LASER-PULSE INTERACTION WITH Cu AND Ti UNDER ATMOSPHERIC PRESSURE AND VACUUM

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ABSTRACT

Ruby laser-pulse interaction with Ti and Cu using free-generated and Q switch mode under atmospheric pressure and vacuum has been applied. Laser pulsing in the case of Ti was 5 ms and 30 ns. In the case of Cu laser pulse duration of 30 ns was constant in all conditions. Previous optical microscopic analysis of developed damage in Cu was reviewed in greater detail using scanning electron-microscopy. Various types and sizes of damages in Cu have been defined, both under atmospheric pressure ad vacuum. Damages in the investigated material appeared to be of irregular crater-like shape. Differences in crater size and shape from Ti - laser-pulse interactions have been observed. Resulting crater structures, shapes and sizes under atmospheric pressure and vacuum were compared using the same laser-pulse duration period of 30 ns. Interpretation of the interaction type in the sense of expressing coefficient of reflection, refracting index for given wavelength, conductance, and specific heat would be of great significance. Major characteristics in the course of developing interaction are critical levels of laser beam power density for melting and evaporation.

INTRODUCTION

Theoretical basis

Wide use of titanium and its alloys is mainly because of their favourable characteristics, like lower density, high specific strength and strong resistance to corrosion. In case of copper and its alloys, the importance is of its high conductivity.

During the last few years much attention has been payed to testing and developing these materials owing to the need for exact microstructural analyses that follow transformations in materials that usually appear under different types of implemented technologies. Especially under laser treatment, considerable heating and cooling rates appear whether or not welding, cutting, thermal treatment or drilling is applied. Whenever some of these treatments are applied, structural and phase transformations occur under conditions of super-fast laser heating and cooling. It is well known, Rykalin et al (1990), Grigoranc et al (1988), that on location of laser beam contact with metal surface, under circumstances of poor reflection, large ammount of heat is released in a short time, inducing the heat rate of several million degrees per second. After interacting with the beam, the instantaneously heated segment is surrounded by cold metal, thus providing fast cooling.

It is assumed that, Krylow et al (1978), separation caused by evaporation of material from the surface initiates increase in dislocation density. It is also evident, Backović (1993), that a shock wave travelling through intrinsic material layers causes plastic deformation.

This type of experiments involves interactions of importance in the sense of expressing reflection coefficients, transparency, refracting index for given wavelength, conductivity and specific heat. A particular aspect is given for determining conditions of cracking in the material under defined laser radiation energy state and duration, whereby crack length is given by the expression:

$$L = (\beta E_y T'/(1-2E_p)\ \sigma_r\ r(t) \qquad (1)$$

and tangential stress,

$$\sigma_e = (\beta E_y T'/3(1-2E_p)\ r(t)\ \rho^2 \qquad (2)$$

where, β is the coefficient of linear volume expansion, E_y Young's modulus, T' transformation temperature in region of melting front, r(t) crater, E_p - Poisson's ratio, ρ - density of material.

As major parameters considering the expected interaction, the following specific values should be defined:

$$q_c(1) = 0.885 \cdot T_m \cdot a \cdot \sigma \qquad (3)$$

$$q_c(2) = 0.885 \cdot T_v \cdot a \cdot \sigma \qquad (4)$$

where, $q_c(1)$ and $q_c(2)$ represent critical power density levels of laser radiation for melting and evaporation of material, respectively, s duration of laser impulse, $a = \lambda/\rho c$ - thermal conductivity, c specific heat.

EXPERIMENTAL RESULTS

Ruby laser interaction has been investigated for titanium and copper under atmospheric pressure and vacuum. Laser pulse durations in the case of titanium were 5 ms and 30 ns. In the case of copper durations were always 30 ns. Energy levels for titanium were approximately 3 J for interactions in vacuum and air. Energy levels used for copper were the same for vacuum conditions. Energy values per impulse for copper, under atmospheric pressure, were in the range 0.1 - 2.6 J.

Material damages were analyzed by optical microscope and in more detail by scanning electron microscopy, as shown in Fig.1 - 12. Figures 13 - 15 represent acoustic recordings for specified distances from target (titanium and copper).

RESULTS AND DISCUSSION

Figure 1 shows circular shaped damage in titanium under atmospheric pressure, with diameter d ≈ 3.45 mm. A laterally developing crack of length l = 1.85 mm is also visible.

In Fig.3 a damage in titanium caused by laser beam interaction in vacuum is mainly circular. Diameter value is aproximately d ≈ 1.73 mm, indentation depth is not great with edges having both minor and major deformations. A structure not uniformly deformed is shown in Fig.4.

Damage in titanium is shown in Fig.5, also for vacuum,in which case the diameter is 1.68 mm. This case is characterized by larger indentation depth compared to that in Fig.3. A new structural state has been developed, which is clearly depicted on Fig.6.

Damage in copper, shown in Fig.7, is induced under atmospheric pressure, being also of circular shape, aproximately d = 1.79 mm in diameter, and energy E = 0.2 J. In Fig.8 are shown damages in copper, one next to the other, created also under atmospheric pressure, but with energies E = 2.6 J. An approximate diameter value is d ≈ 2.7 mm. Figure 9 shows a structure of damaged surface within the central area, and in Fig.10, edges of damages created with energy E = 0.2 J are shown.

Structures in edges of vacuum induced damages in copper are shown in Fig.11 and 12. Acoustic recordings in the frequency and time domain for samples of defined geometry are shown in Fig.13, 14, 15 for both Ti and Cu.

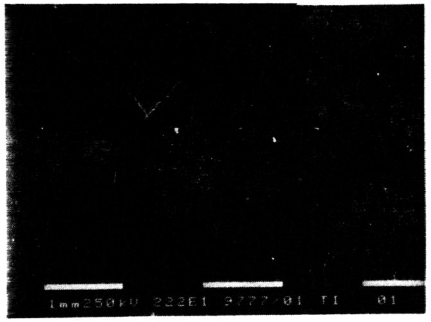

Fig. 1. Ti - atmospheric pressure
E = 0.2 J

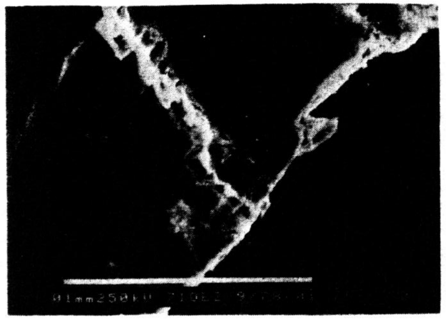

Fig. 2. Ti - atmospheric pressure
E = 2.6 J

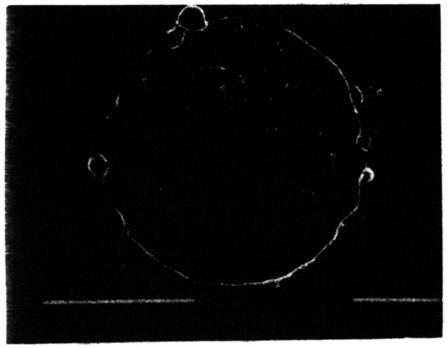

Fig. 3. Ti - vacuum
E = 0.2 J

Fig. 4. Ti - vacuum
E = 2.6 J

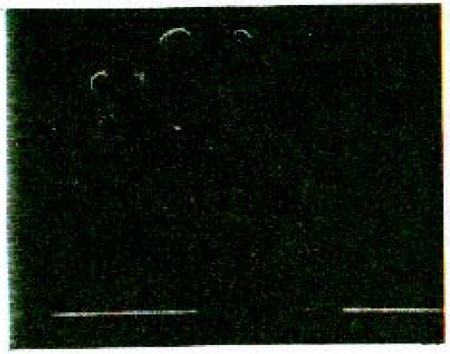

Fig. 5. Ti - vacuum
E = 0.2 J

Fig. 6. Ti - vacuum
E = 2.6 J

Fig. 7. Cu - atmospheric pressure
E = 0.2 J

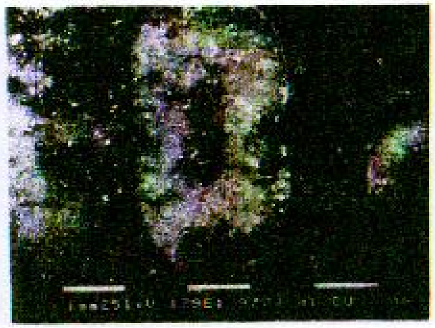

Fig. 8. Cu - atmospheric pressure
E = 2.6 J

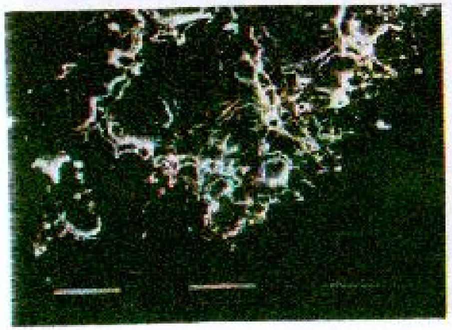

Fig. 9. Cu - atmospheric pressure
E = 0.2 J

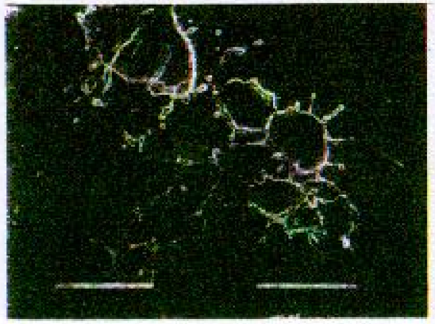

Fig. 10. Cu - atmospheric pressure
E = 2.6 J

Fig. 11. Cu - vacuum
E = 0.2 J

Fig. 12. Cu - vacuum
E = 2.6 J

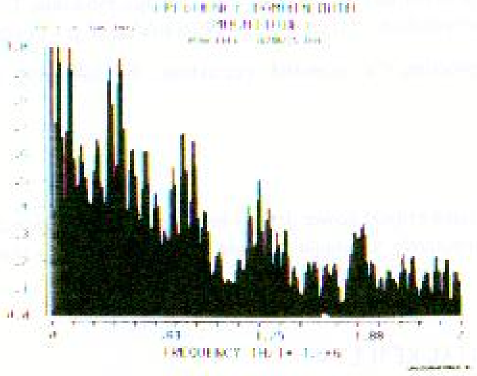

Figure 13. Ti - Acoustic recording, frequency domain

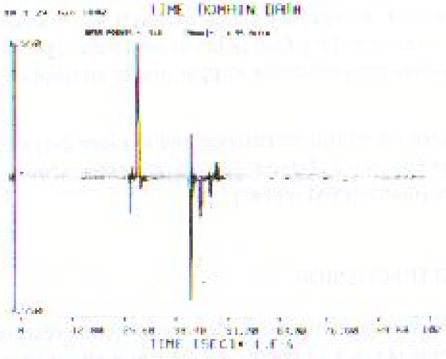

Figure 14. Ti - Acoustic recording, time domain

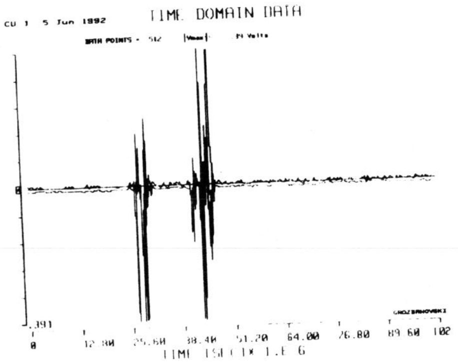

Figure 15. Cu - Acoustic recording, time domain.

CONCLUSIONS

1. Ruby laser interaction with titanium and copper has been analyzed under conditions of atmospheric pressure and vacuum.
2. In the case of Ti experiments were carried out under free generation mode and Q switch, and in the case of Cu only with Q switch mode.
3. Mono-pulse regime was used.
4. Scanning electron microscopy enabled detailed analyses of damages that lead to structural changes in tested materials:
   - in titanium, under atmospheric pressure, cracks were located in the central part of damage, and scarcely appeared on edges;
   - cracks were not noticed in titanium in vacuum, but material merging on edges was recorded, as well as structural changes in the central area;
   - in copper, under atmospheric pressure for both energy levels, traces of inhomogeneous structures and great ammounts of oxides were recorded;
   - in copper under vacuum, within the edges, a great deal of overflowing of the material and related improper merging took place.
5. Also of great interest is the analysis of final expressions for crack lengths under mentioned experimental conditions.

LITERATURE

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