Karlsruhe Institute of Technology

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Surface modification of alloys exposed to extreme environment

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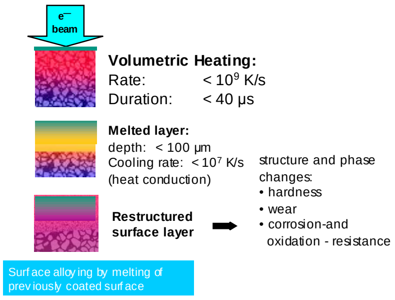
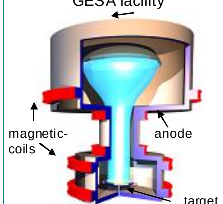
Pulsed Electron Beam Facilities

GESA - Gepulste ElektronenStrahl Anlagen

Using intensive pulsed electron beams, material surfaces can be volumetrically heated, melted and vaporized to a depth of about 100µm. Previously deposited thin coatings (e.g., Al) can be alloyed into steel surfaces. The parameters of the facilities are shown in the scheme below.





Electron beam parameter:

electron energy:	50 - 400 keV
energy density :	~ 6 MW / cm²
pulse duration (controllable):	1 - 40 µs
Beam diameter:	5 - 10 cm

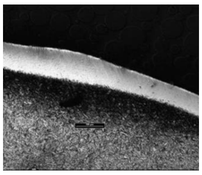
Potential applications of Pulsed Electron Beam surface modification

Car industry: gears; Energy production: turbine blades; Nuclear applications: corrosion resistant cladding tubes; Medicine: implants, surgical tools; Manufacturing industry: cutting tools, surface finishing

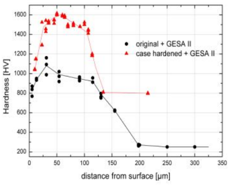
Gears

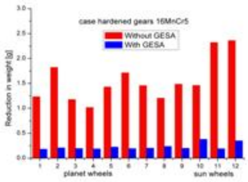
Grain-sizes of most materials are reduced and their hardness is increased ➔ reduction of abrasive wear

Hardness of gears increased by 60 to 80% - reduction in weight 6 to 8 times lower for GESA treated gears



Cross section of 16MnCr5 after GESA modification





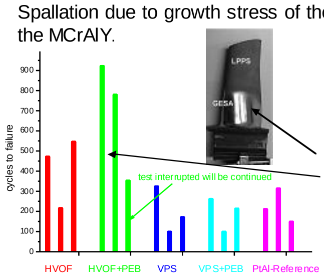
Hardness profile and abrasion

Turbine blades

Increase of efficiency of an industrial gas turbine ➔ higher gas temperatures.

Thermal barrier coatings (TBC) made of ZrO_2 are deposited on top of MCrAlY coatings, but frequent spallation of such TBC ➔ envisaged gas temperatures can not be reached.

Spallation due to growth stress of the thermal grown oxide scale (TGO) on top of the MCrAlY.

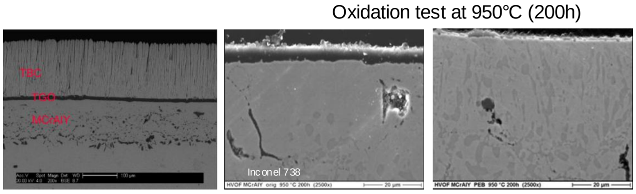


Improvement in lifetime by a factor of 2 high velocity oxide fuel (HVOF) sprayed MCrAlY's

Improvement in lifetime by a factor of 4 GESA treated HVOF coating

GESA of VPS (vacuum pressure spray) sprayed MCrAlY's shows no improvement.

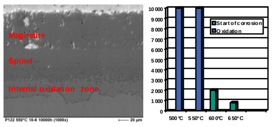
Oxidation test at 950°C (200h)



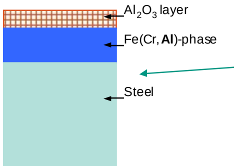
HVOF sprayed MCrAlY coating *GESA treated coating*

Ferritic-Martensitic Steel

for liquid heavy metal-cooled nuclear systems



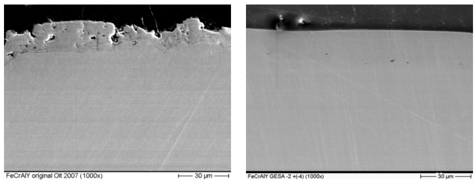
Martensitic steels are operable below ≤ 550 °C. Problematic is the huge oxidation rate: up to 50 -100 µm/10.000 h and frequent spallation of oxide scale.
→ contamination of liquid metal
→ reduced heat removal capability



Solution for corrosion and severe oxidation of T91 steel: Surface alloying with Al: ➔ oxidation resistance in liquid lead alloys by the selective formation of an alumina scale (4 wt% < Al < 8 wt.%).

➔ thin protective Al_2O_3 scales in contact with liquid Pb/PbBi having an appropriate oxygen concentration.

Cladding tubes for Pb/PbBi cooled transmutation devices are coated with a thin 30µm thick FeCrAlY layer (Low Pressure Plasma Spraying - LPPS). This layer is melted together with some µm of the substrate using the GESA facility:

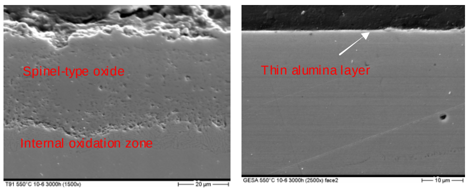


T91 covered with FeCrAlY (LPPS) *T91 covered with FeCrAlY (LPPS) + GESA treatment*

After GESA treatment: coating is entirely dense and metallic bonded to the substrate.

Influence on corrosion behaviour

Exposure for 3000h in lead-bismuth eutectic melt at 550°C, with *optimal oxygen concentration* 10^{-6} *wt%*:



T91 without coating *T91 with GESA treated FeCrAlY coating*

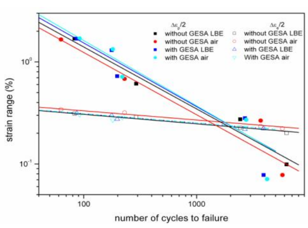
GESA treated samples show a thin and protective alumina layer

Influence on the mechanical properties:

Low-cycle-fatigue tests and pressurized tube experiments ➔ no negative influence of the such modified layers onto the mechanical properties.

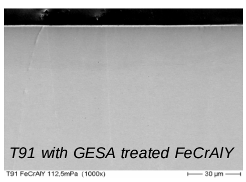
T91 with GESA treated FeCrAlY

5000 h at 600 °C in flowing LBE (10^{-6} wt% oxygen)



LCF test showing no negative influence of GESA modified surface layer

Specimen surface condition before testing	Average strain ε, %	Average creep velocity (calculated) v, %
as received	0.7	$3.52 \cdot 10^{-4}$
modified steel surface (Al + GESA)	0.74	$3.71 \cdot 10^{-4}$



Tangential wall stress 112.5 MPa

T91 with GESA treated FeCrAlY

No change in oxidation behaviour and no decrease in strength during LCF test

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