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Microstructural investigations for laser welded joints of Ti–22Al–25Nb alloy sheets upon large deformation at elevated temperature

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ABSTRACT

In order to provide reference for the gas forming of Ti–22Al–25Nb alloy tube blanks with a laser beam welded joint, microstructure and tensile deformation behavior of the alloy with a joint were investigated using uniaxial tensile tests at 990 °C, with a tensile speed of 0.016 mm/s. Both of the samples with a longitudinal joint and a transverse joint were applied in the tensile tests. The longitudinal joint samples showed a better high temperature deformability than the transverse joint ones, which partly attributed to the decrease of α_2-phase grains along the β/B2-phase grain boundaries and more dynamic recovery and discontinuous dynamic recrystallization in the longitudinal joint. These results indicated that the laser welded joint could experience a large deformation at a proper temperature and strain rate, which was a potential method for the preparation of tube blanks for gas forming components.

1. Introduction

As a kind of lightweight material with high specific strength and good creep resistance performance at the temperature ranging from 600 °C to 800 °C, Ti_2AlNb-based alloys have been attracting much attentions as the potential intermediate-temperature structural materials [1,2]. To produce thin-walled hollow components with complex cross-section shapes, gas forming process was presented and verified effective for titanium alloy tubes [3,4]. The gas forming components of Ti_2AlNb-based alloy have a great application prospect in aerospace. However, for Ti_2AlNb-based alloys, it is difficult to obtain thin-walled tube blanks. Especially, if the products need blanks with a diameter larger than 200 mm and only 2 mm in thickness, a rolling and welding process could be the most efficient and economical way for producing the tube blanks. Then, the thin-walled hollow components can be formed with gas forming by using the welded tube blanks. In this case, the formability of the weld seam has significant effects on the forming process of the components.

Many efforts have been devoted to improve the welding properties of Ti_2AlNb-based alloys. A laser beam as a concentrated energy source provides the possibility for the development of high power fiber laser [5–8] which has been well utilized for the joining of such alloys. The well-quality joints without cracks and porosities can be obtained for the Ti–22Al–27Nb (at.%) alloys using laser beam welding method [8]. For the purpose of evaluating the service properties of the welded parts, the elongation of the weld seam was tested at ambient temperature (e.g. 20 °C) and some typical service temperatures (e.g. 650 °C). Wu et al. [7] researched the laser beam welding of a Ti–24Al–17Nb (at.%) alloy and carried out the three-point bending test and the transverse tensile test of the joints. The results indicate that the weld microstructure primarily consists of B2 phase. The welding parameters have no effect on the phase constitution but the microstructure size and orientation. The inducing crack strain and the fracturing strain decrease with the increasing heat input when the joints are subjected to longitudinal three-point face bend tests at ambient temperature. The ductility will decrease seriously as the solidification structure exhibits obvious orientation, particularly when the columnar crystal direction is perpendicular to the tensile direction. The laser welded experiments and the same transverse tensile tests of the joints reported by Lei et al. [5] show the similar results on the weld metal ductility at ambient temperature. Microstructure analysis shows that cellular grains whose orientation is perpendicular to the boundary between the fusion zone and the heat affected zone are generated in the weld. The microstructure of the weld metal is composed of B2 phase, due to the fast cooling rate in the laser beam welding process and the high content of niobium. At the service temperature of 650 °C, the average tensile strength of the joints is about 733 MPa, with an elongation of 2.93%. The limited number of O phase slip systems is considered to be responsible for the low ductility values. The fracture surface shows an intergranular fracture feature.

However, currently the published results are mainly focused on the mechanical properties and the microstructure evolution of joints at the ambient temperature and some service temperatures. To form a

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component with complex shape from the welded tube blanks by gas forming, the deformability of the joint at a proper forming temperature must be investigated firstly.

The formability of the rolled sheet of Ti_2AlNb-based alloys has been investigated by a lot of scholars from several countries. Lin et al. [9] carried out the gas forming of a Ti–22Al–25Nb alloy sheet at 970 °C. For most Ti_2AlNb-based alloys sheets, generally the suggested proper forming temperature ranges from 950 to 1000 °C [8], which is in the $(\alpha_2 + O + B2)$ or $(\alpha_2 + B2)$ phase field [10]. In this temperature range, the elongation of Ti_2AlNb-based alloys sheets has the maximum value in the strain rate range of 10^{-4}–$10^{-1}\ s^{-1}$ [11]. Therefore, it is necessary to investigate the microstructure and deformability of the Ti_2AlNb-based alloys with a laser beam welded joint in the temperature range of 950–1000 °C. Additionally, during the gas forming process, the joint inevitably undergoes longitudinal and transverse strain. However, such investigations have been rarely documented.

The alloy with a nominal composition of Ti–22Al–25Nb (at.%) is a significant member of the Ti_2AlNb-based alloy group because of its excellent mechanical properties [12]. The work by Zhang et al. [13] showed that a microstructure of fine equiaxed α_2 and O phases distributing in B2 matrix showed excellent superplasticity in the temperature range of 900–1000 °C. Zhang et al. [14] reported that with the increase of the solution temperature, the slender secondary O laths increased, which made the strength increase and the ductility decrease. A high-temperature B2 phase incorporated in the Ti–22Al–25Nb alloy further improves ductility [15]. For the dissimilar joining of the Ti–22Al–25Nb alloy and TC11 titanium alloy, the O/α_2 particles not only strengthen the tensile strength, but also embrittle the coarse boundaries [16]. In this paper, the microstructure and tensile mechanical properties of a laser welded Ti–22Al–25Nb alloy joint deformed at 990 °C were investigated with both longitudinal joint and transverse joint samples.

2. Experimental procedure

The as-received material with a nominal composition of Ti–22Al–25Nb was a hot-rolled sheet with a thickness of 1.5 mm, consisting of β/B2, α_2 and O phases. Fig. 1 shows the phase and grain boundary distribution maps, kernel average misorientation (KAM) maps and polar figures (PFs) of the as-received sheet. The volume fractions of β/B2, α_2 and O phases were respectively 36%, 40.6% and 23.4%. O and α_2 phases homogeneously distributed in the β/B2-phase matrix. The high angle grain boundaries (HAGBs, 15°–180°) were still dominant in the as-received sheet. HAGBs are generally caused by dynamic recrystallization (DRX) and grain coarsening through the consumption of the neighboring grains [17], while the low angle grain boundaries (LAGBs, ≤15°) usually derive from the movement and rearrangement of dislocations [18]. Fig. 1b shows the KAM maps where colors with high values represent high residual stress meaning high dislocation density [19]. The volume fraction of regions with low residual stress (KAM ≤ 1) of the entire base metal (BM) was about 64.8%. As regards β/B2 phase, the fraction of regions with a KAM value ≤1 was 55.9% which was calculated by the area of regions with a KAM value ≤1 in β/B2 phase divided by the total area of β/B2 phase. Similarly, the fractions of regions with a KAM value ≤1 in α_2 and O phases were 76.7 and 67.1%, respectively. Fig. 1c shows that β/B2 phase possesses a typical rolling texture

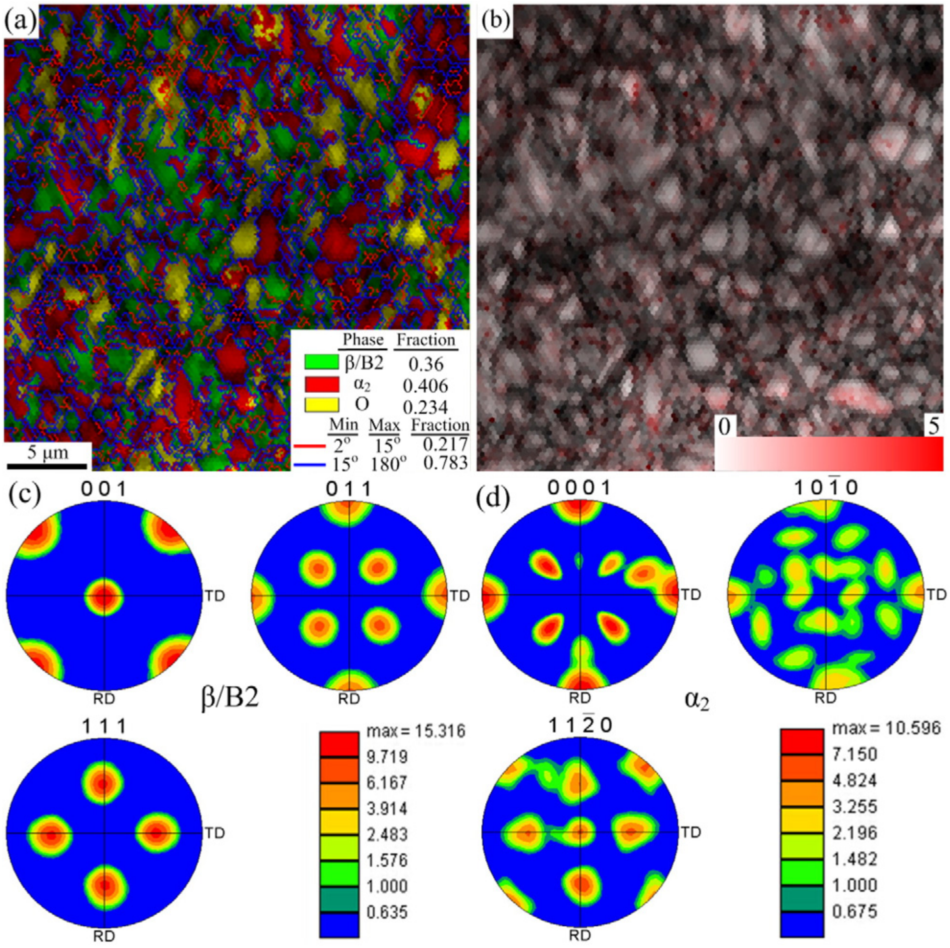

Fig. 1. Phase and grain boundary distribution maps (a), kernel average misorientation maps (b) and polar figures (c, d) of β/B2 and α_2 phases of the as-received Ti–22Al–25Nb alloy.