Optics & Laser Technology 46 (2013) 29–36

Contents lists available at SciVerse ScienceDirect

Optics & Laser Technology

journal homepage: www.elsevier.com/locate/optlastec

Epoxy-paint stripping using TEA CO_2 laser: Determination of threshold fluence and the process parameters

Manoj Kumar [a,*], P. Bhargava [a], A.K. Biswas [c], Shasikiran Sahu [d], V. Mandloi [a], M.O. Ittoop [a], B.Q. Khattak [b], M.K. Tiwari [c], L.M. Kukreja [a]

[a] Laser Materials Processing Division, Raja Ramanna Centre for Advanced Technology, Indore, MP, India
[b] Chemical Treatment Laboratory, Raja Ramanna Centre for Advanced Technology, Indore, MP, India
[c] Indus Syncrotron Utilization Division, Raja Ramanna Centre for Advanced Technology, Indore, MP, India
[d] Pandit Ravi Shankar Shukla University, Raipur, MP, India

ARTICLE INFO

Article history:
Received 9 November 2011
Received in revised form
3 April 2012
Accepted 19 April 2012
Available online 23 May 2012

Keywords:
Laser paint stripping
TEA CO_2 laser
Epoxy paint

ABSTRACT

It is shown that the threshold fluence for laser paint stripping can be accurately estimated from the heat of gasification and the absorption coefficient of the epoxy-paint. The threshold fluence determined experimentally by stripping of the epoxy-paint on a substrate using a TEA CO_2 laser matches closely with the calculated value. The calculated threshold fluence and the measured absorption coefficient of the paint allowed us to determine the epoxy paint thickness that would be removed per pulse at a given laser fluence even without experimental trials. This was used to predict the optimum scan speed required to strip the epoxy-paint of a given thickness using a high average power TEA CO_2 laser. Energy Dispersive X-Ray Fluorescence (EDXRF) studies were also carried out on laser paint-stripped concrete substrate to show high efficacy of this modality.

1. Introduction

Stripping of painted metal and concrete surface is an important requirement in nuclear installations for decontamination [1,2] purpose and in aerospace industry [3] in order to check the metal surface underneath the paint for possible fatigue damage. Paints are generally removed from painted surfaces either by chemicals or abrasives. Though these chemical and abrasive based techniques are fairly effective, but suffer from certain drawbacks. These processes often generate mixed waste and may damage the substrate surface too. Moreover, chemical or abrasive based methods frequently drive some fraction of the contaminated paint residue deeper into the material, particularly, if the material is porous.

However, when lasers are used for paint stripping, a thin layer of paint absorbs the laser radiation resulting in the stripping of the paint layer by vaporization or ablation [3]. In laser paint stripping the amount of secondary solid waste generated is much less than the initial amount of paint [4]. Paint stripping with CO_2 laser [5–10], excimer laser [2,9], Nd-YAG laser [8,9,11] and diode laser [12–14] has been demonstrated successfully. The choice of a particular laser for paint stripping depends on the optical properties of the paint at the irradiation wavelength, paint thickness and on the material from which paint is to be removed. Paint stripping using excimer laser has demonstrated that aluminum and steel substrate retains good surface quality after stripping without getting thermally damaged [15]. However, as the removal of paint per pulse is rather small the processing time is generally longer. Epoxy grey paint stripping with Nd:YAG laser was extensively studied as a function of repetition rate (1 Hz–10 kHz), laser fluence (0.1–5 J/cm^2) and pulse duration (5 ns and 100 ns) [16]. The best paint ablation efficiency of 0.3 mm^3/ (J pulse) was obtained for 10 kHz at 1.5 J/cm^2 for 100 ns pulse. Nd:YAG lasers offer distinct advantage of fiber beam delivery but when the metal surface need to be protected after paint stripping, excimer and CO_2 lasers are preferred. A 1 kW pulsed TEA CO_2 laser (pulse energy $\sim$3.8 J, repetition rate $\sim$265 Hz) was developed for paint stripping of various metallic and composite aircraft panels [6]. Due to high absorption of CO_2 laser radiation in paints and low absorption in the underlying metallic base resulted in efficient removal of paint without damaging the substrate.

Compared to other lasers, TEA CO_2 laser has a distinct advantage in terms of high efficiency, high peak power and higher absorption coefficient [17] for most of the paints. Higher absorption of CO_2 laser by the paints makes it the ideal choice for paint stripping. Further, relatively low absorption of CO_2 laser wavelength in metals protects the metal underneath the paint from damage [6].

Extensive studies have been carried out to establish the process parameters or the thickness of the paint removed at a given fluence for laser stripping of a particular paint coated on conductive and non-conducting substrates. Experimental trials

* Corresponding author.
E-mail address: gmanoj@rrcat.gov.in (M. Kumar).

0030-3992/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.optlastec.2012.04.021

were carried out to remove 14 μm thick black paint on concrete block using Nd:YAG, CO_2 and excimer lasers [8]. An engineering curve was established to find the stripping time for a particular paint of given thickness. It is important to note that experimental trials are required to identify the process window for laser stripping of a specific paint. In other words, the process parameters need to be found for each type of paint by extensive experimental trials. In a recent work on paint stripping using Nd:YAG laser, the effects of laser fluence, repetition rate and pulse duration on threshold fluence were studied for epoxy paints [16]. It was found that the threshold fluence was lower at high repetition rate due to accumulated heat at high repetition rate. Moreover, threshold fluence was low for shorter (5 ns) pulse compared to longer pulses (100 ns). However, threshold fluence has been reported to be independent of pulse duration due to poor conductivity of the paints and heat is confined only within the irradiation zone [18,19]. Reportedly, the lower value of threshold fluence for shorter pulses is possibly due to the change in absorption coefficient at high intensities [16]. In the works referred above, experiments were conducted to understand effect of process parameters on paint thickness removed and an empirical relation between the paint thickness stripped and the laser fluence was established.

The parameters which govern the laser paint stripping are absorption coefficient $\alpha(\lambda)$ and the threshold fluence E_{th} of the paint at a given laser wavelength λ. These parameters are related as [14]

$$h = \frac{1}{\alpha} \ln \left[\frac{E}{E_{th}} \right] \tag{1}$$

where, h is the paint thickness removed per pulse and E is the incident laser fluence. Generally, $\alpha(\lambda)$ is known for a given material or may be found by FTIR and E_{th} can be determined by experimental trials [13,14,20,21]. Knowledge of these two parameters, allows one to find the process window for stripping of a certain paint using a specific laser. Although many experimental studies on laser paint stripping were reported but the determination of E_{th} and evaluation of Eq. (1) based on material properties of the paint has not been considered.

In this context the objective of the present work is to use the material properties of epoxy paint to estimate the threshold fluence and validate it with the value obtained in laser paint stripping experiment. We show that determination of $\alpha(\lambda)$ using FTIR spectroscopic method and the threshold fluence E_{th} from the material properties of the paint allows one to foretell the thickness of the paint that would be removed per pulse at a given incident laser fluence even without experimental trials. We use this relation between the laser fluence and paint thickness removed per pulse to investigate the laser stripping process of epoxy paint on metals/concrete substrate using high repetition rate TEA CO_2 laser. Effectiveness of TEA CO_2 laser removal of epoxy paint from a concrete substrate has been demonstrated using energy dispersive X-ray fluorescence technique.

2. Experimental determination of threshold fluence

The aim of the experimental study is to establish relationship between thickness h of paint stripped per pulse and laser fluence E as indicated in Eq. (1). From the fluence versus h curve, E_{th} can be readily evaluated for a given paint. In the present experimental study, epoxy paint was selected as it is widely used in aerospace industry and nuclear installations because of its excellent chemical and water resistance and good adhesion to both concrete and steel. Moreover, epoxy is a standard paint material whose physical properties are well documented in the literature [22–25]. The physical properties would be used later to determine the threshold fluence for epoxy and compare it with experimental values. Epoxy paint was first spray coated on aluminum substrate and subsequently thermally cured. The coating thickness was kept high enough (> 250 μm) in order to avoid effect of the substrate conductivity on the paint removal process. For paint stripping experiments at low repetition rate, a compact TEA CO_2 laser delivering maximum 1.0 J of energy was used.

The laser beam was focused on the painted surfaces by a ZnSe lens of 25 cm focal length. The laser irradiation of painted surfaces was first carried out in ambient air. Post-irradiation, with a fixed number of shots, the thickness of paint removed was measured by a contact gauge (Micro-hite 600) having 1 μm resolution. The total thickness measured by the instrument was divided by number of shots to obtain the average thickness h of paint removed per pulse.

Since paint stripping process could be influenced by the intensity of laser besides its fluence, epoxy paint stripping was carried out with short and long CO_2 laser pulses at a given fluence. Short pulses (FWHM ~ 200 ns) were generated with a nitrogen lean gas mixture CO_2:N_2:He::180:40:580 and long pulses (total pulse width ~3.0 μs) using a nitrogen rich gas mixture CO_2:N_2:He::120:250:430. The pulse shapes in both cases are shown in Fig. 1a and b. When laser stripping of epoxy was carried out at a constant fluence of 8.4 J/cm^2, the paint thickness removed per pulse was seen to be more in case of long pulse compared to that due to short pulse. This was due to plasma formation during irradiation with short laser pulse in front of the target which shields the target and defocuses the laser beam [6,26]. Due to these reasons, the paint stripping process was also not very efficient and clean with short laser pulses. The plume generated over the target without and with plasma is shown in Fig. 2a and b

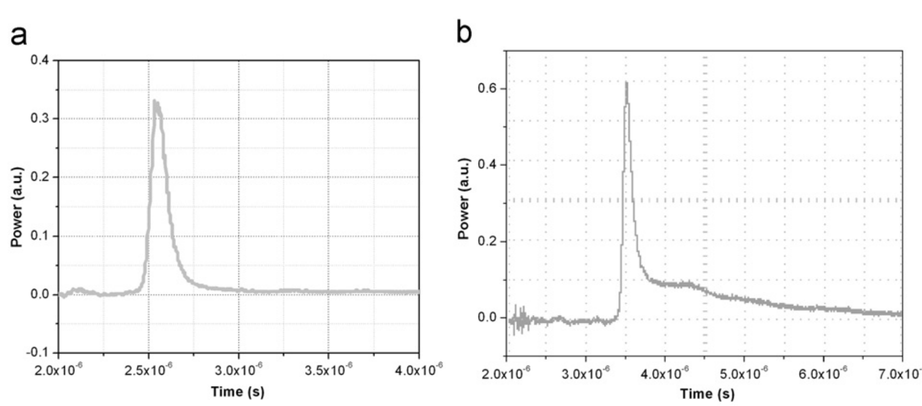

Fig. 1. (a) Laser pulse shape with nitrogen lean gas mixture (CO_2:N_2:He::180:40:480). (b) Laser pulse shape with nitrogen rich gas mixture (CO_2:N_2:He::120:250:530).