VII Encontro SBPMat

CORRELATION OF PHYSICAL-CHEMISTRY CHARACTERISTICS OF IRRADIATED TITANIUM SURFACE WITH Nd:YVO4 PULSED LASER PARAMETERS

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Introduction

Laser pulses used in Laser Surface Modifying Process (LSMP) or in Laser Drilling Process (LDP) have typically the duration of several tens of nanoseconds and an energy fluence varying from tens to hundreds J/cm². The power density achieved causes a lot of material to be ejected from the target but is not sufficient to move it far from the evaporation zone in such a short time creating a high-density vapor cloud (ablation plume). The evaporation conditions play a key role in the ablation plume formation and further evolution thereof. A rigorous physical account of them is impossible without simultaneous consideration of the ablated material gas dynamics and the heat transfer in the target [1]. An interesting operational model described by Ganesh et al. [2] shows when the absorbed fraction of the incident light energy of a laser beam directed towards a solid surface, melts and vaporizes it, and a back pressure is created on the liquid free surface. This pressure pushes the melt away in the radial direction and forces the vapor and liquid expulsion like demonstrated in Figure 1.

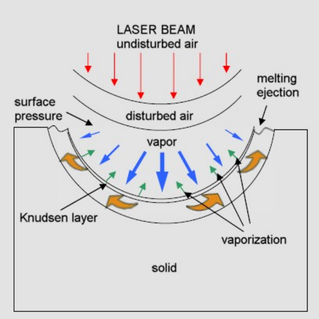

Fig. 1. Schematic diagram of laser drilling process [2].

The high heating and cooling rates during the LSMP result in a non-equilibrium state where the pulsed laser ablation has the following main steps according to NANAI et al. [3]: (a) absorption of laser energy into the surface layer; (b) changes of that energy into the surface layer; (c) ejection of particles from irradiated area (atoms, ions, molecules); (d) formation of an intense plume of ejected materials and (e) incorporation of species onto the substrate surface layer.

Theoretical studies of laser plume expansion have been focused in the extreme cases of very low and relatively high back pressure. To this last case, considering a pressure of some pascals, the plume expansion is governed by diffusion where the ablated material are thermalized in collisions with the background gas or vapor. In this case, the plume expansion process can be divided into two stages: (i) the ablation plume (vapor cloud) formation and (ii) the propagation of the ablated material through a background gas [4].

Langlade et al. [5] and Pérez del Pino et al.[6] showed in their work with laser remelting of pure Ti and Ti–6Al–4Valloy in air that different titanium oxides such as TiO, TiO2 and Ti2O3 were formed in the surface layers of the samples by varying Nd:YAG laser beam configuration. Recently, working with a Nd:YVO4 pulsed laser irradiation on titanium surface with scanning velocity of 100 mm/s and 500 mm/s and repetition rate of 5 kHz and 35 kHz in air, this author [7] found TiO, Ti_2O, Ti_3O e Ti_6O formation.

The aim of this work, is the study of the ablation plume as a insulating environment over the irradiated surface of pure titanium by Nd:YVO4 laser in air, promoting the oxygen impoverishing in the formed oxides.

Experimental

The laser irradiation procedures were done in air with Nd:YVO4 - 10W equipment. The laser beam parameters to the irradiation conditions is showed in Table I:

Table I. Laser parameter configurations.

Laser parameter Configurations	Scan.vel. (mm/s)	Rep.rate (kHz)	Peak power (kW) *	Pulse width (ns) *	Avrg. power (W) *	Pulse energy (mJ) *	Fluence (J/cm²) **
A	300	35	14.5	17	8.6	0.24	93.3
B	100	5	50	10	3.8	0.56	93.3

*Data from the equipment curves.

**Fluence (accumulated energy per unit area) = (Pulse energy x Repetition rate) / (Φ_{BEAM} x Scanning velocity)

The analytical and characterization methods used in this study were SEM, AFM and XRD. The crystalline structures of samples were investigated by X ray powder diffraction (Seifert XRD 3000 TT diffractometer) and the quantitative phases analysis was obtained by the phases identification and full profile adjustment methods using the programs Crystallographica Search Match [8] and Powder Cell [9] respectively.

Results and Discussion

The Figure 2 shows the comparative dimensions of the plumes for A and B configurations at the same time period on the titanium surface. Although the laser configurations have the same cumulative fluence, it can be observed by plume characteristics and Table I values, the configuration A has the higher laser intensity (average power/(time x spot area)). This is confirmed by the AFM topographic appearance of the titanium irradiated surfaces at A and B configurations and the SEM melted spot area by one pulse in 35kHz and 5kHz. The ablation phenomenon occurred in the irradiated surfaces at both laser configurations (Figure 3). The resulting phase composition of the titanium irradiated surfaces at A and B laser configurations by XRD and adjustment method is presented in the Table II. It is possible to perceive the inverse relationship of the amount of "lower oxygen oxides" (Ti3O and Ti6O) in the irradiated surfaces with the laser intensity, even with the same cumulative fluence.

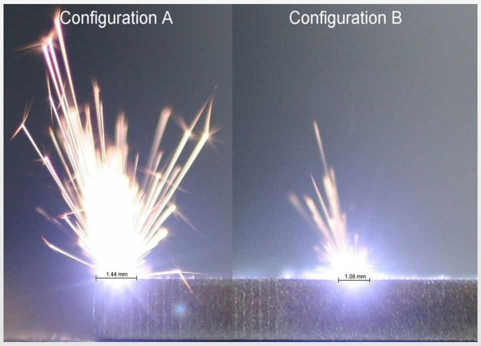

Fig. 2. Plume sizes for A and B configurations at the same time period.

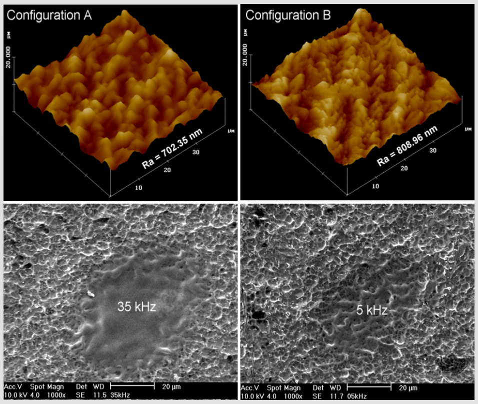

Fig. 3. Topography of the irradiated surfaces and the melted spot area.

Table II. Phase composition of the titanium irradiated surfaces.

Laser Configuration	αTi (%)	βTi (%)	TiO (%)	Ti_2O (%)	Ti_3O (%)	Ti_6O (%)
A	47.4	11.2	7.3	25.7	0.0	8.3
B	62.2	13.4	0.0	4.5	13.7	6.2

It was expected the oxygen most poor oxides would occur in the irradiated surface at *configuration A* because its higher intensity and major plume volume. One variable that can influence negatively this expectation is the *scanning velocity* (SC) of the laser beam. This is understandable if the *heat affected zone* is exposured to the air, still in melting state, due to *plume dislocation speed (PDS)* be higher than *solidification rate (SR)* of the material, justifying the XRD lower values to αTi and βTi in *laser configuration A* as a consequence of *a thicker oxide layer formation*. In a general manner it is possible correlate the quantity of the oxygen most poor oxides (Q) in a titanium irradiated surface by Nd:YVO4 laser beam according to the following relationship:

$$Q = k(SR/PDS); \qquad k = \text{constant} \tag{1}$$

Conclusions

- The laser beam plume suggests to insulate the *heat affected zone* in the irradiated surface;
- The percentage of titanium oxides with poorest oxygen content in the irradiated surface depends inversely on *laser scanning velocity : solidification rate of the material* relationship;
- The oxide layer thickness depends directly on *laser scanning velocity : solidification rate of the material* relationship.

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