

Structure of the surface layers on zirconium products after dynamic impact of the microbodies

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Abstract. The effect of modifying the surface of products made of zirconium alloy E110 by magnetic abrasive treatment (MAT), abrasive blasting treatment (ABT) and cold jet treatment (Cold Jet) on the texture and residual stresses formation is studied. Cold Jet does not change the basal texture of the initial sheet of E110 alloy. The ABT leads to a significant weakening of the basal texture in the initial sheet, the basal texture fraction decreases from 85 down to 44 %, and the proportion of the prismatic texture increases from 4 up to 27 %. Surface modification by MAT results in weak texture changes which are manifested only in the increase of the pole density for non-basal orientations. After the ABT compressive stresses of 400–450 MPa are formed on the surface of the alloy; as the distance from the surface increases, the value of compressive stresses decreases and at a depth of 80 μm the stresses become tensile. The depth of the modified layer after MAT is $\sim 15\text{--}20\ \mu\text{m}$. The value of residual compressive stresses on the surface of the alloy after MAT is 200–250 MPa.

1. Introduction

To improve corrosion resistance of zirconium products surface cleaning operation is required. In this case the use of grinding operation results in tensile residual stresses formation and various types of etching in hydrofluoric solutions lead to an increase in the amount of hydrides in the surface layers. In this work, we investigated the effect of magnetic abrasive treatment (MAT), abrasive blasting treatment (ABT) and Cold Jet thermo kinetic treatment on the structural state of the surface in zirconium products made of the E110 alloy.

The MAT process is the exposure of the surface to magnetic abrasive powders which are elastically fixed in a magnetic field existing in the working gap between magnetic poles of a magnetic abrasive machine. The ABT process consists in the impact-kinetic effect on the surface by working microbodies. The Cold Jet process consists in thermo kinetic surface treatment using dry ice pellets (solid fraction of CO_2) being sprayed by air stream under pressure; its effect on the surface combines thermo shock occurring due to the difference in temperatures of the dry ice ($-79\ ^\circ\text{C}$) and the treated surface with the kinetic impact of beating granules. Cast iron chipped shot (CICHS) and steel chipped shot (SCHS) were used as magnetic abrasive powders for MAT, and microspheres from glass and oxidized zirconium served as microbodies for ABT.

In this work, we investigated the effect of surface modification on the crystallographic texture of surface layers and distribution of residual stresses in surface layers. These characteristics are chosen because it is known that crystallographic texture influences not only performance of zirconium



products [1–6], but also the orientation of monoclinic and tetragonal oxide modifications and their ratio in the oxide layer [7–9]. It is also known that morphology and texture of hydrides depend on texture of the substrate and residual stresses [10, 11]. These effects are conditioned by the presence of orientation relationships between the lattices of zirconium with oxides and hydrides which can change under the influence of residual stresses.

2. Texture and residual stresses after surface modification

Figure 1 shows the results of the study on the effect of treatment type for zirconium components surface on texture characteristics. The texture of the initial material in the form of a sheet with the 2 mm thickness was characterized by a pronounced basal texture with the fraction of 85 % (figure 1(a)), while the prismatic texture fraction was only 4 % (figure 1(b)). Modification of the surface is accompanied by a significant weakening of the basal texture for the ABT process, which is characterized by a reduction in the basal texture fraction to 44 % and an increase in the prismatic texture fraction from 4 to 27 %. Modifying the surface by the MAT leads to slight changes in the texture which are manifested only in an increase in the pole density of non-basal orientations. This is most clearly manifested in a certain strengthening of the prismatic texture fraction (from 4 to 7–8 %), which is clearly seen in figure 1(b).

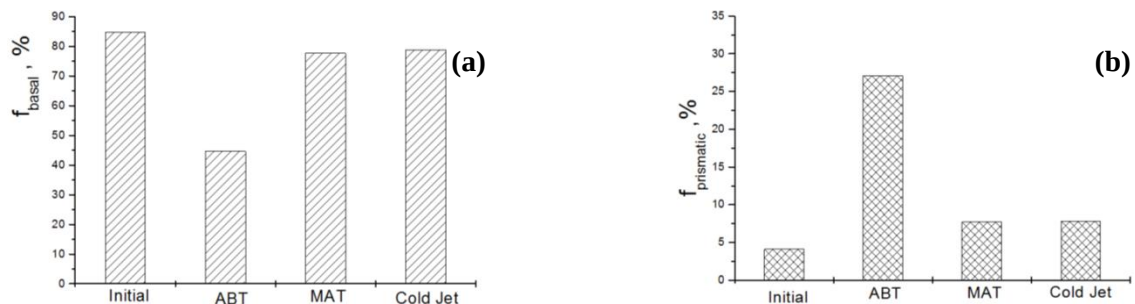


Figure 1. Effect of the surface treatment type for the fuel cladding made of the E110 alloy on texture characteristics: **(a)** the basal texture fraction; **(b)** the prismatic texture fraction.

Figure 2 shows the results of a layer-by-layer distribution of residual stresses after processing by the ABT mode which results in the most noticeable changes in the texture on the surface. Compressive stresses of 400–450 MPa are formed on the surface.

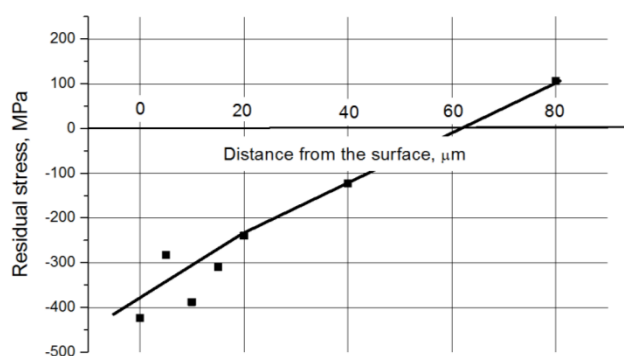


Figure 2. Distribution of residual macro-stresses over the cross section in E110 alloy sheet of 2 mm after ABT.

As the distance from the surface increases, the value of the compressive stresses decreases and at a depth of 80 μm the stresses become tensile. The depth of the modified layer after the MAT by CICHs and SCHs does not differ and equals $\sim 15\text{--}20\text{ }\mu\text{m}$, and the treatment with Cold Jet does not lead to appreciable changes in the texture. The values of the compressive residual stresses in the fuel cladding after the MAT by CICHs and SCHs are 200–250 MPa.

3. Investigation of the oxide layers structure on a modified surface

The formation of oxide layers on the surface of alloy samples differs significantly for different modification variants with a clear correlation between the structure of the metal substrate and the

morphology of the oxide layer. The ABT (figure 3(d), (e)) is characterized by the multiple nature of oxidation sites which reflect a strong hardening of the surface accompanied by fragmentation of the initial grains and un-texturing, which leads to an increase in the number of nuclei of oxide grains. After the MAT (figure 3(c), (d)) and Cold Jet (figure 3(a), (b)) the oxide replicates structure of the metal substrate while, as it is clearly seen in the 3D image, the rate of the oxide growth at the grains boundary dominates, which results in discontinuities formation, and in the case of Cold Jet treatment in reduction of protective properties of the surface oxide.

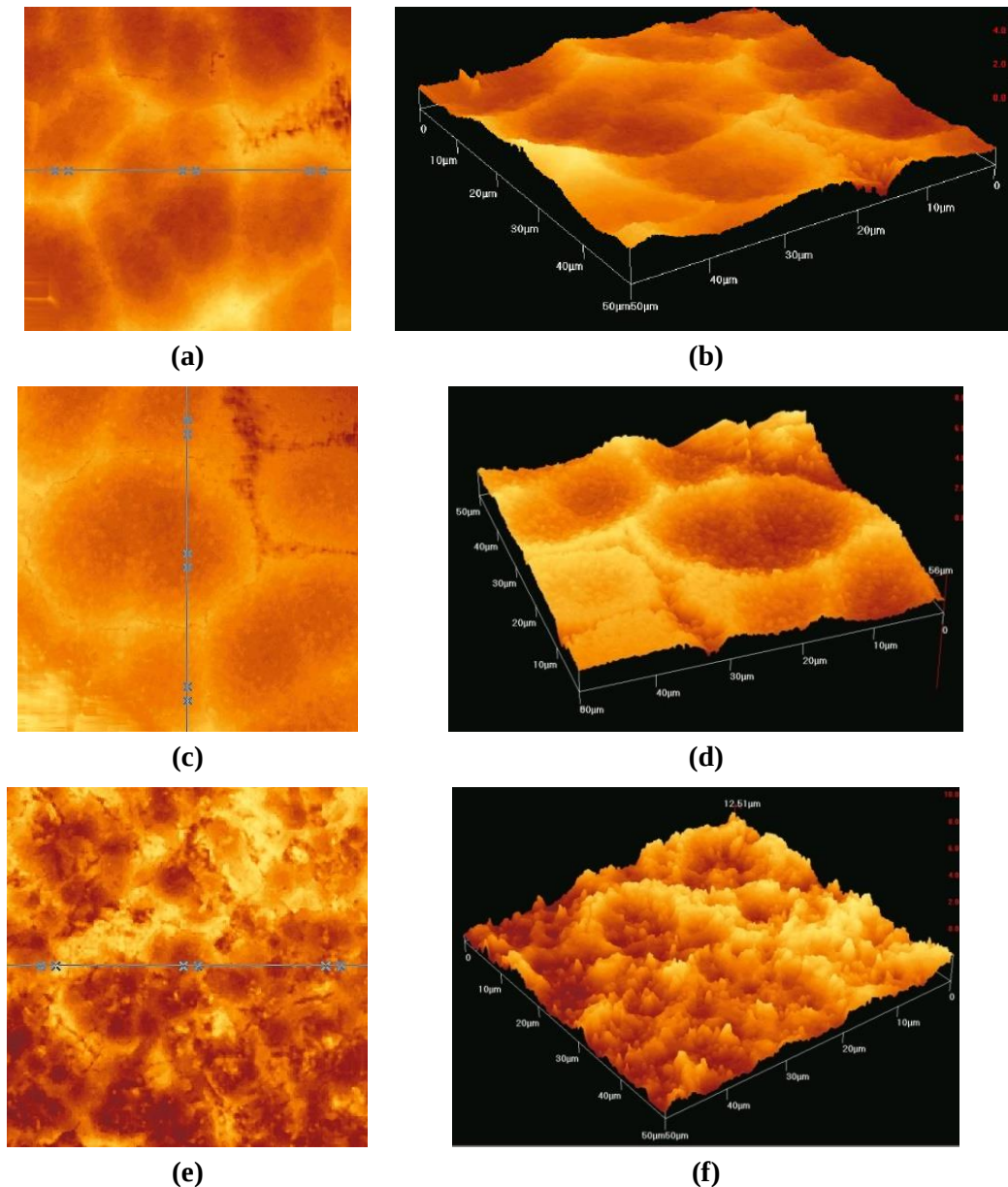


Figure 3. 2D (a), (c), (e) and 3D (b), (d), (f) images of the oxides surface on the modified surface of the E110 alloy after exposure for 7.2 ks at 800 °C: (a), (b) Cold Jet treatment; (c), (d) MAT by SCHS; (e), (f) ABT.

However, the oxide having been formed on the surface of zirconium after the MAT has higher protective properties. Naturally, in the case of the ABT which corresponds to a much larger fraction of the oxide grains boundaries and, correspondingly, a larger fraction of discontinuities (figure 3(d), (e)), protective properties of the oxide (table 1) are substantially lower than for other modification modes.

Table 1. Effect of the surface treatment method for the E110 alloy on the properties of oxide films being formed during corrosion tests for 30 days at the temperature of 400 °C and the pressure of 20.3 MPa.

Treatment method	Microhardness (HV), kgf/mm ²	Barrier voltage, V	Protective properties index (1/CW), cm ⁴ /mg·μF
Etching	257	250	3.8
Grinding	420	250	2.9
MAT by CICHs	683	300	13.3
MAT by SCHS	695	275	12.2
ABT	880	150	1.8
Cold Jet	280	250	4.5

Acknowledgments

The research was carried out at the expense of a grant from the Russian Science Foundation (project No. 15-19-00241).

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