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High Temperature Materials

The Role of Interacting Failure Mechanisms for APS-TBC Life Time

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Introduction

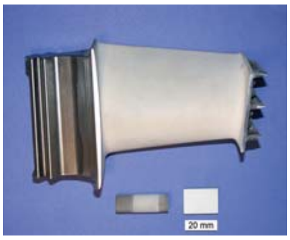

Fig. 1 A real TBC coated turbine blade and smaller laboratory oxidation sample.

Air plasma sprayed thermal barrier coating systems (APS TBC) are made from yttria stabilized zirconia (YSZ) and are currently used to protect the superalloy components (i.e. blades and vanes, see Fig. 1) found in land based gas turbines and aero engines. Most thermal barrier coatings eventually fail, i.e. top coat spallation, during cooling from high temperature, see Fig. 2.

Zirconia, ZrO_2, is known to be a fast oxygen ion conductor at high temperatures. Consequently, oxidation of the underlying superalloy occurs, and a thermally grown oxide (TGO) film forms at the YSZ/alloy interface. In an effort to provide corrosion resistance an aluminum rich metallic coating (termed a Bond Coat, or BC) is applied to he superalloy prior to the deposition of the YSZ top coat. During high temperature exposure the bond coat oxidizes and produces a protec ive Al_2O_3 TGO.

The aim of this project is to develop life time predic ion models for both the YSZ TBC and the aluminum rich metallic BC. Theses models are to be embedded into user friendly software. Finally, the models and the software will be validated with laboratory data.

Fig. 2 Spalled TBC laboratory oxidation samples.

Two Failure Modes

Fig. 3 YSZ Top Coat Failure

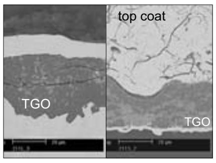

Fig. 4 Al Depletion Failure

The APS TBC top coat can spall by two failure modes. The first is hat the YSZ top coat can develop macro cracks and then debonds from the sample, Fig 3. The second is that the aluminum rich bond coat becomes depleted of Al. This causes the formation of rapidly growing Ni(Co,Cr) spinels in the Al_2O_3 TGO, which in turn develops macro cracks and hen the TBC fails, Fig 4.

Both of these failure modes have been extensively investigated in he DECHEMA laboratories. Life time prediction models for both failure modes have also been developed, see references 1, 2 and 3. Below is presented the software developed for these failure modes, namely:

- Thermal Barrier Coating Lifetime Analysis 1.0, is the software for modeling the spallation due to the degradation of the YSZ top coat.
- Bond Coat Al Simulation 1.0, is the software for modeling the spallation due to the depletion of aluminum.

Software for the YSZ Top Coat Failure Mode

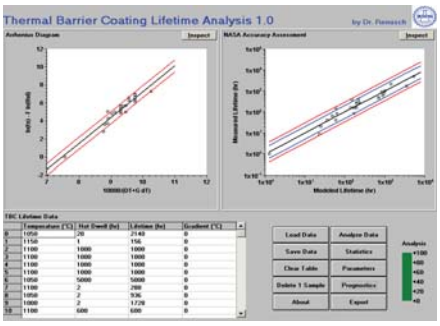

Fig. 5 Data Analysis Screen

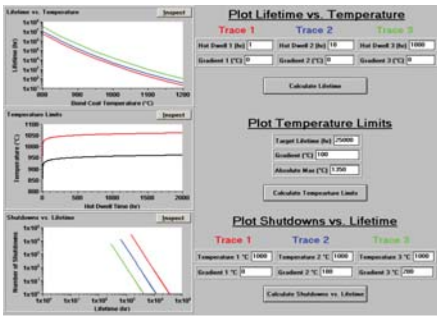

Fig. 6 Prognostics Screen

The software for the spallation due to the degradation of the YSZ top coat, has two calculation screens, namely, the *Data Analysis Screen* and The *Prognostics Screen* shown in figures 5 and 6, respectively.

The Data Analysis Screen

The measured life times from accelerated laboratory testing are entered into the spread sheet. The software analyzes the laboratory data and the results are graphically displayed in an Arrhenius Diagram and NASA accuracy assessment plot. From these figures the user can quickly assess the quality of the analysis.

The Prognostics Screen

This screen uses the modeling parameters determined by the above analysis to predict the life time of the YSZ top coat. The software will calculate the life times as a function of bond coat temperature for a given input of hot dwell time and temperature gradient (top plot in figure 6). Form his screen the bond coat and YSZ top coat surface temperature limits for a target life time (i.e. 15000hr or 25000hr) can be calculated (middle plot in figure 6). Finally, the gas turbine operational limits (i.e. number of turbine shutdowns vs. spallation life time) can be calculated for given input of temperature and temperature gradient (bottom of figure 6).

Software for the Al Depletion Failure Mode

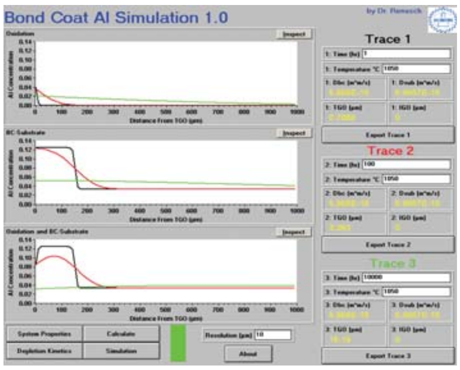

Fig. 7 Aluminum Profile Screen

The software for the spallation due to the Al depletion of bond coat aluminum, has two calculation screens, namely, the *Aluminum Profile Screen* and The *Depletion kinetics Screen* shown in figures 7 and 8, respectively.

The Aluminum Profile Screen

The purpose of this screen is to provide calculated Al profiles that can be compared to measured Al profiles. The calculations are made for a given exposure time at a certain temperature.

The plot on the top of the screen shows the modeled Al profile produced by the growing Al2O3 TGO. The plot in the middle of the screen shows the Al profile produced by the inter diffusion of Al between the bond coat and superalloy substrate. The plot on the bottom of this screen can be compared to measured Al profiles, for the purpose of validating the modeling parameters. This plot is the mathematical difference of the two plots above it.

12/34 System **12/56 SX System**

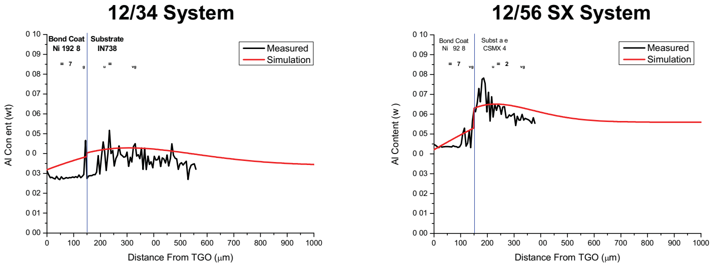

Fig. 8 Measured and simulated aluminum profiles for the 12/34 and 12/56 SX system after 5000 hr at 1050°C

An example of the measured and simulated Al profiles are plotted in figure 7 for the 12/34 and 12/56 SX systems after oxidation at 1050°C for 5000 hr. The bond coat Al is lower than the substrate Al and at the interface there is a step, where this step is a little smaller for the IN738 substrate when compared to he CSMX 4 substrate. This step behavior is caused by the substrates having a lower diffusion coefficient than the bond coat. As can be seen from this comparison, a reasonable agreement between measured and simulated Al profiles is achieved.

References

1) D. Renusch, M. Schütze, “A Prototype Software Tool for Life Time Assessment of Thermal Barrier Coating Systems” Materials Science Forum, vol. 595 598, (2008) pp. 151 158

2) D. Renusch, M. Schütze, “The Role That Bond Coat Depletion of Aluminum Has on the Lifetime of APS TBC Under Oxidizing Conditions”, Materials and Corrosion, 59, No. 7 (2008) pp. 547 555

3) D. Renusch, M. Schütze, “The Role of Interacting Failure Mechanisms for APS TBC Life Time”, Abschlussbericht, Deutsche Forschungsgemeinschaft project No. DFG Schu 729/16 (2009) (in English)