Borides in advanced gamma titanium aluminide alloys

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A reduction of fuel consumption and greenhouse gas emissions requires the development of novel engineering materials which combine light weight with high strength at elevated temperatures. Among these, intermetallic γ-TiAl based alloys are the most promising candidates for replacing the twice as dense Ni base super-alloys in high temperature applications such as turbine blades in aviation and industrial gas turbines [1].

One important aspect for an industrial mass production of TiAl components is the development of near net shape production routes, such as casting or forging. However, in the as-cast condition TiAl alloys can suffer from coarse microstructures and pronounced casting textures whereas forging can result in strong deformation textures. Alloying with boron can reduce these undesirable effects. Hereby titanium borides are formed which can act as grain refiners or induce dynamic recrystallization during forging or static recrystallization during subsequent heat treatments. Thus a more homogeneous and refined microstructure is obtained. Nevertheless, microstructure control is still problematic, since the refinement mechanism of borides is not well understood [2].

Borides can serve as nucleation sites for several alloy matrix phases during solidification as well as during solid state transformations. The nucleation potency and thereby the grain refinement potential of the borides mainly depends on the crystal lattice orientation relationship between boride and matrix phase. However, four different titanium boride phases have been observed in γ-TiAl based alloys: the hexagonal di-boride TiB₂ (C32 structure, P6/mmm), two kinds of orthorhombic mono-borides TiB, one with B2₇ structure (Cmcm) and a second, which is assumed to be metastable, with Bf structure (Pnma) and at last an orthorhombic intermediate boride Ti₃B₄ (D7b structure, Immm). Up to now, the identification of borides in γ-TiAl based alloys was only done by microscopy methods, such as SEM or TEM. This leads to several inherent disadvantages that only a very limited number of borides are investigated, that the specimen situation at room temperature, where the investigation is done, may differ significantly from the higher temperatures of interest and that crystallographic data in SEM is not easily accessible.

In order to study the formation of borides and their influence during heat treatments in advanced γ-TiAl based alloys we performed in-situ high-energy X-ray diffraction (HEXRD) experiments with TiAl alloys with different Boron contents. Cylindrical samples with dimensions of 10mm length and 4mm diameter were heat treated under Ar inert gas up to 1400 °C with the quenching dilatometer DIL 805A/D. The HEXRD experiments were performed at the HZG beamline HEMS in transmission geometry with a photon energy of 100 and 87 keV and a beam size of 1mm x 1mm.

A comparison of Ti-45Al (in at.%) with 2 at.% B and without B is shown in Figure 1. Both alloys underwent an identical heat treatment (heating up to 1350 °C with 5 °C/s – holding at 1350 °C for 2 min – cooling down to 50 °C with 2 °C/s). Whereas the alloy with 2 at.% B shows almost continuous diffraction rings indicating a fine grained microstructure only a few diffraction spots are visible for the alloy without B indicating pronounced grain growth in the high temperature single phase field of the hexagonal α-Ti(Al) phase at 1350 °C. The difference in the microstructure is preserved after cooling down to 50 °C, however, more spots or rings are visible due to the transformation of α-Ti(Al) to γ-TiAl and α₂-Ti₃Al. Additionally, in the alloy with 2 at.% B weak rings indicate the presence of hexagonal TiB₂ phase. This demonstrates that TiB₂ can act as an efficient grain refiner for pure α-Ti(Al).
Figure 1: Diffraction rings of Ti-45Al and Ti-45Al-2B (in at.%) during heat treating at 1350 °C and after cooling down to 50 °C. The ring morphology indicates different microstructures (see text).

Additional room temperature measurements with boron containing TiAl alloys show that different kinds of borides are formed depending on the Nb content (Figure 2). In the alloys with 2 at.% Nb beside the two main phases, $\gamma$-TiAl and $\alpha_2$-Ti$_3$Al, the hexagonal TiB$_2$ phase can be identified clearly. It should be noted that this is possible even at low boron contents (0.5 at.%). Otherwise, the additional reflections in Ti-45Al-6Nb-2B (in at.%) can be attributed to the orthorhombic mono-boride with B27 structure.

Figure 2: Diffraction patterns of several $\gamma$-TiAl based alloys (compositions are given in at.%). $\lambda = 0.142$ Å. The characteristic peaks of the different phases are marked below.

Further experiments are planned to study whether the boride phases differ regarding grain refining efficiency and mechanism.

References
