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Droplet assisted laser cleaning of metals and alloys

José Manuel López López[1], Jeremy Coupland[1], Sundar Marimuthu[1]

[1] *Optical Engineering Group, Wolfson School of Mechanical and Manufacturing, Loughborough University, Loughborough, United Kingdom*

Email: J.M.Lopez-Lopez@lboro.ac.uk

Abstract
Surface cleaning is increasingly important in modern manufacturing. Traditional laser cleaning process is predominantly a thermal process and cannot be applicable for next generation of devices manufactured in the micro/nano scale. This paper report on a new surface cleaning technique that we called as droplet assisted laser cleaning (DALC) and demonstrate it as an alternative to the existing laser based cleaning process (ablation and shock). The DALC experimental setup comprise of a 355nm Q-switched Nd:YAG laser synchronised with a liquid micro-droplet dispenser. Each laser pulse, from a 355nm Q-switched Nd:YAG laser was used to vaporise a single liquid micro-droplet. The explosive vaporisation of liquid droplet, result in generation of high impulse shock pressure, which was used for surface cleaning. This process exploits the combined potential of laser shock cleaning and opto-hydrodynamic processing, through explosive vaporisation of liquid droplets. The experimental setup reported in this paper was specifically designed to induce explosive vaporisation of a 300µm water droplet above the contaminated substrate surface. The generation and interaction of impulse shock pressure was investigated using pulsed Schlieren imaging technique. The shock pressure magnitude was estimated using a high precision strain gauge. The effect of laser energy, number of pulse per position, gap distance, scanning speed and laser beam overlap on the cleaning performance was investigated in detail. A grating spectrometer and a CCD based imaging system were used to understand the underlying mechanism of the droplet assisted laser cleaning process. A mild steel substrate, contaminated with micro-polymer particles was used to evaluate the performance of the DALC system, and the results were compared with traditional laser shock cleaning process.

Keywords: Cleaning; Droplet; Liquid; Laser; Shock; Vaporisation.

1. Introduction

In the last decades there has been a huge interest on the interaction between surface and contaminants and the role that laser may play there.

Cleaning a surface or device might be interesting in many scenarios, the main issue happens when the cleaned object size is as tiny as in an electronic component and traditional thermal cleaning processes may destroy the piece [1], alternatively non-thermal processes were used like laser shock cleaning on which a highly focused laser beam of high power ionizes the medium (usually air) producing a strong pressure wave that quickly expands and remove contaminants [2]. Later studies added water, casting a droplet which absorbs light, typically in the IR (1064 nm), the absorbed energy produces a sudden temperature change in the droplet above the vaporization temperature which induces breaking of the droplet into tiny microdroplets that drift the contaminants away [3][4][5].

In this report the effect of UV light is tested (355 nm) on the combined effect of both droplet vaporization and shockwave on the surface cleaning.

The present paper presents the experimental setup and procedure with the details of the synchronisation schematic and the methodology of the experiment itself, parametric studies along with EDX data will be presented on the results section and they will be discussed on the conclusions section.

2. Methodology

Mild steel samples of dimensions (50 × 50 × 1) mm^3 were used as test samples contaminated with 50 µm diameter size NYLON12 particles, in order to improve the adhesive force between the steel and the particles so it becomes stronger than gravity, the samples were moistened with a volatile organic liquid like ethanol.

The light source used for this experiments is a LITRON frequency tripled Q-switched Nd:YAG 355 nm wavelength laser and 8ns pulse duration.

The sample was placed on a 3D stage, below a water dispenser adjusted to cast 300 µm diameter size droplet that will be hit by the laser beam with ranging energies from 25 mJ to 267.5 mJ on a 300 µm diameter spot size on focus. Laser beam and water dispenser are synchronized to operate in 10 Hz.

Some important parameters were identified and hence the experiment studies the impact of the variance of these magnitudes on the process. These quantities are the energy output, the gap distance between the explosion point and the sample, the number of pulses and the speed the sample is moving.

Shadowgraphy, spectography and pressure measurements were taken in order to understand the interaction between the light and the droplet. Additionally an optical microscope was used to show the effect of the cleaning process on the samples, observing three important regions: the cleaned area were there are none or almost no contaminants, this is the place where the explosion effects are more important, the contaminated area, which is far away enough so the effects of the cleaning is negligible and the interface where the cleaning effects are low but still important enough, this region shows intermediate features of the other two.

EDX analysis were carried in order to quantify the differences between those three areas.

2.1. Spot study

The effect of the (DALC) for a steady position was observed for the effect that energy, gap distance and number of shots have on it. Due that synchronization of the beam and droplet is not 100% reliable several spots were cleaned for a sample, then the diameter measured and their values processed.

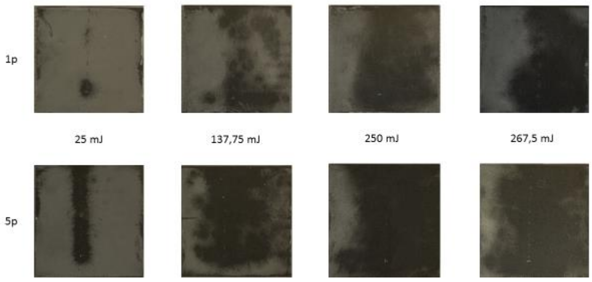

Figure 1. Effects of DALCM for one (top) and three (bottom) pulses and different energies for 1 mm gap distance.

2.2. Linear cleaning

This configuration allows to understand the effect of the scanning speed for cleaning effects under the hypothesis that a very slow speed is equivalent or similar to the steady case whereas for high speed and low energy configurations the cleaning effect tends to zero.

2.3. Surface cleaning

While cleaning a surface by adding several cleaned lines the superposition may play an interesting role. A 0% overlap might leave more contaminants, especially those related to the interface, than a higher overlap which also allows to clean the surface using higher speeds or lesser energies.

3. Results

Figure 3 shows the diameter of the area cleaned for 1 mm gap distance depending on energy output and number of pulses for the spot experiment. It can be noticed for low energies that there is a saturation point for number of pulses.

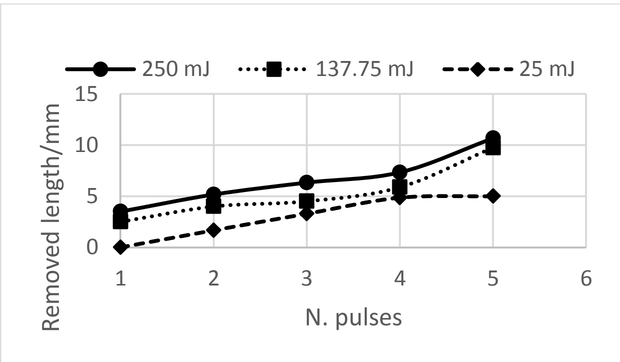

Figure 2. Removed length for 1 mm gap distance for different energies and number of pulses.

The experiment also shows dependence between the size of the area cleaned and the distance gap, the scanning speed and the overlap. Figure 4 shows the effect of the scanning speed for lines.

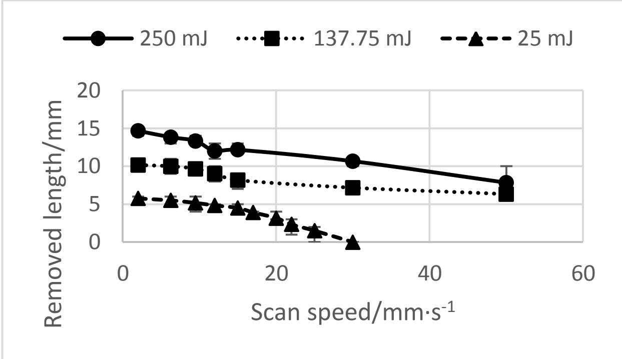

Figure 3. Removed length for 1 mm gap distance for different energies and scanning speeds.

And EDX map was carried on different samples in order to shows the composition difference for the three different areas.

Table 1 EDX results for the main diferente áreas.

Area	Element	Weight %
Contaminated	Carbon	58.408
	Oxygen	0.115
	Silicon	0.094
	Iron	38.258
Interface	Carbon	38.377
	Iron	61.623
Cleaned	Carbon	7.228
	Iron	92.772

4. Discussion

This report shows the importance of the main parameters of the cleaning process, the energy output and the number of pulses enhance the cleaning, but whereas the energy shows no restriction there is a saturation point for the number of pulses. The increase of the gap distance implies a downfall on the cleaning but while this feature changes slightly for close distances it quickly drops to zero after a certain value that depends on the energy output. The scan speed has a similar effect though its downfall is not as sudden as for the gap distance, however the effect are more important for small energies. Finally the overlap effect for cleaning shows a slight improvement.

The EDX shows the quantified composition differences between the three studied areas for (115 × 115) μm^2 surface size, showing 58.6% of residues for the contaminated area, it drops to 38.4% at the interface and is reduced to 7.2% at the cleaned area. Whereas the cleaned area depends on the studied parameters the interface remains as a couple of mm size are for every configuration.

In further works a more detailed study of the adhesion force should be pursued to get a better understanding on the force balance that intervene on the process. Also a more absorbing energy configuration is desirable, that way the explosion might show additional features and more challenging contaminants may be removed like paintings, glues or smaller size particles.

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