Acta Materialia 126 (2017) 145–153

Contents lists available at ScienceDirect

Acta Materialia

journal homepage: www.elsevier.com/locate/actamat

Full length article

Effect of hot rolling and primary annealing on the microstructure and texture of a β-stabilised γ-TiAl based alloy

Petra Erdely [a, *], Peter Staron [b], Emad Maawad [b], Norbert Schell [b], Joachim Klose [c], Svea Mayer [d], Helmut Clemens [d]

[a] Recipient of a DOC Fellowship of the Austrian Academy of Sciences at the Department of Physical Metallurgy and Materials Testing, Montanuniversität Leoben, Roseggerstr. 12, A-8700 Leoben, Austria
[b] Institute of Materials Research, Helmholtz-Zentrum Geesthacht, Max-Planck-Str. 1, D-21502 Geesthacht, Germany
[c] GfE Fremat GmbH, Lessingstr. 41, D-09599 Freiberg, Germany
[d] Department of Physical Metallurgy and Materials Testing, Montanuniversität Leoben, Roseggerstr. 12, A-8700 Leoben, Austria

ARTICLE INFO

Article history:
Received 25 November 2016
Received in revised form
19 December 2016
Accepted 21 December 2016
Available online 30 December 2016

Keywords:
Titanium aluminides
Texture
Microstructure formation
X-ray synchrotron radiation
Processing

ABSTRACT

Titanium aluminide alloys based on the ordered γ-TiAl phase are intermetallic materials well suited for lightweight high-temperature applications. The TNM alloys, a specific, β-solidifying group among them with a nominal composition of Ti-43.5Al-4Nb-1Mo-0.1B (at.-%), offer a homogeneous and fine-grained microstructure upon casting. This advantage has been exploited to develop a lab-scale hot rolling process in which a cost-effective ingot breakdown of the starting material is omitted. The present work establishes a fundamental understanding of the processes prevailing in the material during hot rolling and primary annealing. Microstructural analysis and texture measurements conducted at a synchrotron radiation source allow to study deformation, recovery, recrystallisation, as well as phase transformation mechanisms in detail. Different hot rolling procedures conducted within the (α+β) and (α+β/β$_o$+γ) regions of the phase diagram are considered and investigated with regard to the prevalent mechanisms. Hot rolling in the (α+β) region entails an α$_2$ phase texture novel in γ-TiAl based alloys. Hot rolling in the (α+β/β$_o$+γ) region near the γ-solvus temperature particularly promotes the breakdown of the initial microstructure in TNM alloys. A specially designed hot rolling process prevents the accumulation of a modified cube texture component in the γ-TiAl phase that is typically linked to anisotropic mechanical properties.

1. Introduction

Intermetallic γ-TiAl based alloys provide a combination of engineering properties that are essential for lightweight high-temperature applications. Especially their low density, high strength at elevated temperatures, and good oxidation and hot gas corrosion resistance suggest their utilisation, for example, as structural materials in aerospace applications. For some of these applications, γ-TiAl based alloys have been processed and used in the form of hot-rolled sheets [1–5]. Due to their attractive properties, the potential of γ-TiAl based sheets is large. Nevertheless, they are not yet fully commercialised as they are difficult to manufacture. Details on the sheet rolling of TiAl alloys, which is a multi-pass process, are reviewed for so-called 2nd generation γ-TiAl based alloys in Refs. [1,2], including a discussion on the advantages and disadvantages of different prematerial routes, i.e. ingot and powder metallurgy.

For the hot rolling of γ-TiAl based alloys, the demands on the starting material are uncompromising. To obtain a crack-free sheet within the narrow range of processing parameters, the microstructure has to be fine-grained and free from inhomogeneities [1]. When ingot material is used, it is usually subjected to a thermomechanical processing, i.e. an ingot breakdown, prior to hot rolling [3]. However, for γ-TiAl based alloys that solidify via the body-centred cubic (bcc) β phase instead of following a peritectic solidification path, a preceding ingot breakdown can be omitted as has recently been demonstrated [5–7]. In the β-solidifying TNM alloys, which represent a particular group of γ-TiAl based alloys with a

* Corresponding author.
E-mail addresses: petra.erdely@unileoben.ac.at (P. Erdely), peter.staron@hzg.de (P. Staron), emad.maawad@hzg.de (E. Maawad), norbert.schell@hzg.de (N. Schell), joachim.klose@gfe.com (J. Klose), svea.mayer@unileoben.ac.at (S. Mayer), helmut.clemens@unileoben.ac.at (H. Clemens).

http://dx.doi.org/10.1016/j.actamat.2016.12.056
1359-6454/

nominal chemical composition of Ti-43.5Al-4Nb-1Mo-0.1B (in at.-%), the ensuing hot rolling is additionally facilitated due to an elevated amount of β phase present at high temperatures [8–10]. The β phase in the TNM alloy is deliberately stabilised by the alloying elements Nb and Mo, which in combination give its name to this class of alloys [11]. The as-cast and hot-isostatically pressed microstructure is equiaxed, fine-grained, homogeneous, and basically free from segregation or texture [12].

At room temperature, TNM alloys consist primarily of the three intermetallic phases α_2-Ti_3Al ($D0_{19}$ structure), β_o-TiAl (B2 structure), and γ-TiAl ($L1_0$ structure). Two of these phases, α_2 and β_o, undergo an order/disorder transition at elevated temperatures ($T_{eut} = 1160–1175$ °C and $T_{\beta o \rightarrow \beta} = 1175–1205$ °C [13]) and thereby form the related α (A3 structure) and β phase (A2 structure). Upon heating, the γ-TiAl phase remains ordered until reaching its dissolution temperature $T_{\gamma,solv}$ at roughly 1255 °C [13], the exact transformation temperatures being dependent on the actual chemical composition of the material. TNM alloys can be hot-rolled in different regions in the phase diagram under a variety of conditions regarding the predominating phase fractions [5]. As a result, different microstructures and textures can be created.

First texture measurements on γ-TiAl based alloys have been conducted in the nineteen-nineties by Fukutomi et al. [14] and Hartig et al. [15,16]. They investigated the formation of texture in the γ phase upon compression, and its stability in the course of recrystallisation and heat treatments. Following rolling experiments, Hartig et al. [15] described the appearance of a cube-like recrystallisation component, which is today known as modified cube texture. Bartels et al. [3,17] investigated the development of textures during casting, thermo-mechanical treatments, hot rolling in the (α+γ) region, and primary annealing of γ-TiAl sheets. The appearance of the modified cube texture within the γ phase was linked to the anisotropic mechanical properties of the sheets [17]. As a result of the higher amount of α/α_2 phase in hot-rolled TNB and γ-TAB alloys, Schillinger et al. [18] described for the first time the deformation texture of the α_2 phase in γ-TiAl based alloys. Due to similarities to textures reported for two-phase Ti-base alloys, the established terminology of basal and transverse texture components was chosen to describe the main textural features. The deformation texture of the β/β_o phase in γ-TiAl based alloys has been described by Stark [19], who investigated the hot rolling of Nb-rich TNB alloys. The texture of the β_o phase was found to be composed of texture components characteristic of bcc metals.

In all of these previous studies, hot rolling was performed either in the (α+γ) region, or in the ($\alpha+\beta/\beta_o+\gamma$) region with minor amounts of β phase. However, besides hot rolling in the ($\alpha+\beta/\beta_o+\gamma$) region with adjustable phase fractions (e.g. majority of α phase, majority of γ phase, or both with respect to β), TNM alloys offer the opportunity to be hot-rolled in the (α+β) region. This opportunity introduces deformation mechanisms and transformation pathways not yet investigated in γ-TiAl based alloys. In this regard, a type of α_2 texture novel in γ-TiAl based alloys is reported and explained in the present work.

By adopting the approach of texture measurements using synchrotron radiation [20,21], the present work establishes a correlation between deformation, recovery, recrystallisation, and phase transformations and the hot rolling temperature as an important processing parameter. In this context, the impact of these fundamental mechanisms on the microstructure and texture of β-stabilised TNM alloys is detailed. An original approach to minimise the accumulation of texture components typically linked to anisotropic mechanical properties is proposed, underlining the importance of fundamental studies for process design and optimisation.

2. Material and methods

2.1. Material and processing

The material used for the present study was produced by GfE Metalle und Materialien GmbH, Germany. Prematerial of a nominal chemical composition of Ti-43.5Al-4Nb-1Mo-0.1B (in at.-%) was vacuum arc remelted and cast to ingots (slugs) [11]. The ingots were encapsulated and hot-isostatically pressed (HIP) for 4 h at 1200 °C and 200 MPa. The microstructure of the cast/HIP TNM material, which represents the initial state relating to the hot rolling experiments, is fine-grained and homogeneous (Fig. 1). Small, globular or partly plate-like α_2, β_o, and γ grains surround lamellar α_2/γ colonies of sizes roughly below 50 μm. In the colonies, a small fraction of precipitated β_o is present [22].

The cast/HIP ingots were hot-rolled at different temperatures as indicated in Fig. 2. The hot rolling was laid out as a multi-pass process including reheating segments as described in Refs. [1,2]. The nominal furnace temperatures defining the three different temperature ranges were 1350 °C (region A), 1200 °C (region B), and 1250 °C (region C), respectively. In Fig. 2, temperature ranges are given due to the inevitable cooling during hot rolling. The reduction per rolling pass was set to 10%. Eventually, the sheets were furnace-cooled close to industrial processing conditions. Due to reasons of confidentiality, further processing parameters cannot be disclosed in the present work.

The primary annealing (PA) after the hot rolling was conducted for 1 h at 1100 °C in the ($\alpha_2+\beta_o+\gamma$) region using a vacuum furnace. The aim of this heat treatment was the removal of residual stresses and the flattening of the sheets, while phase fractions approach stable thermodynamic equilibrium conditions [1]. After cooling, the sheets were ground to their ultimate sheet thickness t ranging from 0.8 to 2 mm.

2.2. Experimental techniques

The texture measurements were conducted at the side-station P07B of the high-energy materials science (HEMS) beamline of HZG at PETRA III, DESY, Germany. Prismatic specimens with a cross-section of $t \times 1.2t$ mm^2 and a length of 20 mm were cut from the sheets. The rolling direction was oriented parallel to the largest dimension. The specimens were mounted on a goniometer such that the rolling direction pointed upwards along the ω rotation axis, while the incoming X-ray beam impinged in transmission geometry perpendicularly to this axis onto the specimen. For the measurements a mean energy of 87 keV corresponding to a wavelength of 0.1424 Å was used. During exposure, the specimens were rotated around the ω axis through 180° in steps of $\Delta\omega = 5°$. A Perkin Elmer 1622 flat panel detector with a pixel matrix of 2048 × 2048 and a pixel size of 200 μm was used to record the 37 resulting diffraction patterns for each specimen. Prior to the measurements, the setup was calibrated using a LaB_6 powder.

The software programme Fit2D [23] was used for the integration of azimuthal sections of the diffraction patterns. For the α_2 phase, the $(20\bar{2}0)$, $(20\bar{2}1)$, and $(20\bar{2}2)$ rings were used, for the β_o phase the (110) and (200) rings, and for the γ phase the (001), (002), (200), and (112) rings (Fig. 3). Using the in-house software package SABO, the intensity distribution along the selected Debye-Scherrer rings was transformed into pole figures as explained in detail in Ref. [24]. In the calculations, corrections for the changing volume and absorption were included. For the estimation of the orientation distribution functions (ODFs), as well as for the recalculation of pole figures not accessible by direct measurement, the Matlab toolbox for quantitative texture analysis (MTEX) [25] was used. De la Vallée Poussin kernels of a half width and resolution of 5° each were