Use of intense pulsed electron beams for modification of materials

Wladimir An, Renate Fetzer, Annette Heinzel, Fabian Lang, Frank Zimmermann, Alfons Weisenburger, Georg Müller

Pulsed Electron Beams Facilities - GESA
Applications: Heat treatment, Surface fusing, Surface alloying
Pulsed Electron Beam / material interaction

Interaction of electrons with materials

Ionisation
X-rays
Secondary and backscattered electrons

Penetration depth depending on
Energy of electrons and Z of material

Energy dissipated as heat

⇒ Volumetric heating of material
Technical realization of the pulsed electron beam facility GESA (Efremov – KIT development)

- HV
spark gap

Cathode

Cold cathode (not heated), rigid and reliable
large emission surface (1000th cm²)

⇒ large beam diameter
long time stability of operation
Main parameters of GESA facilities

<table>
<thead>
<tr>
<th>Geometry</th>
<th>Electron energy, keV</th>
<th>Current, A</th>
<th>Pulse duration, µs</th>
</tr>
</thead>
<tbody>
<tr>
<td>GESA1</td>
<td>quasi-planar</td>
<td>60 - 150</td>
<td>up to 600</td>
</tr>
<tr>
<td>GESA2</td>
<td>quasi-planar</td>
<td>60 - 400</td>
<td>up to 380</td>
</tr>
<tr>
<td>GESA4</td>
<td>cylindrical</td>
<td>60 – 150</td>
<td>up to 4000</td>
</tr>
</tbody>
</table>
Heat Treatment - Hardening of materials

Treatment parameter: 215 keV 53µs 2 pulses 16MnCr5

Increase in hardness from 200 to 1100 – original
800 to 1600 – case hardened
Heat Treatment – improvement of material properties

Gears for gear boxes - reduction of wear

Reduction in weight by 5 to 10 lower due to GESA heat treatment

Significant increase in fatigue strength by combining GESA heat treatment with subsequent annealing

Ti-Alloy blades for aircraft engine
Increase in fatigue strength, f=3000 Hz, 450 °C – VT8M
Heat Treatment – Structural refinement of MCrAlY – oxidation resistance

Cross section of GESA treated MCrAlY

Surface of GESA treated MCrAlY

GESA treatment results in grain refinement and oriented growth perpendicular to surface
Heat Treatment – Structural refinement of MCrAlY – high temperature oxidation resistance

Initial oxidation behaviour of HVOF coating with and without PEB posttreatment

Test conditions: T=950 °C 2h’s in air

Significantly reduced oxide scale growth on the PEB treated HVOF coating
Heat treatment – crystallisation amorphous Si – PV cells

Modell system:
7μm Si, Al, Ti - steel as base material
PEB: 60keV

XRD shows crystalline Si after treatment
Surface alloying – metallic bonding of coatings
Coating (LPP, PVD, …) + GESA

The procedure consists in two steps:

(i) coating the surface steel with Al-containing alloy (Fe-Cr-Al alloy, Ti, Cr, ..)

LPPS spraying, PVD deposition of different coating materials
Fe15Cr11.5Al, Ti, Cr, ....
Surface alloying – metallic bonding of coatings
Coating (LPP, PVD, …) + GESA

The procedure consists in two steps:

(i) coating the surface steel with Al-containing alloy (Fe-Cr-Al alloy, Ti, Cr, ..)
(ii) melting the coating and the surface layer of the steel using intense pulsed electron beams (GESA process – KIT/EFREMOV).

GESA treatment results in:
metallic bonding, surface alloying, pore removal, surface smoothening
Surface alloying, bonding of metallic coatings – increase of corrosion resistance in liquid metals PbBi at 550°C

- Austenitic steel
- F/M steel
- Surface alloyed (Al) Austenitic steel

Severe dissolution of alloying elements (Ni). Dissolution rate up to 1 µm/h.

Huge oxidation rate of F/M-9Cr-steels.

Thin slowly growing oxide scales.
Surface alloying, bonding of metallic coatings – increase of corrosion resistance in liquid metals

PbBi at 550°C

no dissolution
attack

no excessive
oxidation

Protective Alumina
layer

![Graph showing volume loss vs. temperature for different steels]
System improvement by PEB treatment of materials – improved corrosion resistance
LM as heat transfer media – improved cooling – higher temperatures

liquid Pb/PbBi cooled nuclear systems

Surface alloying, bonding of Al containing coatings
Mitigate liquid metals corrosion at high temperatures
Mitigate fretting / materials loss
Mitigate degradation of mechanical properties by liquid metal

Generation IV LFR - ALFRED
Coolant: Pb, PbBi
ADS system MYRRHA
Coolant PbBi
System improvement by PEB treatment of materials – improved corrosion resistance

Objectives for this new research area for surface alloying:

- Improve material stability up to 890°C Na

- Mitigate influence of thermal stresses (clouds, day/night)

- Mitigate high temperature air corrosion – outside of receiver – MCrAlY

Liquid Na as Heat Transfer media

High temperature air corrosion

for CSP tower systems