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Intense Pulsed Electron Beams Application of Modified Materials

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Intense pulsed electron beams have been applied for surface modification of materials in our laboratory for several years. An improvement of properties like wear, corrosion and oxidation resistance was found. Three different modification modes can be distinguished: rapid melting and solidification, surface alloying of coatings into the bulk and surface fusing of coatings to the bulk. All three surface treatment processes were investigated using the GESA (Gepulste Elektronen Strahl Anlage) facilities having following parameters: accelerating voltage 80–400 kV; power-density 2–6 MW/cm^2; beam diameter 4–10 cm; pulse duration 4–250 μs. Such pulses applied on material surfaces lead to a change in microstructure and in the case of surface alloying also to a change in chemical composition. This paper will give an overview on applications in different fields of surface modified materials.

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1. Introduction

Intense pulsed electron beams have been applied for materials surface treatment in our laboratories for several years. The large area electron beams generated by the GESA (Gepulste Elektronen Strahl Anlage) facilities offer a wide range of applications for the improvement of materials surface properties like wear, corrosion and oxidation resistance. This process involves rapid melting of a material surface layer under the influence of the electron beam, followed by rapid quenching due to heat conduction into the unaffected bulk material [1]. For realization of the treatment procedure, electron beams capable of melting the surface layer of any material into depths of tens of μm at a rate of 10^9 K/s are required. It is preferable to heat the treated layer without marked evaporation and boiling of the melted phase, and also without significant energy loss due to thermal conductivity inside the bulk material — so called adiabatic mode of heating. In addition this process can be used for alloying additional elements into surface-near regions. This paper will give an overview on applications in different fields of surface modified materials.

2. GESA facilities

All surface modifications are carried out using the GESA facilities [2, 3]. GESA I (1996) and GESA II (2000) have been developed for this purpose in cooperation between the Efremov Institute St. Petersburg, Russia, and the Forschungszentrum Karlsruhe (FZK), Germany, who runs both facilities in its laboratories. Table summarises the most important parameters of the GESA I and II facilities at FZK [2]. The two facilities have the same principal setup: electron injector of triode type with a multipoint explosive emission cathode, transport channel, treatment chamber, magnetic system, high-voltage generator, pulse-duration control unit (PDCU), vacuum system, control rack, radiation protection and mechanical support.

TABLE

Main beam parameters.

Parameters	GESA I	GESA II
accelerating voltage	50–150 kV	200–400 kV
power density	< 2 MW/cm^2	< 6 MW/cm^2
beam diameter	40–60 mm	50–100 mm
pulse duration	4–40 μs	5–250 μs

3. Application of modified materials

Three different treatment modes can be distinguished — changes in microstructure, surface alloying and surface fusing of deposited layers into the bulk.

The volumetric melting and the rapid cooling result in structural changes and modified properties. Grain-sizes of most materials are reduced and their hardness

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is increased. This can result in a reduction of abrasive wear as demonstrated by a wear test with modified and non-modified gears [4]. Hardness of the gears made of 16MnCr5 steel was increased by 60 to 80%. Such treated and non-treated gears were tested in identical gear boxes. The weight of each gear was measured before and after the test and the reduction in weight was 6 to 8 times lower for GESA treated ones. This shows the remarkable increase in wear resistance (see Fig. 1).

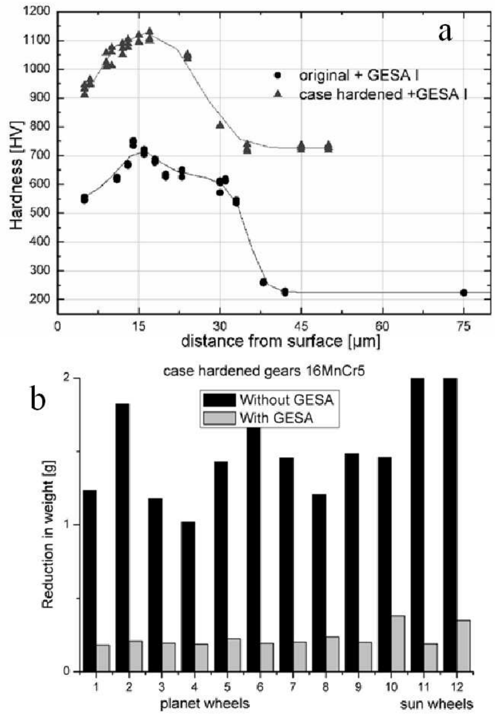

Fig. 1. (a) Hardness profile of gears with and without GESA treatment, (b) reduction in weight after gear test.

Microstructural changes also lead to a change in oxidation kinetics. To increase the efficiency of an industrial gas turbine higher gas temperatures are necessary. Therefore thermal barrier coatings (TBC) made of ZrO_2 are deposited on top of the MCrAlY coating. Spallation of such TBC does not allow us to achieve the envisaged gas temperatures at time. On reason for spallation are growth stresses of the thermally grown oxide scale (TGO) on top of the MCrAlY. Using the GESA facility this TGO growth is limited and therefore also the growth stress is minimized. The difference in TGO thickness after 200 h of exposure to 950°C air is remarkable, < 0.5 μm for GESA treated and 3–8 μm for original ones [5, 6]. Thermal cycle tests of MCrAlY's deposite using different process were performed at Cranfield University [7]. The TBC on top was identical for all experiments. TBC on top of high velocity oxide fuel (HVOF) sprayed MCrAlY's showed an improvement in lifetime by a factor of 2 compared to the actual reference system using PtAl. GESA treatment of this HVOF coatings increases the lifetime further to a factor of almost 4 compared to the reference coating. However PEB of VPS sprayed MCrAlY's do not show any improvement.

Beside rapid solidification surface alloying is another subject of recent investigations. Coatings deposited or foils placed on the material are melted together by the impinging electron beam [3]. The alloying process is more of turbulent nature than dominated by diffusion. The cross-section clearly shows Al rich phases of whirling like structure (Fig. 2a). The amount and the distribution of the alloying element within the bulk can be varied by the thickness of the coating or foil and by the electron beam treatment parameters (Fig. 2b). Surface alloying of Al into various steels using an intense pulsed electron beam increase its oxidation resistance in liquid lead alloys by selective formation of an alumina scale. More than 10 000 h of exposure without significant scale growth was already observed (Fig. 2c). Such surface alloyed steels are required to target application of steels in liquid lead alloys at temperatures above 500°C.

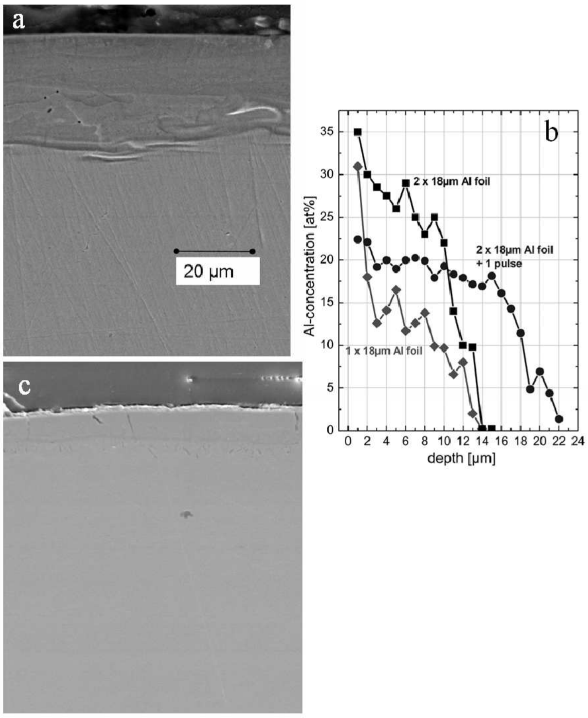

Fig. 2. (a) Al surface alloyed into stainless steel, (b) elemental distribution after Al alloying, (c) cross-section of Al alloyed steel after 10 000 h exposure to lead alloy at 600°C.

For nuclear application a homogeneous Al distribution of defined concentration has to be guaranteed for an entire modified surface. Especially for cladding tubes of about 4 m length this is a critical issue. Therefore surface-fusing of FeCrAlY coatings is investigated as a corrosion protection layer in liquid lead alloys. Cladding tubes intended to be used in Pb/PbBi cooled transmutation devices are coated with a thin $\sim$ 30 μm thick

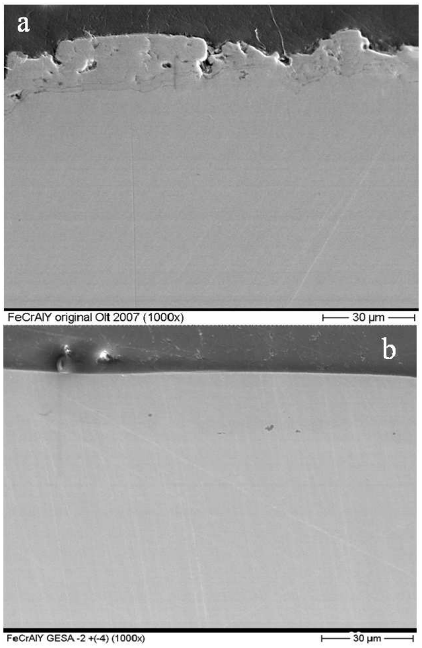

Fig. 3. Cross-section of steel with FeCrAlY coating (a), without (b) with GESA treatment.

FeCrAlY layer and this layer is in the second step melted together with some μm of the substrate using the GESA facility. Cross-section of FeCrAlY layers on a cladding tube without and with GESA treatment are depicted in Fig. 3.

After the GESA treatment the coating is entirely dense and metallic bonded to the substrate. Such layers show the same positive oxidation behaviour like the Al-surface alloyed materials.

The influence of surface fused coating on the mechanical properties is investigated performing low-cycle-fatigue tests [8] and pressurized tubes [9]. Both tests do not show any negative response of such modified layer onto the mechanical properties.

4. Summary and conclusions

Intense large area pulsed electron beams are used for several different applications. Changes in microstructure lead to hardening of gears and increase thereby their wear resistance. Changes in microstructure also decrease the oxidation rate of high temperature alloys. Changes in elemental composition by surface alloying of Al into steels reduce oxidation and corrosion rates in liquid lead alloys significantly. Similar effect could be obtained by surface fusing of Al containing layers to steel matrixes. The GESA's are versatile facilities that allow enhancing material properties.

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