Advanced Coating to Suppress Environmental Embrittlement of TiAl Alloys (ACETAL)

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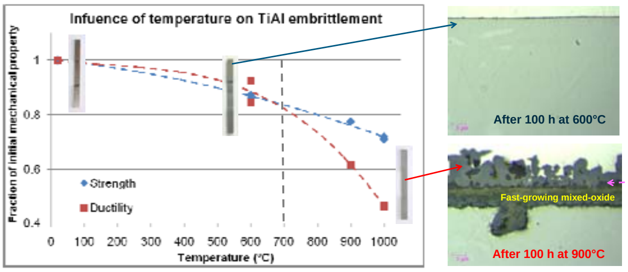
Introduction of TiAl in Aero-engines

Increase of engine efficiency thanks to TiAl alloys

Titanium aluminide alloys have already been introduced into aero-engine components (LP turbine blades) as they feature half the density of Ni-based superalloys and equivalent mechanical properties in hot conditions. The further utilization of TiAl in parts subjected to high thermal load is, however, restricted due to the presence of the Ti-rich α_2-phase (Ti_3Al) in most technological alloys and its oxidation behavior.

Phenomenon of embrittlement due to high temperature oxidation

The rapid diffusion of hot gases in α_2 above T=700°C leads to an accelerated oxidation of the alloy. The arising irreversible loss of the alloy's mechanical properties due to the oxidation behavior, which makes it unsuitable for HT applications, is noticeable once the component has cooled down again to RT. The embrittlement due to insufficient oxidation resistance can be quantified via 4-point bending tests carried out at room temperature. After 100 h of exposure in air at 900°C, a loss of 23% in the alloy bending strength and of 40% in its ductility were determined.

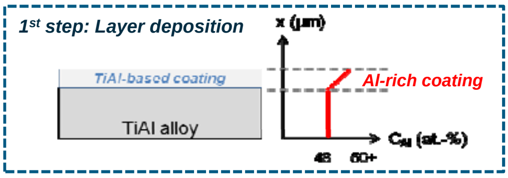


Loss of mechanical properties of the GE4822 alloy as a function of the oxidation temperature after 100 h of exposure, measured by 4-point bending tests.

Surface treatment to prevent oxidation and embrittlement

2-step treatment: Al-enrichment + Halogen effect

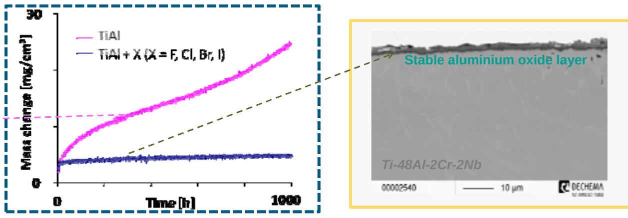
1st step: An **Aluminium-rich γ-TiAl barrier** is deposited on the GE alloy to isolate the oxidation-sensitive α_2 phase from the atmospheric oxygen (embrittlement activator). The aluminium reservoir in the coating will prevent depletion in the substrate in step 2.



SEM cross-section of HVOF, PVD and CVD-coated GE alloy specimens, respectively, prior to surface fluorination. Thickness and coating composition are process-dependent

2nd step: Halogen effect :

Subsequent **fluorination** of the coated TiAl alloy to change the oxidation mechanism at high temperature via Plasma-Immersion-Ion-Implantation (PI³) or via a PFTE liquid-phase route. This results in the suppression of the uncontrolled oxide growth.

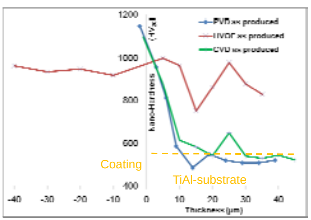


Oxidation kinetics of TiAl with/without halogen treatment and SEM cross-section of a fluorine-treated 3 µm CVD coating after 100 h of oxidation at 900°C.

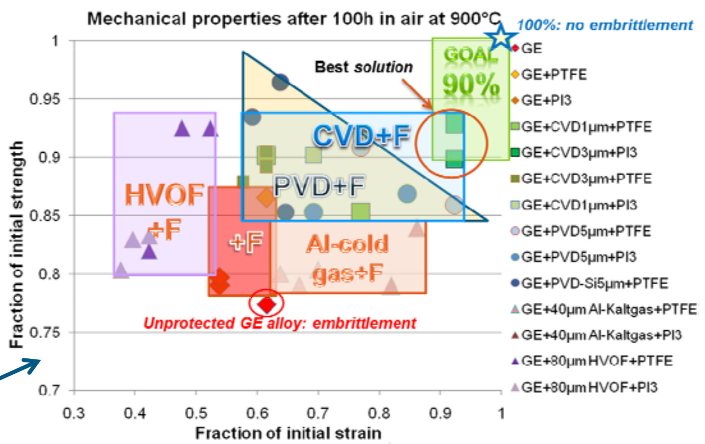
Effect of the surface-treatment on the mechanical properties of TiAl after oxidation

Reduction of the embrittlement via 2-step surface treatment

The mechanical resistance of 2-step-treated GE alloys, using several combinations coating/halogen effect, after exposure in air at 900°C for 100 h was measured via 4-point bending tests. **Oxidation protection** was always reached and additionally, all combinations lead to an **improvement of strength, of ductility or both** after oxidation; thus reducing the intrinsic embrittlement of the TiAl alloy. The most efficient combination tested so far, vis-à-vis suppressing the embrittlement, was a 3 µm CVD coating with a F-PI³ treatment, where over **90% of the initial mechanical properties** of the GE alloy were maintained after 100h of exposure at 900°C. The ACETAL treatment shows a **significant contribution in the embrittlement reduction**. These results are being approved by other mechanical tests (tensile, rotation bending).



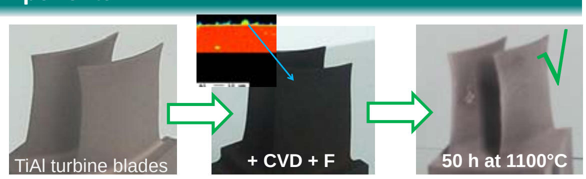
Nano-hardness profiles of as-coated GE alloy specimens. No change in the alloy properties after deposition with CVD- and PVD-processes. Sub-surface hardening but absence of oxygen diffusion in the alloy.



*Mechanical resistance of oxidized GE specimens (100 h at 900°C) with different ACETAL treatments measured via **4 point-bending** tests. Results displayed as a fraction of the initial alloy strength and ductility.*

Applicability of ACETAL to industrial components

The 2-step surface treatment to reduce the embrittlement of TiAl alloys was applied to industrial components with a complex geometry. TNB-alloy turbine blades were coated with an aluminium-rich CVD layer and F-sprayed (controlled oxidation of the coating and intact TiAl-substrate after high-temperature exposure). The blades were oxidized for 50h in air up to a temperature of 1100°C. The protective effect of the surface treatment at these temperatures was ensured by the presence of a stable alumina layer. The Al-rich coating was the metal-source for the halogen effect during oxidation, which preserved the substrate properties. The **applicability to industrial parts is proved** here.



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