Laser interactions with Ti,Ni and Al Alloys

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Abstract. The TEA CO_2 laser interaction with Ni, Ti and Al alloys is evaluated experimentally as well as by adequate numerical calculations. The chosen alloys are important in machine tool industries. Different tasks for laser processing, from commercial as well as theoretical point of view, can be introduced, too. The operation could be made in UV, IR and visible range. Some questions of laser efficiancy as well as the relationship of modern commercial lasers for these material depend on chosen dynamical regimes and technological operation (welding or cutting). The performed experiments could be possible with various other laser types , but the efficency depend on laser efficiency and material characteristics.

Introduction

Laser treated Ni, Ti and Al alloys, due to improved good mechanical and electrical characteristics, have broad use in aerospace, electro-technique, microelectronics, machining tool technologies, etc. [1-6]. The theoretical relationship between crater and diameter of laser damage in various dynamical regimes are sometime very distant from experimental results.

Al alloys were categorized as materials with poor thermal properties versus laser techniques, and this problem was somehow solved in time.

On the other hand Ti is known as the material, hard processible with non-laser “classical” treatment (high melting and boiling points). Ternary alloy of titanium with broad application (rotor shovels), present good combination of hardness and ability for plastic deformation, if the adequate technological operations were performed. The same processing techniques for titanium alloy were performed as for dural, but in coresponding time maner.

Ni alloys as material with extreme resistance to corrosion and high temperature oxidation are of importance for refractory elements production (resistance to creep). Thanks to chromium and cobalt, plastic defformation performances were increased while aluminum and titanium contribute to precipitation hardening. Processing techniques were performed as for dural in coresponding time maner. The selected processing techniques enable the extraction of specific phases and carbide particles.

Artificial ageing process performed after dissolving, firing, annealing of the material is in the focus of this work.

Experimental details

Samples testeed in this work are Al, Ni and Ti alloys. Chemical composition of laser treated alloys is given in Table 1.

Table 1. Alloys composition

Al-Cu-Si alloy	Al: 90-94%	Cu or Si 3-5%			
Ni alloy Inconel 718	Ni(+Co)50-55% Cr:17-21%	Mo:2,8-3.3% Co:1%	Ti:0.65-1.15% Nb(+Ta)4.75-5.5%	C:0.08% Si:0.35; Cr18.5%,Fe18.5% Al:0.2-0.8%	Cu:0.3% Mn:0.35%
Ti –Al-V Alloy IMI 318.6-4	Ti:90%	V: 4%	Al:6%		

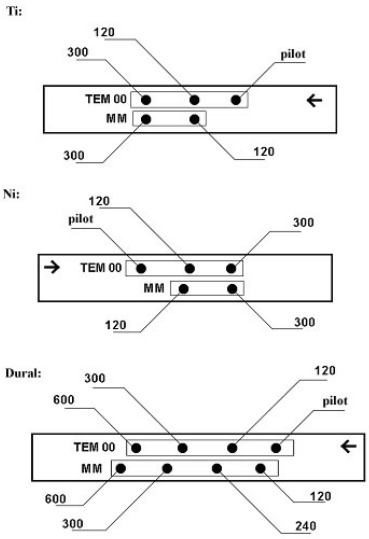

Fig.1. Scheme of exposition for different samples by CO_2 laser

Samples are exposed to CO_2 TEA lasers as is presented in Fig.1.

Applied laser was an efficient small scale TEA CO_2 laser for multifold purposes. It was applied with $CO_2/N_2/He$ as well as with other combination. Discharge volume 14 cm^3 vol, flowing TEA CO_2 laser. The work was in ternary and binary gas mixtures. The ternar conventional mixture was $CO_2/N_2/He$ and unconventional CO_2/X,($X=N_2/H_2$, N_2/C_2H_2, H_2/He). Conventional binary gas mixtures CO_2/N_2 and CO_2/He. The unconventional gas mixture is CO_2/H_2 . The detail of the typical parameters of those type operating regimes are given in [7].

The Fig.2 and Tables 2 and 3 are given the details of the experiment: samples content, exposition conditions. In Fig.2 is presented typical pulse shape for laser which could be further averaged for multi/mode working regime.

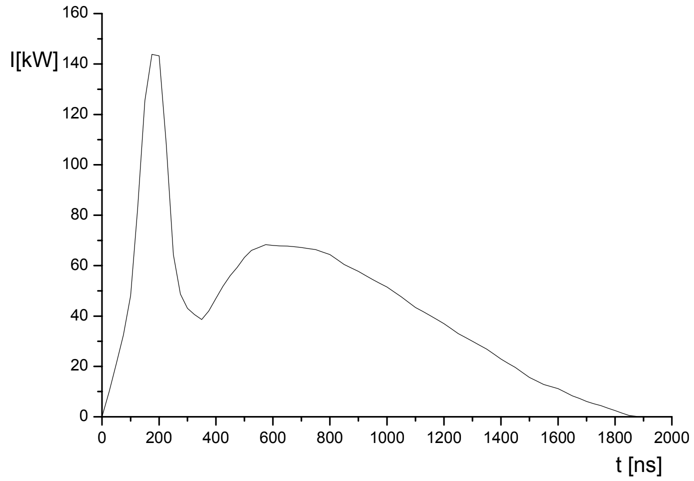

Fig.2 Typical shape of TEA CO_2 laser

Table 2. Average mono-pulse laser power including repetition rate

TEM_{00}	Multimode
187 mJ	386 mJ

Table 3. Energy of TEM_{00} and multimode laser beams for single and multimode working regime (e.g. exposition)

Number of accumulated laser pulses (ALP)pulses for given damage (at spot)	TEM_{00}	Multimode
1	85mJ	180mJ
120	10.2 J	21.6 J
240	20.4 J	43.2 J
300	25.5 J	54.0 J
600	51.0 J	108 J

Exposition represents :N Ee;N-number of ALP, Ee-Pulse laser output energy

The samples are exposed to monopulse and multifold laser regimes, with the single pulse shape shown in Fig.2 an 3, respectively, energies in upper Tables 2a and 2b were calculated after this pulse shape [16].

Results and Discussion

The samples are analyzed first visually and by optical microscope. The chosen results are presented in Figs. 3-6.

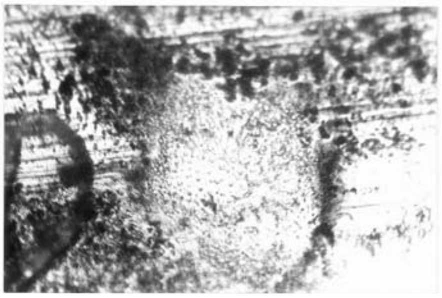

Fig. 3. Damage in the Ti alloy damage by TEA CO_2 laser, Spot 2; 120 pulses; E_{pulse}=85mJ;

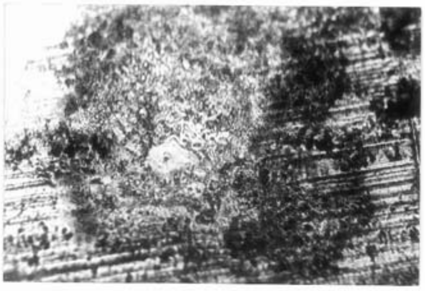

Fig. 4. Damage in the Ti alloy damage by TEA CO_2 laser, Spot 1; 300 pulses; E_{pulse}=85mJ;

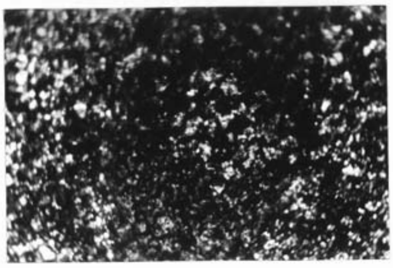

Fig. 5. Damage in the Ni alloy damage by TEA CO_2 laser, Spot 3; 300 pulses; E_{pulse}=85mJ;

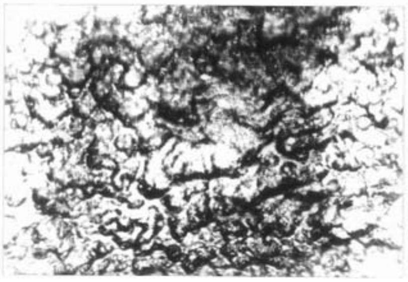

Fig. 6. Micrograph of the Ni alloy damage by TEA CO_2 laser, Spot 3; 120 pulses; $E_{per\ pulse}$= 120mJ;

Mathematical model of interaction. The case of the laser interaction with a thin plate specimen is considered by thermal modeling [8-16]. Some of the results are presented in Fig.7 .under various assumptions up to the melting points of the respective material.

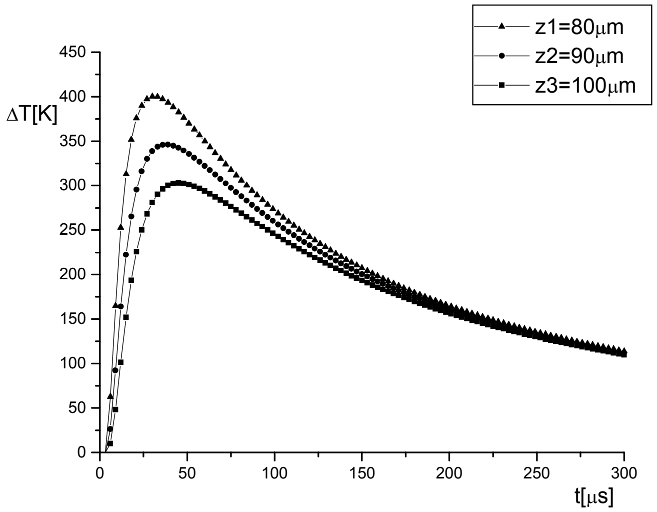

Fig. 7.Temperature distribution for TEM_{00} mode in center of beam Dural sample; h=1 mm-plate like sample ; beam diameter 0.6mm; depth in sample $z_1=80$ μm; $z_2=90$ μm; $z_3=100$ μm; Gaussian beam profile

The part of partial differential equations used for thermal modelling is based on

$$\begin{aligned} &\frac{1}{a}\frac{\partial T(z,r,t)}{\partial t} = \Delta T(z,r,t) \\ &-\lambda\frac{\partial T}{\partial z} = A\varphi(t)\cdot q(r) \quad z=0 \\ &-\lambda\frac{\partial T}{\partial z} = \alpha T\,, \qquad z=h \\ &T(z,r,0)=0 \\ &T(z,\infty,t)=0 \\ &t>0,\, 0\le z\le h,\, 0\le r \end{aligned} \tag{1}$$

where:λ-coefficient of thermal conductivity, a= λ /ρc, c-specific heat, ρ- material density, α-heat transfer coefficient which determines the rate of heat losses, h-plate thickness, A-absorption coefficient of the material and T is the difference between the interior domain and the ambient temperatures. The calculations were made for Gaussian and top hate laser beam profiles, respectively.

Conclusion

Some experimental and numerical results for laser material interaction for different working regimes of laser in case of Al-Cu-Si, Inconel 718 and Ti-Al-V alloys were presented.

The thermal model of interaction was used and various analytical solutions and numerical results for temperature field distribution were given. For mono-mode laser working regimes, Gaussian beam profile was assumed and in the case of multi-mode regimes top-hat profile was considered.

Al-Cu-Si, Inconel 718 and Ni-Al-V alloys have very different thermal properties, These variation is assumed to be imposed by the respective temperature distributions. During multipulse regimes various processes damaging the surface of the material are verified in metallographic light microscope analysis.

In regard to laser working regimes according experiments it can be concluded:

- Damages are different depending on the dynamic working regime
- Laser in multi and monomode regimes provokes various damage structures, complex in multimode and almost circular in mono-mode.

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