

## Abstract:

The reduction of fuel by the implementation of more lightweight materials is one of the main goals in the aerospace industry. The substitution of Ni-based superalloys by  $\gamma$ -TiAl in aero engines allows weight savings up to 50%. For operating temperatures of more than 800°C, however, oxidation protection coatings in combination with thermal barrier coatings on  $\gamma$ -titanium aluminides are required. Intermetallic coatings are generally applied as bond coats in thermal barrier coating systems. Inside cooled components made from  $\gamma$ -titanium aluminides could be used at further higher service temperatures with such thermal barrier coating systems.

In the present study intermetallic bond coatings based on Ti-Al-Cr with additions of yttrium or zirconium were deposited on  $\gamma$ -titanium aluminides using magnetron sputtering. The main goal of this work was to evaluate the potential of these bond coats to develop a protective thermally grown oxide layer of  $\alpha$ -Al<sub>2</sub>O<sub>3</sub>. Besides offering sufficient oxidation protection for the substrate material, these bond coats have to provide adequate adhesion for the ceramic top coat. Furthermore, the implantation of fluorine into the  $\gamma$ -titanium aluminide surface to establish a thermally grown  $\alpha$ -Al<sub>2</sub>O<sub>3</sub> layer by the selective oxidation of aluminum was investigated. In cooperation with *DECHEMA-Forschungsinstitut*, physical and chemical fluorine treatments in combination with thermal barrier coating systems were evaluated. Ytria partially stabilized zirconia top coats were deposited on  $\gamma$ -titanium aluminide samples with pre-oxidized intermetallic bond coats and others after fluorine-treatment using electron beam physical vapor deposition. The lifetime behavior of these thermal barrier coating systems under thermocyclic conditions at 900 and 1000°C was determined, followed by scanning and transmission electron microscopic analyses using energy dispersive X-ray spectroscopy. The crystal structures of the different phases in the bond coats and the fluorine-treated surfaces were examined using X-ray spectroscopy and X-ray diffraction and selected area diffraction.

The addition of yttrium to the system Ti-60Al-13Cr (in at.%) leads to the development of precipitates of the monocline Y<sub>4</sub>Al<sub>2</sub>O<sub>9</sub> metal oxide. This phase is mainly enriched at the grain boundaries of the bond coat and also in the thermally grown Al<sub>2</sub>O<sub>3</sub> layer preventing

inwards diffusion of oxygen. This so-called *reactive element effect (REE)* promotes a diffusion-controlled, parabolic oxide growth. The lifetime behavior of the resulting thermal barrier coating systems exceeds more than 1000 1h-cycles at 1000°C. In contrast, zirconium is substituted in the crystal structures of the intermetallic phases in the bond coat resulting in an increased oxygen solubility. As a consequence, the oxidation resistance of the Ti-Al-Cr bond coat with additions of zirconium is diminished.

The fluorine treatment is a promising alternative to the deposition of intermetallic bond coats on  $\gamma$ -titanium aluminides. The fluorine treatment leads, depending on temperature and F-concentration, to the formation of volatile fluorine compounds and further to a fluorine reservoir in the Al-depleted zone. In the presence of oxygen, a thermally grown oxide layer of  $\text{Al}_2\text{O}_3$  with an Al-depleted zone in the  $\gamma$ -titanium aluminide surface developed. Thermal barrier coating systems in combination with this method achieved a lifetime of more than 1000 1h-cycles at 1000°C. At high temperature exposure a thermally grown oxide layer of  $\text{Al}_2\text{O}_3$  with an Al-depleted zone in the  $\gamma$ -titanium aluminide surface were developed. The fluorine treatment leads, depending on temperature and F-concentration, to the formation of the volatile dimer  $(\text{AlOF})_2$  and further to a crystalline  $\text{AlF}_3$  phase in the Al-depleted zone.

In the present work, the deposition of thermal barrier coatings at a substrate temperature of 1000°C on  $\gamma$ -titanium aluminides was achieved for the first time applying the fluorine treatment. The optimal columnar structure of thermal barrier coatings using electron beam physical vapor deposition could be achieved, which so far was just possible on Ni-based super alloys.