International Journal of Scientific Engineering and Science
Volume 3, Issue 10, pp. 48-50, 2019. ISSN (Online): 2456-7361

A Research on Optical Fiber Laser Interaction with Materials, Applied on Surface Cleaning of Mechanical Parts

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Abstract— *Currently in Vietnam, the mechanical cleaning methods are mainly traditional ones such as shot blasting, sand blasting, manual cleaning, or cleaning with chemical compounds, to name a few. Shot blasting and sand blasting have low productivity, they can cause damage as well as deformation to surface and are ineffective with small details whose the oxide layer has high mechanical durability. Manual cleaning by hand has low productivity, uneven cleaning quality. Chemical methods produce a lot of toxic waste which affects the environment. Laser cleaning technology can overcome these disadvantages and is fully suitable for Vietnamese conditions. The objective of the paper is to study the interaction of materials with lasers, applied in the design of metal oxide cleaning systems of mechanical parts. The results showed that the ability to clean iron oxide with peel thickness of up to 68μm and the relationship between the thickness of the stripped layer of rust and steel substrate capacity.*

Keywords— *Metal oxides cleaning, optical fiber laser, interaction between materials and laser.*

I. INTRODUCTION

Laser cleaning technology was first introduced in 1970 for the purpose of preserving tangible cultural heritages [1]. Since then, this technology has been continuously researched, developed and widely applied. This technology not only cleans metal oxides, non-metallic oxides, stone surfaces, glass surfaces, but also cleans surface paint. Due to the outstanding advantages of laser surface-cleaning technology, this technology is increasingly used in many fields including mold industry, automobile, ship and vehicle, machines, optical parts, micro-mechanics and even in the restoration of statues or sculptures that are oxidized due to age.

High-power laser sources now have the ability to work in flexible pulse generation mode, from 50 to 1 million pulses per second, pulse durations in the range of 10nm - 300nm allow generating large instantaneous energy in super-short period. This feature allows the removal of a very thin surface layer at the micrometer to nanometer level; therefore, causes less thermal deformation of the substrate layer and can customize the surface depth which needs to be removed by changing the frequency and pulse duration and source power. Whereas, traditional cleaning methods such as sand blasting, shot blasting, high-pressure water jets, chemical methods, etc. often cause damage, surface deformation [2], [4].

A great advantage of Laser is the ability to precisely control the position in the material and the density of accumulated energy, from which it is possible to perform processing on multi-layer, multi-component and precise machining surfaces in desired areas. Laser cleaning uses intense laser pulses to selectively remove uncleanness from solid surfaces while the base substrate is unaffected. Laser cleaning becomes an effective alternative to water spraying, abrasive spraying or chemical-based cleaning methods. The working principle is quite simple, it does not need large space to work, also the cleaning time is quite fast so it is very convenient. The process is dust-free, does not cause noise to the surrounding environment. However, this method requires a high power Laser source, and needs to follow the safety rules when working with Laser [6], [7].

This paper will present experimental results to study the interaction of materials with lasers, applied in the design of mechanical surface cleaning systems using optical fiber lasers.

II. EXPERIMENTAL METHOD

2.1. Theory of Radiant-Energy Absorption

When electromagnetic radiation hits a surface, the waves travel as shown in Figure 1. Some of the radiation is reflected, some absorb and some pass. When it passes through the new surface, it will be absorbed according to Beer Lambert's law, I = I0e -βz. Absorption factor β depends on the environment, wavelength and intensity of radiation.

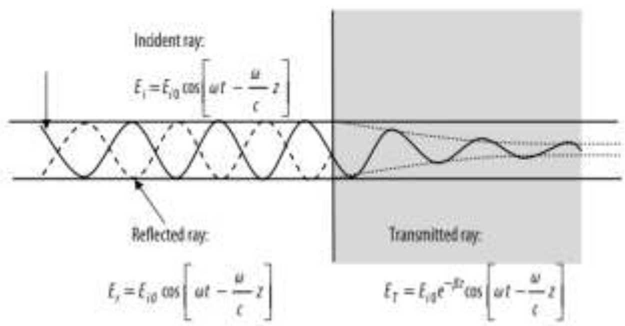

Fig. 1. The phase and amplitude E of an electromagnetic ray have a frequency of transmission in the z direction, striking a common surface of air - the solid is reflected and transmitted [3]

The plasmas can absorb strongly if their free electron density is high enough. The electron density in plasma is given by the Saha equation:

$$\ln\left(\frac{N_1}{N_0}\right)^2 = -5040\left(\frac{V_1}{T}\right)+1.5\ln\left(T+15.1385\right) \qquad (1)$$

Where N_1 is the ionization density, N_0 is the density of atoms, V_1 is the ionization potential (eV) and T is the absolute temperature (K). This indicates that a temperature of between $10.0000^oC \div 30.0000^oC$ is required to absorb significant energy.

The reflectance for normal incident angles from the dielectric or metal surface in the air (n = 1) can be calculated from the refractive index n and the k factor (or attenuation as described in on) for that material:

$$R=[(1 - n)^2 + k^2] / [(1 + n)^2 + k^2] \qquad (2)$$

For translucent materials like metals, the absorbance A is:

$$A = 1 – R \qquad (3)$$

$$A = 4n / [(n + 1)^2 + k^2] \qquad (4)$$

Where k is the reduction factor, based on Beer Lambert's law. Some values of these constants for different materials are shown in Table I [5].

TABLE I. Brewster's refractive index and angle for different materials [5]

Material	λ (μm)	Refractive index		Brewster Angle
		k	n	
Al	1.06	8.5	1.75	60.2
	10.6	34.2	0.108	88.3
Fe	1.06	4.49	3.81	75.2
	10.6	32.2	5.97	88.2
Ti		3.48	2.88	70.8
Glass		-	1.5	56.3

2.2. ANSI Z136 Standards

The ANSI Z136 laser safety standard of the National Standards Institute is the basis for Occupational Safety and Health Administration (OSHA) bill to assess laser damage to tissue and is also the basis references to occupational safety legislation for many countries are associated with laser use. The laser classification based on power source is shown in Table II [8]

TABLE II. Brewster's refractive index and angle for different materials [5]

Laser	λ (μm)	Class I	Class II	Class III	Class IV
HeNe cw	0,9328	6,8μW	1mW	0,5W	>0,5W
Ar cw	0,5145	0,4μW	1mW	0,5W	>0,5W
CO_2 cw	10,6	0,8mW	-	0,5W	>0,5W
Co_2 pulse 100ns	10,6	80μj	-	10j/cm^2	>10j/cm^2
Nd cw	1,064	0,2mW	-	0,5W	>0,5W
Nd pulse 20ns	1,064	2μj	-	0,6j/cm^2	>0,6j/cm^2

2.3. Establish Cleaning Procedure on Brimo MF50 Device

- Check equipment, power sources: The main power supply (24V DC) must ensure continuous power supply.
- Calculating and selecting parameters: Based on the sample of the material to be cleaned to determine the wavelength, pulse width, pulse frequency.
- Attach the details
- Start the device
- Set the selected parameters
- Carry out cleaning
- End process: Record the parameters and technical developments

2.4. Experimental Cleaning Process on Iron Oxie and Aluminum

- Cleaning details: divide the surface into evenly spaced intervals, about 1cm each.
- Microscope: Magnification X4, X10, X40, X80. Microprocessor knob with 200 bars divided by 1μm each.
- Brimo MF50 cleaning equipment: f = 254mm, λ = 1064mm, maximum capacity of 50W.
- After the details have been divided into equal intervals, place the details on the microscope.
- Calibrate the microscope to get the clearest image of position $\mathbf{A_1(x_1,y_1)}$, then record the scale value of the adjustment price as $\mathbf{a_1}$. Remove details from the microscope and perform cleaning.
- After cleaning, continue to attach details to a predefined position and calibrate the microscope to get the clearest picture. We obtain the value of $\mathbf{a_2}$. Value $|\mathbf{a_1} - \mathbf{a_2}|$ is the thickness of the rust layet to be cleaned.

III. EXPERIMENTAL RESULTS AND DISCUSSION

The results of cleaning iron oxide on steel substrate are shown in table III and graphs 2, 3.

TABLE III. The results of cleaning iron oxide on steel substrate

Capacity (%)	Rust layer thickness (μm)
100	68
90	50
80	44
70	40
60	24
50	6
40	4

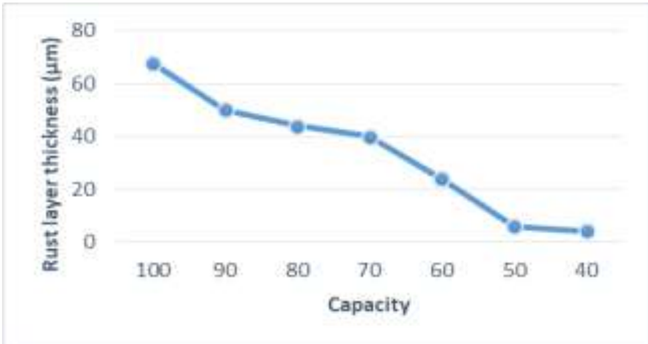

Fig. 2. Graph showing the thickness of rust stripped according to capacity on steel substrates.

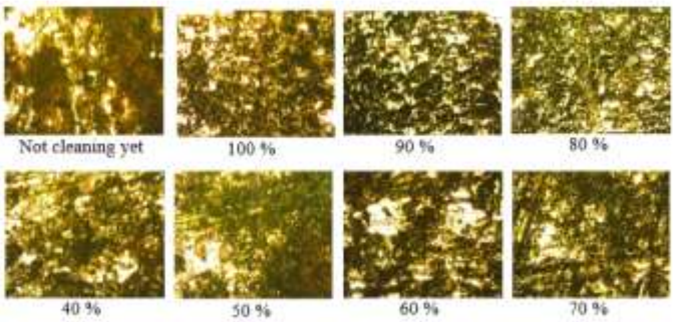

Fig. 3. Image of iron oxide surface taken from a microscope.

International Journal of Scientific Engineering and Science
Volume 3, Issue 10, pp. 48-50, 2019. ISSN (Online): 2456-7361

- Based on the graph, it can be seen that with the condition of keeping the other technological parameters and only changing the capacity from 100% to 40%, the thickness of the peeled rust layer also decreases.
- With a capacity of 100% => 90%, the thickness of the rust layer is reduced significantly from 68µm to 50µm.
- With a capacity of 90% => 70%, the thickness of peeled rust layer is not reduced much. It can be seen that the cleaning efficiency for the power thresholds of 90% - 70% is similar.
- With a capacity of 70% => 50% of the thickness of the peeled rust layer is reduced sharply, indicating that the ability to clean at this power threshold is significantly reduced.
- At the threshold of 50% => 40%, the thickness of the rust layer is very small and almost no longer capable of cleaning.

IV. CONCLUSION

Through the research and development of a cleaning process using fiber optics and the results of interaction studies of materials with lasers applied in the design of metal oxide cleaning systems of mechanical parts, it has been shown that ability to clean iron oxide with a peel thickness of up to 68µm, and has built a relationship between the thickness of the stripped layer of rust according to capacity on the steel substrate..

Research Development Directions

Continuing to study and complete the system of optical heads controlling laser scanners and stone tables. From there integrated and built a complete system for cleaning.

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