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Applied Surface Science 252 (2006) 2131–2138
applied surface science
www.elsevier.com/locate/apsusc

Laser fluence, repetition rate and pulse duration effects on paint ablation

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Received 17 January 2005; received in revised form 8 February 2005; accepted 8 February 2005
Available online 17 May 2005

Abstract

The efficiency (mm^3/(J pulse)) of laser ablation of paint was investigated with nanosecond pulsed Nd:YAG lasers ($\lambda = 532$ nm) as a function of the following laser beam parameters: pulse repetition rate (1–10,000 Hz), laser fluence (0.1–5 J/cm^2) and pulse duration (5 ns and 100 ns). In our study, the best ablation efficiency ($\eta \cong 0.3$ mm^3/J) was obtained with the highest repetition rate (10 kHz) at the fluence $F = 1.5$ J/cm^2. This ablation efficiency can be associated with heat accumulation at high repetition rate, which leads to the ablation threshold decrease. Despite the low thermal diffusivity and the low optical absorption of the paint (thermal confinement regime), the ablation threshold fluence was found to depend on the pulse duration. At high laser fluence, the ablation efficiency was lower for 5 ns pulse duration than for the one of 100 ns. This difference in efficiency is probably due to a high absorption of the laser beam by the ejected matter or the plasma at high laser intensity. Accumulation of particles at high repetition rate laser ablation and surface shielding was studied by high speed imaging.

PACS: 81.65 Cf; 42.62 Cf; 61.82 Ms

Keywords: Laser ablation; Repetition rate; Paint stripping; Pulse duration; Thermal confinement regime

1. Introduction

For the last few years, material processing with nanosecond pulsed laser for the etching of polymer surfaces [1–9], tissue ablation [10–12] or paint removal [13–20] has been widely studied. The development of new high repetition rate and high power lasers allows to use lasers for large surface cleaning and large area depainting. For industrial depainting, laser application seems advantageous compared with chemical or mechanical processes. Laser application may offer a dry process with a lower waste volume and may be automated. Experiments on

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0169-4332/$ – see front matter
doi:10.1016/j.apsusc.2005.02.143

laser ablation depainting have been made with nanosecond Nd:YAG laser [13–15], CO_2 laser [15–18], excimer laser [19] and high power diode lasers [20]. CO_2 and excimer laser are commonly used when it is necessary to prevent a metal substrate from damages: with CO_2 laser (10.6 μm), the ablation threshold of a metallic substrate is higher than the one of paint. Excimer laser (UV wavelength leading to photochemical ablation) allows to decrease significantly the thermal effects. High repetition rate Nd:YAG lasers are very useful for the beam transport by an optical fibre on a long distance. This is important for laser decontamination as it allows to move the laser away from the contaminated surface and to avoid its pollution during ablation.

Laser–matter interaction is known to depend on several laser parameters: wavelength, fluence, pulse duration and repetition rate. Paint ablation with a 532 nm wavelength results mainly in thermal ablation, because no apparent electronic transitions inducing direct bond breaking are reported at this wavelength. Studies on laser ablation efficiency are frequently presented with the ''etching curves''. These curves give the dependence of the removed material depth (crater depth) on the laser fluence. They make possible to define the threshold fluence for ablation, i.e. the fluence from which the onset of the ablation is noticeable or becomes efficient. Indeed, with a thermally activated process, no real threshold exists [2]. However, *significant* ablation is observed only above a certain fluence, defined as the threshold fluence that corresponds to a critical temperature reached in the surface layer of the material [21]. Etching curves usually show a saturation behaviour or a negative inflexion at high fluence due to plasma, vapor or released fragments shielding of the surface.

For materials with a low thermal conductivity and with a low optical absorption (similarly to the paints under our study), the heating regime is presented as a ''thermal confinement regime'' [10–12,21–24] because the heat diffusion can be neglected during the pulse absorption. The condition for thermal confinement regime can be expressed as $L_T = \sqrt{D\tau_p} \ll 1/\alpha$, where L_T is the thermal diffusion length, D the thermal diffusivity of the irradiated material, α the optical absorption and τ_p is the pulse duration. Thus, the initial temperature distribution is directly correlated with the deposit of the laser beam energy in the bulk. Therefore, no influence of the pulse duration on the ablation threshold fluence in nanosecond regime is expected in this case.

The effect of the repetition rate on the ablation efficiency is almost not presented in the literature. Studies on laser ablation of polymer in UV spectral range are reported by Burns and Cain [8] and Yung et al. [9]. In these studies, a decrease of the threshold fluence between 10 Hz and 300 Hz repetition rate is observed and the repetition rate effect on the ablation products is described. Roberts [16] presented results on paint removal with a TEA CO_2 laser, and measured higher efficiencies with 1500 Hz than with 1 Hz.

In our studies, laser removal of grey epoxy paint has been investigated with two pulsed repetition rate Nd:YAG laser systems at 532 nm. Epoxy coatings are widely used in the civil industry (e.g. aeronautic or automobile coatings) and in the nuclear one. Specifically designed experimental set-ups were provided to obtain accurate measurements of the laser parameters and crater depths. Special efforts were made to obtain a homogeneous (flat top) laser beam distribution on the interaction zone. The repetition rate and the pulse duration effects on the ablation threshold and on the ablated depth are presented in 0.1–5 J/cm^2 laser fluence range. Surface shielding by accumulation of particles in front of the surface was investigated with a high speed imaging system. The air jet effect on the high repetition rate laser ablation is studied.

2. Experimental set-ups

Two specially developed laser benches (5 ns and 100 ns pulse duration) were provided for our studies on paint ablation with homogenised laser beam (flat top spatial profile).

2.1. Five nanoseconds pulse duration laser bench

Paint ablation was carried out with a Q-switched Nd:YAG laser (Brilliant, Quantel) with 5 ns pulse duration (FWHM) at 1 Hz, 10 Hz or 20 Hz. With a KDP non-linear crystal at 532 nm, the maximum energy per pulse was 180 mJ. The beam was expanded