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LASER INTERACTION WITH PROTECTIVE COATINGS

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1. Introduction

The surface modification studies of protecting coatings with various types of energetic beams, including laser beams, are of great fundamental and technological interest. The surface changes during the interaction processes depend on the beam characteristics, target properties and types of surrounding atmosphere. In an advanced technology application exists a great interest for ceramic coatings, among them especially for titanium ceramics: titanium nitride (TiN), titanium-aluminum nitride (TiAlN) and titanium diboride (TiB_2) (Nenadović, 1997) still exists.

In this work the morphological changes of titanium-ceramics coatings deposited on steel, induced by laser beam, were studied. For this purpose Transversely Excited Atmospheric (TEA) CO_2 laser operating in two different temporal pulse modes was used. Laser induced surface modifications of coatings were observed after 20-500 cumulative pulses action. Threshold damage and the damage yield have been monitored in the course of this work.

2. Experimental

The pulsed laser beam (10.6 μm) is produced by an UV preionized, TEA CO_2 laser. The laser operated with nontypical gas mixtures CO_2/X where X= N_2/H_2 or X= H_2 (Trtica, 2000). The laser operates in two regime: a tail (A pulse type) and tail-free (B pulse type) regime (Fig.1). The laser gave multimode output. The beam cross-section had a typical quadratic form so that the spatial-uniform distribution of intensity can be assumed. Pulse energy output was up to 200 mJ for A pulse and up to 40 mJ for B pulse type. The focused laser beam interacted with coatings at a normal angle in related to the surface in air.

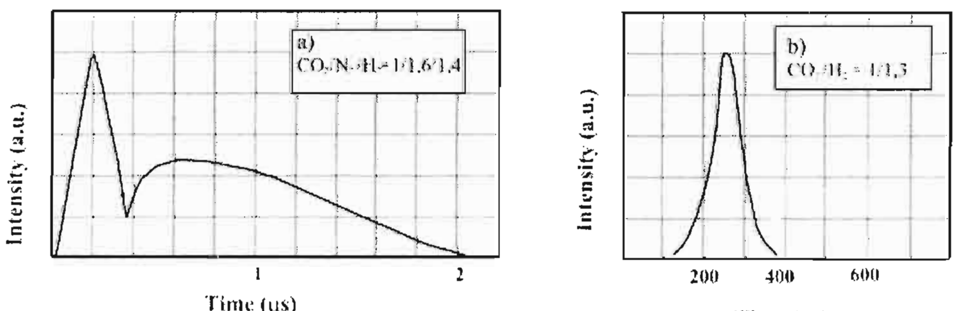

Fig.1. Temporal shapes of the CO_2 laser pulses used in the experiment:
(a) pulse type A (FWHM= 120 ns, tail= 2 μs, (b) pulse type B (FWHM= 80 ns).

The coatings were deposited onto polished steel substrate (high resistant stainless steel AISI 316 and high-speed tool steel AISI M2) by reactive ion sputtering (TiN and TiAlN) and by direct electron beam evaporation (TiB_2). The coatings thickness ranged from 1 to 3 microns. The crystal structure and the composition of the coatings have been performed by X-ray diffraction analysis (XRD) and energy dispersive analysis (EDAX). Optical microscopy, scanning electron microscopy (SEM) and atomic force microscopy (AFM) analyzed the targets morphology before and after laser beam interaction.

3. Results and Discussion

XRD as well as EDAX analysis made before laser irradiation of TiN (Ti,Al)N and TiB_2 coatings have confirmed their polycrystalline structure and the adequate composition of deposited layer. When the laser irradiates the surface, a part of beam energy is absorbed, converted into the heat and consequently, the surface temperature increases. The surface temperature variation $\Delta T(t)$ is directly depending on target absorptivity A (Ursu, 1991). For the investigated coatings, there are no literature data for the absorptivity in spectral range of CO_2 laser radiation. The obtained values of reflectivity R (and absorptivity, A=1-R) of coatings are different, depending on their composition and the substrate on which they were deposited, Table 1.

Table 1. Reflectivity of substrates and coatings.

Target:	AISI 316	TiN/ AISI 316	TiB_2/ AISI 316	AISI M2	TiN/ AISI M2	(TiAl)N/ AISI M2
R [%] (10.6 μm)	86.0	96.0	90.0	83.5	93.0	74.5

Investigation of morphological changes in coatings induced by the laser irradiation has shown their dependence on number of laser pulses: total deposited energy and laser pulse shape. In order to perform quantitatively analysis of pulsed laser beam-target interaction the damage threshold and damage yield has been determined. A damage threshold was defined as the minimum fluence that creates a detectable damage to the surface (Gaković, 1999). The results are presented in Table 2.

Table 2. Damage threshold dependence of laser pulse shape.

Coating	*A pulse* (*M* [J /cm^2])	*B pulse* (*M* [J /cm^2])
TiN/AISI 316	30.4	9.9
TiN/AISI M2	7.6	6.5
(Ti,Al)N/AISI M2	1.4	5.4
TiB_2/AISI 316	6.9	2.2

The results have shown that the damage yield of titanium ceramics coatings depends on laser pulse shape (Fig. 2.). A_s and A_0 represents the modified area on target surface after multiple and one laser pulse, respectively.

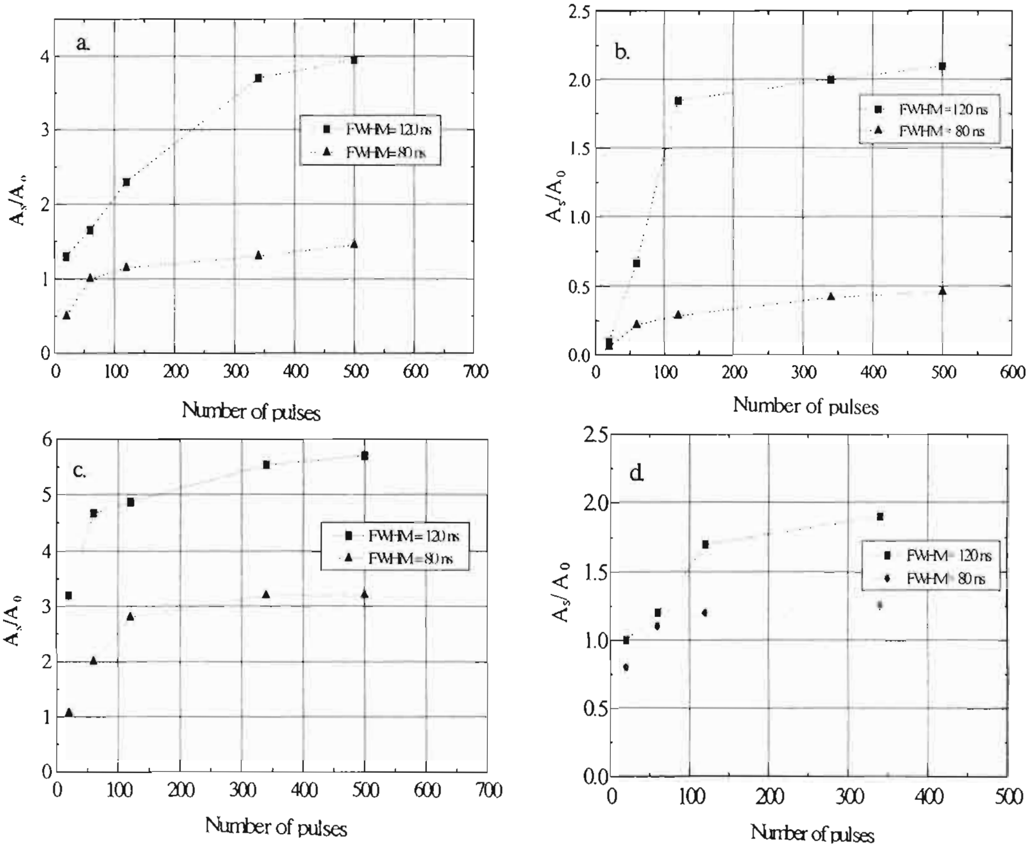

Fig. 2. Damage yield (A_s/A_0) as a function of laser pulse shape and the number of pulses: (a) TiN deposited on steel AISI 316, (b) TiN on AISI M2, (c) (TiAl)N on M2 and (d) TiB_2 on AISI 316 (Laser peak power density= 170 MW/cm^2).

The effects of cumulative laser pulse action on titanium-ceramic coatings were at first analyzed by optical microscopy and details have been obtained by scanning electron microscopy (SEM). Atomic force microscope (AFM) used in these investigations has a mode for three dimensions analysis of the target surface and the topographical changes were observed by this mode. The morphology changes of the TiN/AISI 316, deposited by direct current reactive ion sputtering, thickness of 0.85 micron, induced with 340 cumulative pulses B type without tail, are presented in Fig.3. The laser peak power density was 170 MW/cm^2 and was kept constant.

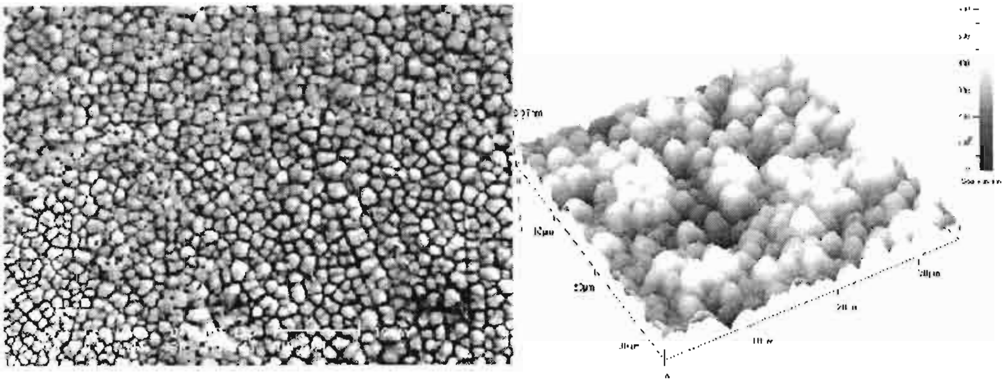

Fig. 3. The morphology changes on TiN/AISI 316 induced by 340 cumulative laser pulses type B (FWHM = 80 ns): (a) by SEM analyzes (bar = 10 μm) and (b) by AFM (scan 35 μm x 35 μm).

4. Conclusions

Protective coatings of TiN, (Ti,Al)N and TiB_2 with adequate quality after deposition process were obtained. The coatings have a fine columnar and fibrous structure and satisfactory mechanical properties.

The results obtained by SEM and AFM have shown that TiN coatings deposited on different substrates have similar behaviour under cumulative laser irradiation. (TiAl)N coating posses lowest reflectivity and most expressed chemical affinity of surface at high temperature. Consequently, significant morphological changes were obtained. Among the coatings, the difference between thermophysical characteristics of substrate and deposited TiB_2 are the highest and under cumulative laser pulse irradiation, the exfoliation is the dominant effect. For all coatings, damage yield was more prominent for laser operating in pulse with tail- A pulse type.

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