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The order/disorder transformation of β phase in binary and ternary γ TiAl based alloys studied by synchrotron and neutron diffraction

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Introduction

Due to their high melting point, low density, and good oxidation resistance, γ-TiAl based alloys have recently started to replace Ni-based superalloys as a material for turbine blades in aircraft engines [1]. Conventional TiAl alloys usually contain the ordered phases γ-TiAl and α2-Ti3Al at lower temperatures and disordered α-Ti(Al) phase at higher temperatures. Additional alloying elements like Nb, Mo, Ta, Cr or Fe, can stabilize the disordered β-Ti(Al) phase (A2 structure), which can transform at lower temperatures to ordered βo-TiAl (B2 structure) or even to more complex phases like τ_2 or ω.

The ductile body centered cubic (bcc) β phase is important for processing because it significantly improves the hot forming behaviour of the material. Otherwise the ordered low temperature βo phase is said to embrittle the material at service temperature. Unfortunately little is known about the exact order/disorder transformation temperatures of β/βo in several ternary alloy systems and the influence of β stabilizing elements is still under research. Additionally, even for the binary TiAl phase diagram the existence of an ordered βo phase field at high temperatures has yet not been finally proofed or rebutted [2].

With conventional in situ investigation methods like differential scanning calorimetry (DSC) an unambiguous assignment of a certain peak to the βo↔β transformation is not possible in TiAl alloys. X-ray diffraction (XRD) measurements are also not suitable because the superstructure reflections are very weak due to the small electron density differences of the different atom sites in the ordered crystal structures. However in situ neutron diffraction (ND) is most suited to study order/disorder transformations in titanium aluminides [3,4]. The neutron scattering lengths of Ti and Al are almost equal in magnitude but of opposite sign. Thus disordered phases, with a Ti:Al ratio close to one, yield only very weak diffraction peaks, because the average scattering length is almost zero. The fundamental reflections in ordered TiAl crystal structures are also very weak because the scattering lengths of Al sites and Ti sites with their opposite sign add up. However the superstructure reflections of these ordered TiAl crystal structures become rather large, because they contain the difference of the scattering lengths of each site.

Materials and Methods

We studied three binary TiAl alloys (Ti-xAl with x = 39, 42 and 45) and five alloys with additional alloying elements (Ti-42Al-2y with y = Nb, Mo, Ta, Cr and Fe). The alloys were produced by arc melting under Ar atmosphere. The melt buttons were remelted 5 times to ensure chemical homogeneity and subsequently heat-treated at 1100℃ for 5 days in order to homogenize the microstructure.

In situ ND measurements were performed in the materials science diffractometer STRESS-SPEC at FRM II in Garching near Munich (Germany). We used a gauge volume of 390 mm3 and a wavelength of 2.1 Å. The detector covered the q-range of 1.7-2.3 2πÅ-1 which enables to monitor superstructure reflections of all three ordered phases simultaneously, namely α2 101, βo 100 and γ 110. A vacuum high temperature furnace was used for the heat treatments and the samples were stepwise heated in a range from 1100℃ up to 1440℃ with a minimum step width of 10℃ in ranges of special interest. The exposure time was varied from 20 minutes to 1 hour in order to have a small peak to background ratio.

Complementary in situ synchrotron XRD measurements were performed in the High Energy Material Science

(HEMS) beamline at DESY in Hamburg, Germany. In order to penetrate the 5 mm thick samples high-energy X-rays with a photon energy of 100 keV, corresponding to a wave length of 0.124 Å, were used. The gauge volume was 5 mm3. The heat treatments were performed in a DIL805A/D dilatometer with a heating rate of 5 K/min from 1000-1250 ℃ and 20 K/min from 1250-1450 ℃. Complete Debye-Scherrer diffraction rings up to a q-value of 5.5 2πÅ-1 were continuously recorded on a PerkinElmer XRD 1621 flat panel detector with a frame rate of 0.15 Hz and an exposure time of 3 s.

Results and Discussion

During the in situ ND measurements the superstructure reflection βo-100 was never observed in the binary TiAl alloys [5]. However the in situ high-energy XRD experiments clearly show the formation of disordered β phase at about 1360 ℃ and 1400 ℃ for Ti-42Al and Ti-45Al respectively. These results proof the direct transformation of disordered α to disordered β in the binary Ti-Al phase diagram without the formation of a high temperature ordered βo-TiAl phase.

In three alloys with β-stabilizing elements, namely with Fe, Mo and Cr, the superstructure βo reflection was observed by ND [5]. The synchrotron experiments show that after the order/disorder transformation β is stable up to the highest temperatures in these alloys.

The ternary alloys with Nb and Ta behave similar to the binary alloys. No superstructure βo reflection was observed by ND, but the high-energy XRD measurements show the formation of disordered β at the highest temperatures. This indicates that Nb and Ta are significantly weaker β-stabilizing elements than Fe, Mo and Cr. Results of the data analysis for neutron and synchrotron data in comparison to each other will be shown.

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