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LASER SURFACE HARDNESS

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The experimental dependence of surface hardness on Nd:YAG laser parameters (laser intensity, laser pulse duration, number of laser shots and laser spot diameter) for aluminum, titanium, nickel, cooper and two kind of steel (21CrMoV57 and 40C130) targets is given. It is show that the target surface hardness increases with laser intensity, with number of laser shots and laser pulse duration. Also, the target surface hardness decreases when the laser spot diameter increases. From these experiments result that the laser hardness is rather a function on laser surface energy density than laser energy.

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1. Introduction

In thermal processing with laser radiation energy deposition and heating in a material are a consequence of the balance between the deposited energy, governed by optical materials proprieties and characteristics of the laser radiation, and the heat diffusion, determined by termophysical materials proprieties and the interaction time. For temperatures below melting temperature the light-induced changes of proprieties occur within the solidus-range. In surface treatment with a laser, the metallic surface is heated locally extremely rapidly and after the laser is switch off it is cools very rapidly. The temperature rises very rapidly to almost melting temperature. Only a thin layer is heated, the other parts of the target remain cold. Due to the high temperature gradients, thermal conduction to the bulk material will cause sufficiently rapid cooling of the heated parts and the resultant structures are often metastable structures with particular proprieties. Heating and cooling rates are of the same order ~10^6 K/s. The advantages and disadvantages of surface treatment with laser beams are thus apparent: precise local treatment, non-equilibrium structures with specific proprieties, difficult procedure for covering large areas with each track influencing the structure of the previous one if the laser beam is moving on the target surface [1]. The laser is not a universal tool and should not be considered simply as a possible substitute for existing methods. It is very effective for treatment of thin surface layers. If thick layers are to be treated then other heat sources are more appropriate. Laser transformation hardening offers decided advantages in local or partial hardening of components or treatments of components which are too large for treatment other by flame hardening.

The hardness of the material is strongly related to its binding behaviour [2]. The metallic binding gives not the highest hardness values but allows a certain amount of plastic deformation. The highest hardness values are obtained for covalent bindings, like diamond. Heteropolar bindings are found for a number of ceramic materials which apart from their hardness show a good oxidation resistance. In reality, the binding behaviour is more complicated and mixed types of binding are possible.

The equation governing absorption of laser energy on the metallic target is given by:

$$I = (1 - R)e^{-z\sum_i \alpha_i} \tag{1}$$

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where I is the laser intensity of the absorbed laser beam and I_0 is the intensity of the incident laser beam. The fraction of the incident light intensity reflected by the target is given by R. The factor α_i represents the coefficient for the light absorption by the i^{th} process which summed over the different absorption processes occurring at the irradiated surface, and z is the penetration depth of the radiation in the material. In the case of laser hardfacing the laser intensity must be below the critical value for melting of material. For same lower laser intensity we account a single term in equation (1) which represent the classical absorption of the electromagnetic radiation by a metallic material.

The critical laser intensity required for melting the surface of the target can be theoretically estimated by the following relationship:

$$I_m = \frac{k_T T_m}{2(1-R)\sqrt{\chi_T \tau_p}} \tag{2}$$

where T_m and k_T are the melting temperature and the thermal conductivity of the material, respectively.

It is know that in the case of laser interaction with the metallic targets the depth of the damage or the interaction corresponds closely to the depth of thermal penetration l_{th} given by the following relationship:

$$l_{th} = \frac{1}{2}\sqrt{\pi \chi_T \tau_p} \tag{3}$$

where χ_T is the thermal diffusivity of the metal and τ_p is the laser pulse duration.

2. Laser and targets

Laser

Experiments have been performed with the neodymium-YAG laser of our laboratory operating at 1.064-μm wavelength. The laser delivers Gaussian pulses of 2 ms, 2.5 ms and 3 ms full width at half-maximum (FWHM) with a repetition rate till 20 Hz. The laser output energy can be ranging between 0 and 15 J. The laser spot diameter can also be modify from 0.3 mm to 8 mm. In instance the maxim laser intensity is about 1.06×10^7 W/cm^2. For the hardness experiments we have used lower laser intensities. All experiments were performed in air at normal conditions.

Targets

For experiments we have used metallic targets of aluminum, titanium, nickel, cooper and two kind of steel: 21CrMoV57 and 40C130, with 1.5-mm thick and 10-mm diameter. Their surfaces were polished using a P 1000 grade polishing paper. In order to improve the laser absorption the surface of the targets was painted with a very thin black paint. The measurements of the target surface hardness were performed with a microhardness device.

3. Experimental results

First we have calculated the critical laser intensity for melting the target surface using equation 2. The results for our target materials are given in Table 1. Then we have measured the experimental values for critical laser intensity obtained when we use our laser. In order to compare these values the results are given in the same Table 1.

Table 1. Calculated and measured values of critical laser intensity.

Targets	Al	21CrMoV57	40C130	Ti	Cu	Ni
I_{cr} (W/cm^2)	4.2×10^3	1.7×10^4	1.5×10^4	9.5×10^3	1.1×10^4	6.5×10^3
	7.6×10^3	6.9×10^3	6.5×10^3	7.5×10^3	7.9×10^3	7.5×10^3

The calculated depth of thermal penetration, equation 3, is given in Table 2 for three values of laser pulse duration.

Table 2. Calculated values of thermal penetration depth for three laser pulse durations.

Targets		Al	21CrMoV57	40C130	Ti	Cu	Ni
l_{th} (μm)	τ_p=1 ms	261.6	97.1	104.8	68.6	296.5	118.9
	τ_p=2 ms	369.9	137.3	148.2	97.0	380.4	168.2
	τ_p=3 ms	453.1	168.2	181.5	118.8	513.5	205.9

We have performed a first experiment in order to obtain the dependence of surface target material hardness on laser intensity. The results are given in Fig. 1. The laser irradiation parameters were: pulse duration 2.5 ms, the laser spot diameter 5 mm, and the number of laser shots 600.

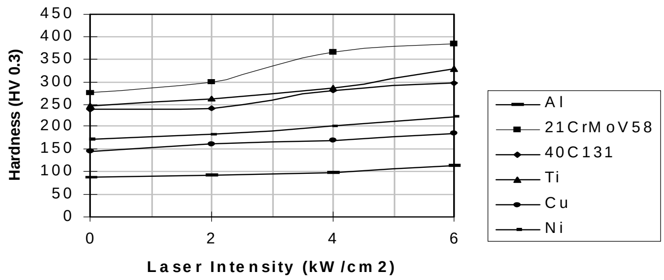

Fig. 1. Surface target hardness vs. laser intensity.

In other experiment we have analyzed the dependence of surface target material hardness on laser pulse duration. The results are given in Fig. 2. The laser energy for each target material was close below the critical value for melting given by Table 1. The laser spot diameter was 5 mm and the number of laser shots was 600 as in previous experiment.

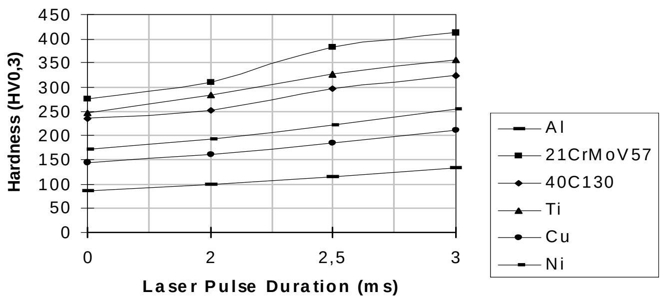

Fig. 2. Surface target hardness vs. laser pulse duration.

The dependence of surface target material hardness vs. number of laser shots is given in Fig. 3. The laser energy for each target material and the laser spot diameter were the same as in previous experiment.

Fig. 3. Surface target hardness vs. number of laser shots.

In our last experiment we have analyzed the dependence of surface target material hardness vs. laser spot diameter. The laser pulse duration was 2.5 ms, the laser energy for each target material was the same as in previous experiment and the number of laser shots was 600. The results are given in Fig. 4.

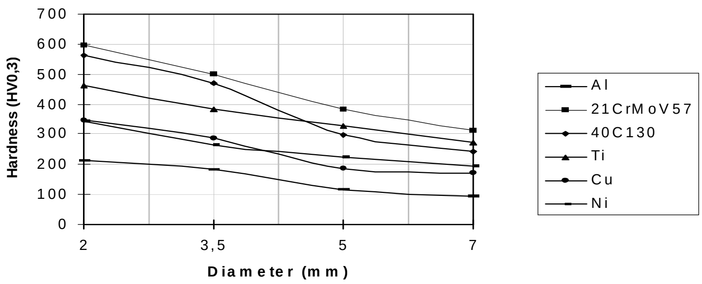

Fig. 4. Surface target hardness vs. laser spot diameter.

4. Conclusions

We have measured the metallic target surface hardness before and after laser irradiation below melting temperature in order to study the hardness dependence on Nd:YAG laser parameters: laser intensity, laser pulse duration, number of laser shots and laser spot diameter. From our experiments it results that the laser surface hardness increases with laser intensity, laser pulse duration, number of laser shots and decreases when laser spot diameter increases.

References

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