized lamellar colonies, as shown in **Figure 4.**. The average colony size was 34.6 μm compared to 62.8 μm in Ti-46.3Al-2.5V-1.0Cr-0.3Ni. This suggests that the Gd-containing particles retarded the growth of the α grains during the heat treatment. They were found homogeneously both inside the lamellar colonies and at the boundaries. On the other hand, there was no obvious difference between the duplex microstructures in the two alloys probably because the mutual pining of the α and γ grains was sufficiently effective in stopping grain growth without needing the Gd-containing particles.

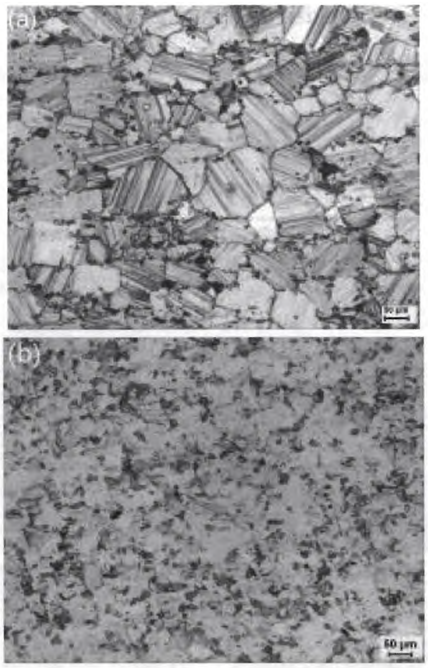


Figure 4. Near fully lamellar microstructures after heat treatment of the 85% forged (a) Ti-46.3Al-2.5V-1.0Cr-0.3Ni and (b) Ti-46.3Al-2.5V-1.0Cr-0.3Ni-0.15Gd alloys, showing much refined and homogeneous colonies in the latter.

4. Conclusions

(1) Forging to an accumulative 85% height reduction can produce sufficient macroscopic strains throughout the TiAl ingots so that a uniformly recrystallized microstructure was produced in almost the entire volume.
(2) Minor addition of Gd further improves the microstructure homogeneity in the intensively forged TiAl pancake. Complete spheroidization and recrystallization occurred even in the stagnant zone.
(3) The Gd-containing particles appeared to be effective in producing a better refined and homogenized near fully lamellar microstructure.

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