A Shark Skin for High Temperature Applications

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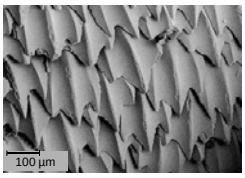
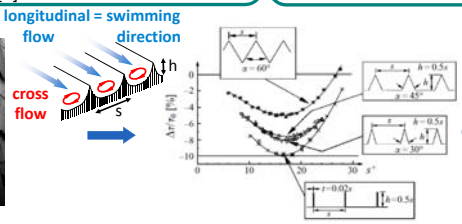
Aim To achieve drag reduction effects by growing riblet structures in-situ, which mimic a shark skin surface through high temperature oxidation of γ-TiAl. The protection of the substrate against corrosion is also considered.

Surfaces with different riblet geometries have already been tested in the laboratory. An overview on the correlation between the riblet shape and the measured drag reduction is available in the literature [1].

Substrate Intermetallic titanium aluminides qualify for applications like turbocharger rotors for the automotive industry, turbine blades and vanes in aero engines or land-based gas turbines. However their use for high temperature components is restricted by their poor oxidation resistance above 750°C. Between 800°C and 1000°C a fast-growing mixed oxide layer (titania i.e. TiO_2 and alumina i.e. Al_2O_3) with a layer of titania on top develops on the γ-TiAl substrate.

Fluorine Effect Very small amounts of halogen microalloyed in γ-TiAl lead to the formation of a slow-growing alumina barrier, which protects the substrate against further oxidation [2]. This change in oxidation mechanism allows operation temperatures up to 1050°C. Key parameters for a positive halogen effect are the fluorine amount and the temperature.





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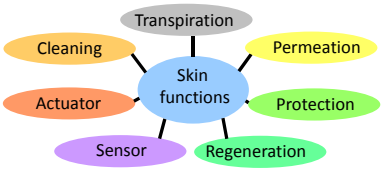
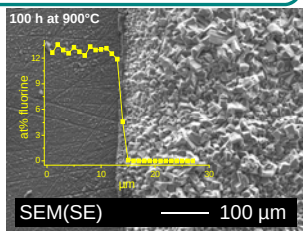




Scales of the great white shark carrying tiny riblets: Riblets hamper the cross flow which causes most of the wall shear stresses [3].

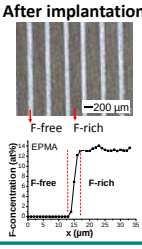
The impact of the riblet geometry: Calculated drag reduction coefficient ($\Delta\tau/\tau_0$) for riblets with different geometries (s^+: so called Reynold`s number for riblets) [1].

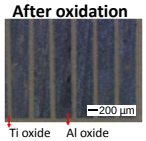
HAUT-Concept: The material reacts with the high temperature environment changing the physical or chemical properties. The key in the development of **adaptive protective coatings** is to control this interaction.

Riblets on γ-TiAl via the Fluorine Effect: The riblet microstructure results from different local oxidation rates on fluorine treated and untreated areas (thin oxide and thick oxide).

Riblets via Beamline Ion Implantation

After implantation / After oxidation

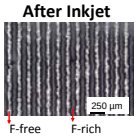


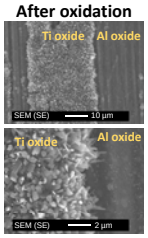


- **Implantation parameters: $2x10^{17}$ F^+/cm^2 and 30 keV**
- **Exposure parameters: 800°C, 100 h, air**

Riblets via Liquid Phase Application

After Inkjet / After oxidation

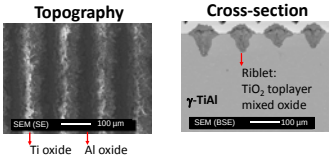




- **Inkjet fluorination with trifluoroacetic acid**
- **Exposure parameters: 800°C, 24 h, air**

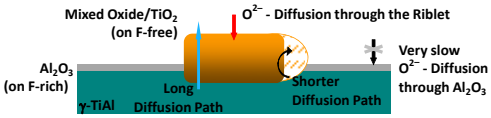
Riblets via Laser Dehalogenation

Laser Dehalogenation with preoxidation / After oxidation



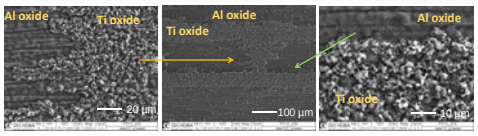
- **Fluorination: dipping in diluted HF**
- **Preoxidation parameters: 900 C, 24 h, air**
- **Engraving laser: ca. 0.5 W**
- **Further exposure for riblet growth: 900°C, 114 h, Air**

Stability of the Riblets Geometry



Lateral growth of the riblets at the boundary mixed oxide-alumina

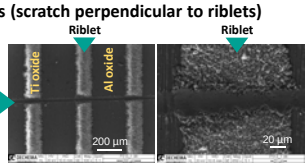
- Drag-reduction effect depends on the riblet geometry (height, width, spacing between riblets)
- Lateral growth slows down during exposure because the diffusion paths become longer
- If the grinding grooves are oriented parallel to the F-rich domains, less lateral growth is observed



Regeneration potential in case of damage (Scratch Test)

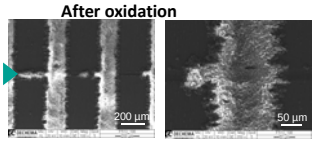
Damaged riblets (scratch perpendicular to riblets)

- Exposure prior to scratch: 900°C, 24 h, air
- Scratch force: 1 N



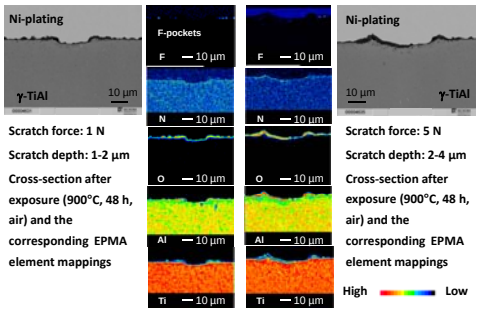
After oxidation

- Exposure after scratch: 900°C, 96 h (4x24 h), air

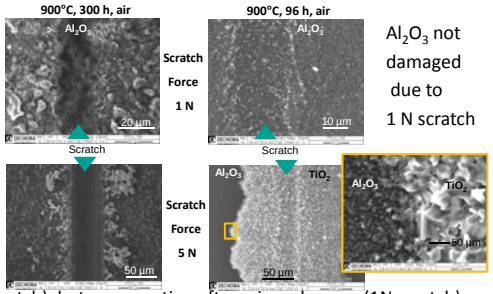


- Riblet regenerates
- TiO_2/mixed oxide growth on the damaged Al_2O_3

EPMA on damaged Al_2O_3



Damaged Al_2O_3 (longer exposure time prior to scratch)



Al_2O_3 not damaged due to 1 N scratch

- No regeneration of Al_2O_3 in case of severe damage (5N scratch), but regeneration after minor damage (1N scratch)

Conclusions and Outlook

- Riblets stability
  - Lateral riblet growth alters the aspect ratio of the structure, which influences the long term performance in terms of drag reduction
  - Substrate roughness can reduce the lateral riblet growth
- Regeneration potential
  - Riblets of mixed oxide with a toplayer of Ti-Oxide have a good regeneration potential
  - Al_2O_3 developed on a halogenated sample with a longer oxidation time (300 h at 900°C) prior to scratch test shows a better resistance to 1N scratch and subsequently no damage
- In-situ structuring of γ-TiAl is possible
- Riblets of TiO_2/mixed oxide separated by Al_2O_3 ⇒ might need stabilisation methods (i.e to reduce the lateral growth) in order to assure drag reduction effects for long- term exposure at 900°C and above
- To complete the riblet characterisation further investigations are planned
  - Aerodynamic measurements in oil channel at DLR Berlin
  - Mechanical and erosion tests
  - Influence of the fluorine distribution on the lateral growth

Literature: [1] D.W. Bechert et al, Journal of Fluid Mechanics **338** (1997); [2] A. Donchev et al, Intermetallics **14** (2006); [3] http://news.softpedia.com/news/The-Shark-Coating-42520.shtml
Project partners: DLR (German Aerospace Center), Köln; Technische Universität, Dresden; Technische Universität, Berlin