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ODS+Hf and AISI 316L STEEL SURFACE VARIATIONS at HIGH LASER INTENSITY, 10^{13} W/cm^2, in AIR and VACUUM: COMPARATIVE STUDY

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Abstract. The behavior of Oxide Dispersion Strengthened (ODS) steel with addition of hafnium, as well as AISI 316L steel, at high laser intensity of ~10^{13} W/cm^2 in ambiences of air and vacuum, was studied. Irradiation source was Ti:Sapphire laser operating at 804 nm and pulse length of ~65 fs. Morphological and chemical studies were considered, thus that: (i) given laser intensity induced damages on both steels with the damage being more prominent on AISI 316L steel; (ii) various surface features were present, such as coral-like structure and Laser Induced Periodic Surface Structures (LIPSS), with LIPSS being dominant on the surface; (iii) the interaction was accompanied by generation of plasma above the target, and (iv) chemical analysis has shown that surface elemental content also depends on the ambience used.

1. INTRODUCTION

The development of materials with extraordinary characteristics for applications in engineering (aerospace) and especially in nuclear complex is of constant interest nowadays, Trtica et al. 2020[a]; Suri et al. 2010. In this context, ODS+Hf as well as AISI 316L steel have desirable properties making them potential candidates for use in fusion technology. Among other, both steels have relatively high melting temperature (T_m) (higher by ~100 °C in case of ODS steel) and very good resistance to thermal loading. Both steels are serious candidates for structural fusion reactor materials, and their behavior under strong heat and radiation fluxes, in one approximation, can be simulated using high intensity laser radiation, see

Farid et al.: 2014; Montanari et al.: 2017. The goal of this work was to obtain data on the state of the material/steel under high laser intensity of the order of 10^{13} W/cm^2 in air and vacuum ambience – these researches are still insufficient thus they have applicative as well as fundamental significance.

2. EXPERIMENTAL

ODS steel employed in this work is 16Cr3Al+Hf ODS steel with the following constituents: Fe-16Cr-3Al-1.5W-0.35Y2O3+0.5Hf (wt%; Fe balance), see Dong et al.: 2017. Hafnium was added in the form of powder with purity 99.9% and average size 10 μm before the synthesis process. AISI 316L steel was standard commercial product. The samples were in the shape of plates, 10 × 10 mm, 500 microns thick, with the average roughness 0.8 μm. Experimental setup is explained in details in works, see Trtica et al. 2020[a,b]. Characteristic parameters of the Ti:sapphire laser are as follows: wavelength 804 nm, pulse duration around 65 fs, maximum output energy 12 mJ, operated in TEM_{00} mode. Laser beam was focused with 150 mm lens to 20 μm diameter (irradiated surface was positioned in front of the focus therefore spot sizes on the samples were larger). Irradiation effects were studied in air and vacuum. Microstructural characterization of the samples was conducted using scanning electron microscope (SEM), equipped with energy dispersive X-ray analyzer (EDX) for chemical analysis of the surface. Morphology of the laser-induced damages was investigated using optical profilometer.

3. RESULTS and DISCUSSION

In the main, laser surface variations are affected by numerous parameters of irradiation process – laser parameters (wavelength, pulse duration, pulse count, intensity, etc.), as well as material (absorptivity) and ambience parameters. The effects of fs-laser at 10^{13} W/cm^2 intensity acting on ODS+Hf steel in ambiences of air and vacuum are given in Fig. 1. Registered surface alterations after 100 accumulated pulses are the following: (i) the damage spot has a diffuse character in air unlike the one obtained in vacuum ambience; (ii) central irradiated zone shows sporadic coral-like structure without the appearance of cracking. Also, the initial development of Laser Induced Periodic Surface Structures (LIPSS) was recorded in this region, larger LIPSS with period ~2.4 microns and smaller LIPSS (~0.6 microns) perpendicular to the larger ones; (iii) in the peripheral zone only LIPSS were noted and, (iv) the interaction was accompanied by generation of plasma above the target. Profilometric analysis, Fig. 1, showed the damage was on a superficial level, deeper in vacuum (~2.0 μm) than in air (~1.75 μm), implying that coupling between laser radiation and the surface in vacuum is more efficient. Fs-laser – metal target interaction, see Trtica et al. 2020[a,b], is a complex process which in one approximation comprises the absorption of laser radiation by free electrons, thermalization of electron sub-system (ESS), transfer of energy from ESS to the lattice subsystem, its thermalization, etc.

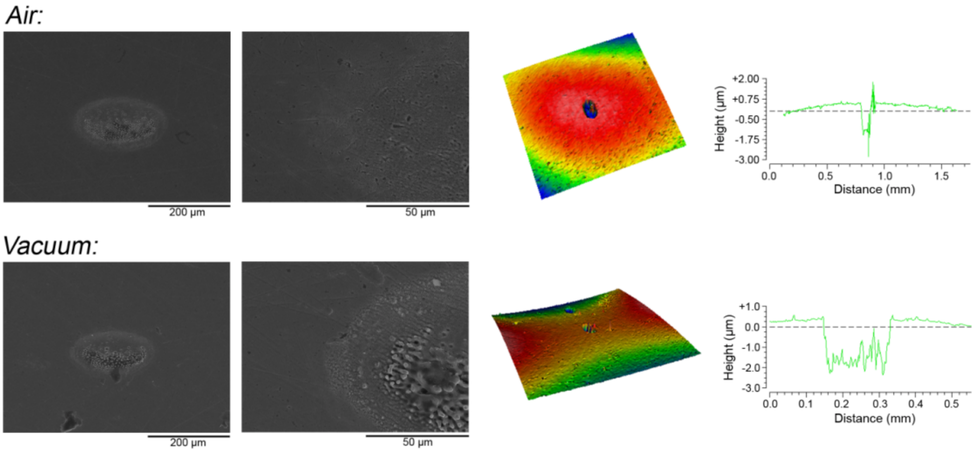

Figure 1: Analysis of the laser damage on ODS+Hf steel: SEM – entire spot and peripheral region; profilometry – 3D and 2D analysis. Laser intensity ≈10^{13} W/cm^2.

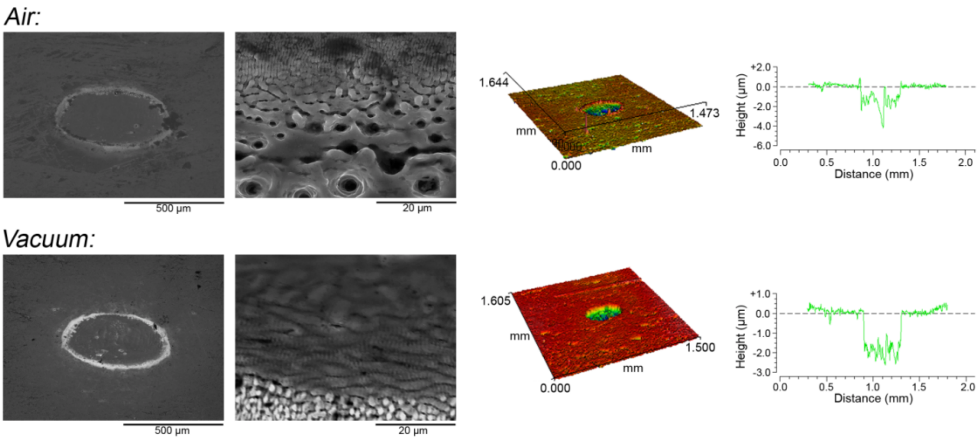

Figure 2: Analysis of the laser damage on AISI 316L steel: SEM – entire spot and peripheral region; profilometry – 3D and 2D analysis. Laser intensity ≈10^{13} W/cm^2.

The effects of fs-laser at 10^{13} W/cm^2 intensity acting on AISI 316L steel in ambiences of air and vacuum is shown in Fig. 2. The noticed surface variations after 100 accumulated pulses can be summarized in the following: (i) the damage spot has a diffuse character in air unlike in vacuum ambience; (ii) generally, the features induced have a more drastic/violent character then in the case of ODS steel. Central as well as peripheral zone are dominantly covered with LIPSS, similar to those on ODS steel; (iii) the transition from coral-like structure to LIPPS is present in the peripheral region; (iv) although the damages are shallow (profilometric analysis, Fig. 2), they showed higher level in vacuum than in air; (v) creation of plasma accompanied this interaction.

It should be pointed out that chemical surface alterations on both steels strongly depend on the ambience used. Also, changes differed depending on the damage area – oxides cleaning in the central zone, oxidation on the periphery in air ambience, local oxidation on ODS steel in vacuum due to oxides contained in the material.

4. CONCLUSIONS

Laser intensity of 10^{13} W/cm^2 induced damages on the surface of ODS+Hf as well as AISI 316L steel. Morphological as well as chemical changes strongly depend on the ambience used. As a rule, more prominent alterations were recorded in vacuum ambience. At this laser intensity used, dominant surface features are LIPSS. The damages are on a superficial level with a tendency to be more prominent on AISI 316L steel, which is probably related to lower melting temperature compared to ODS steel. These investigations have shown that, although laser intensity was high, surface changes are not so significant thus both steels can probably be considered as potential candidates for the use in fusion technology.

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