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Effects of rolling deformation on microstructure and hardness of Ti-45Al-9Nb-0.3Y alloy

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Abstract: The microstructure evolution of as-rolled Ti-45Al-9Nb-0.3Y alloy as well as the nanohardness of β/B2 matrix was investigated by means of scanning electron microscopy (SEM) in backscattered electron mode (BSE) mode, transmission electron microscopy (TEM) and nanoindentation. This high Nb containing TiAl based alloy was rolled with 50%, 60%, 65% reduction, respectively. Omega phase precipitated in B2 phase with an orientation relationship of $\{110\}_\beta//\{11\bar{2}0\}_\omega$ and $<1\bar{1}1>_\beta//<0001>_\omega$. Moreover, with the increase of deformation reduction, rod-like structure which was formed in γ grain transformed from (α_2+γ) lamellae structure into α_2 phase only. Additionally, nanoinentation experiment revealed that the precipitation hardening of ω phase increased the hardness of β/B2 phase.

Keywords: high Nb containing TiAl based alloy; TNB alloy; hot rolling; omega phase; phase transformation; nanohardness; rare earths

γ-TiAl based alloys are a promising high temperature structure materials used in aerospace, automotive and industries due to their low density, high temperature strength and good high temperature oxidation resistance[1–3]. After the first commercial application of γ-TiAl based alloy by Mitsubishi at their Lanser 6 sports car in 1999, Boeing aero-engine manufacturer utilized investment cast γ-TiAl blades in the low-pressure turbine[4–6]. High Nb containing TiAl based alloy (so-called TNB alloy) which has high special strength, excellent creep resistance has been considered as the most promising alternative material to replace superalloy in aerospace industries[7–9].

By alloying with Nb element, the strength of TNB alloy has been remarkably increased, which limits their hot working deformation properties, such as hot forging and hot rolling[10]. However, as a β phase stabilizing element, Nb could extend the β phase region which significantly improved hot workability by providing a sufficient number of independent slip systems in β phase during plastic deformation at elevated temperature[11]. TNB alloy sheets could be produced by canned rolling within a three phase field or a two phase field which contains β phase. Up to now, TNB alloy sheets reported in literature are nearly prepared by powder metallurgy (PM)[12]. TNB alloy sheets obtained by ingot metallurgy processing are not reported in literatures as we know.

Omega phase (ω phase) not only precipitated in TNB alloy after moderate cooling from a β/B2 phase containing field region to room temperature, but also precipitated from β/B2 phase and α_2 phase during thermal exposure within TNB alloy service temperature range[13,14]. The coexistence of ω phase and β/B2 phase was reported to be detrimental to high temperature strength and ductility of TNB alloy, but fine ω phase precipitate was reported to increase creep resistance[15]. However, the previous research did not pay attention to the effect of ω phase on the hot-worked TNB alloy, especially the hardness of β/B2 phase. A detailed study on the coexistence structure of ω phase and β/B2 phase after hot-working is needed to clarify the role of the precipitation of ω phase.

In this paper, the Ti-45Al-9Nb-0.3Y alloy sheet material was fabricated by ingot metallurgy processing. The evolution of microstructure of Ti-45Al-9Nb-0.3Y alloy with different rolling deformation was investigated. In order to understand the influence of the ω phase on the hardness of β/B2 phase, nanoindentation experiment was carried out on β/B2 phase coexisting with ω phase after different rolling reductions.

1 Experimental

Ti-45Al-9Nb-0.3Y alloy ingot was prepared by induction skull melting (ISM) technology in a water cooled

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copper crucible. After homogenization heat treated at 900 ºC for 48 h, hot isosatic pressing (HIPing) was conducted for 4 h at 1250 ºC under a pressure of 170 MPa in Ar atmosphere. The homogeneous ingot was then canned by 304 stainless steel and thermomechanically treated at 1200 ºC with a reduction of 75%. Annealing treatment was conducted at 1000 ºC for 48 h. The process of thermomechanical treatment has been reported in the literature[16].

After thermomechanical treatment, the as-forged alloy was then cut into pieces which were packed in stainless steel can. The canned wrought alloy was rolled on a mill with two rolls of 200 mm in diameter and 300 mm in width. The canned sample which is rolled about 10 passes with a nominal reduction per pass of approximately 7%–10% is preheated at the temperature of 1250 ºC for about 2.5 h, and is reheated between two rolling passes for about 20 min at the temperature of 1250 ºC also. The nominal rolling speed was below 0.5 m/s. After rolling, the rolled sheet was annealed at 1250 ºC and furnace cooling to room temperature. The canned pieces were totally rolled with a reduction of 50%, 60% and 65%, respectively.

Microstructures were analyzed via scanning electron microscopy (SEM) in backscattered electron mode (BSE), transmission electron microscopy (TEM). Scanning electron microscopy technology with a FEI Quanta 200FEG field-emission environmental scanning electron microscope was used. The mechanically polished specimens for SEM were etched in a modified Kroll's reagent of 10 vol.% HF, 4 vol.% HNO_3 and 86 vol.% H_2O. TEM investigations were performed in a FEI Tecnai G2 F30 operated at 300 kV. Specimens for TEM observation were prepared using standard procedures by an ion beam thinner. Phases were determined by an X-ray spectrometer (XRD), which was carried out using Cu Kα radiation (λ=0.154157 nm) and 2θ from 20º to 90º. Nanohardness of β/B2 phase in as-rolled alloy was conducted by a nano-hardness tester. For each grain, 5 indentations were performed to obtain statistical values of hardness.

2 Results and discussion

Fig. 1 shows the microstructures of as-forged Ti-45Al-9Nb-0.3Y alloy. After canned forging, the microstructure is composed of fine equiaxed γ grains, residual crashed (α_2+γ) lamellar colonies and discontinuous β/B2 phase which are distributing along grain boundaries. The volume fraction of residual colony is about 4%. The grain size is merely in the range of 20–40 μm which is much smaller than that of as-cast alloy. Thermo-mechanical treatment could refine grain size and increase high temperature deformation properties and room temperature ductility remarkably[17,18]. Phase composition of as-forged alloy analyzed by the X-ray diffraction technology is shown in Fig. 1(c)). The result confirms that the as-forged alloy mainly consists of γ phase, β/B2 phase and α_2 phases.

Fig. 2 is the microstructure of as-rolled alloy, showing the three dimensional graphs of rolling direction (RD), transverse direction (TD) and normal direction (ND). The microstructure of as-rolled Ti-45Al-9Nb-0.3Y alloy is typically near gamma (NG) structure which is mainly composed of equiaxed γ grain and lump shaped β/B2 phase separating along grain boundaries. Y element added in the material is in the form of Al_2Y phase which is white particle smaller than β/B2 phase and is beneficial to refining grain size and lamellar spacing[2,19,20]. No directional structures are found in the as-rolled materials observed in three dimensions in Fig. 2, which is similar with other researchers' reports in the literatures (e.g. Refs. [21,22]). As shown in Fig. 2, the largest grain size of as-rolled material is about half larger than that of as-forged alloy. The reason why grain grows during hot rolling process is that being reheated at 1250 ºC between two passes provides the energy of grain growth. This reason had been reported by authors in other paper[16]. Stacking fault energy (SFE) is an important factor that effects the dynamic recrystallization efficiency during hot working process[23]. The low SFE of TiAl based alloy restricts the occurrence of dynamic recovery and is in favor of dynamic recrystallization (DRX)[24]. The volume fraction of DRX grains increases with the increase of strain and strain rate, with the decrease of deformation temperature. In this hot rolling process, temperature is relatively high and deformation is small in every pass

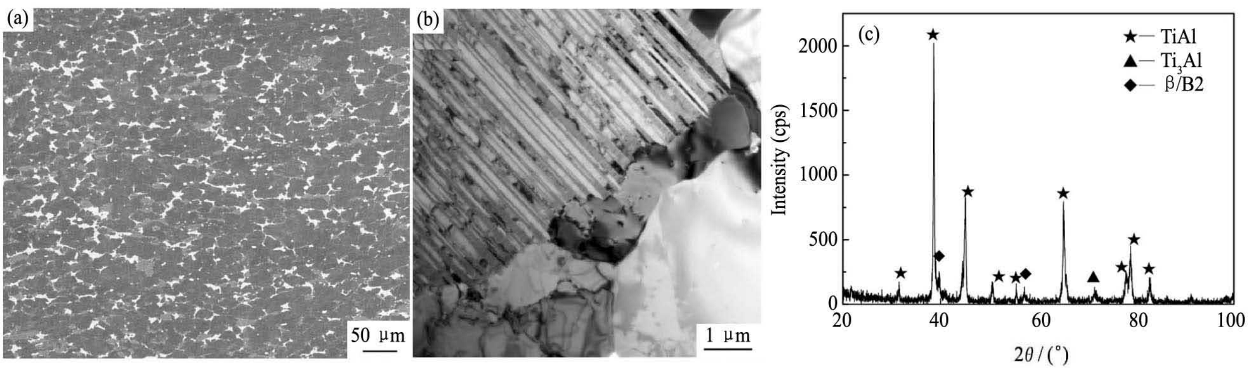

Fig. 1 Microstructures and phase composition of as-forged Ti-45Al-9Nb-0.3Y alloy
(a) BSE micrograph of as-forged alloy; (b) TEM micrograph of as-forged alloy; (c) XRD pattern of as-forged alloy