# Laser cleaning of steel structure surface for paint removal and repaint adhesion

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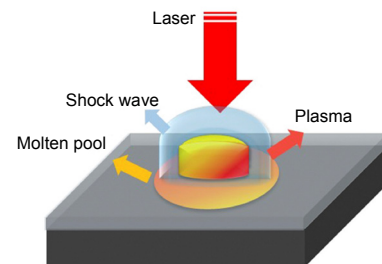
Abstract: Paint removal from steel structure is executed for shipyards of marine and offshore engineering. Due to environmental unfriendliness and unhealthy drawbacks of sand blasting technique, laser ablation technique is proposed as a substituting method. By absorbing high energy of the 1064 nm pulsed laser, the paint is vaporized quickly. The ablated debris is then collected by using a suction pump. Initial metal surface of the steel is exposed when laser beam irradiates perpendicularly and scans over it. The cleaned surface fulfills the requirements of surface preparation standards ISO 8501 of SA2. The adhesion is further characterized with pull-off test after carrying out painting with Jotamastic 87 aluminum paint. The repainting can be embedded onto the laser cleaned surface to bond much more tightly. The excellent adhesion strength of 20 MPa between repainted coating and the substrate is achieved, which is higher than what is required by shipyards applications.

Keywords: laser; steel structure surface; paint removal; repainting adhesion

1   Introduction

In shipyards, paint removal is conventionally done by sand blasting, which is environmentally unfriendly as the fine grit particles used during sand blasting are difficult to be cleaned up. Sand blasting also poses health problems to workers, requiring them to be suited up in the proper attire [1]. Thus, an alternative method of paint removal can remove or reduce the negative effects on the environment and the workers can increase the productivity of the yard tremendously.

Laser ablation has been widely applied to surface cleaning of metal artefacts [2], microelectronics [3] and nuclear decontamination [4]. Various types of coating materials, such as oxides [5-7], polymers [8-9] and paints [10-11] can be removed efficiently. For paint removal from steel structure with laser, some research work has been carried out. Madhukar et al. studied the influence of laser pa-

rameters on removal of paint on stainless steel and aluminum with both continuous wave (CW) and pulsed lasers [12]. In our previous work, a sealed CO_2 slab laser was used to remove marine paint on mild steel plates, and the influence of overlapping of neighboring scan lines of laser beam was studied [13]. Due to chipping, scraping and leaching [14-15], paint removing and repainting are necessary for shipyard maintenance and repair as an economic and environmentally friendly approach. However, to our best knowledge, few papers have studied repainting adhesion. In this paper, laser ablation to remove paint on steel structure is investigated as a substituting method for sand blasting, which is typically done in offshore and marine industries. Nd:YAG nanosecond pulsed laser of the 1064 nm wavelength is used. Three different sets of laser parameters are used, aiming to clean the paint and roughen the steel surface for repainting. After repainting the steel surface, the pull-off test is performed to measure the paint adhesion. This work provides a potential approach for paint removal not only in the marine industry but also in the maintenance of vehicles, aircrafts, radar systems and nuclear industries.

2　Materials and methods

2.1　Laser paint removal process

Fig. 1 shows the experimental setup of laser removal of paint. The steel structure surface covered by paint is obtained from the shipyard as the objective. The steel plate is horizontally placed on the *X-Y* axis platform with the laser beam perpendicularly irradiates on it. A suction pump is used to absorb the ablated paint debris. In this work, the Nd:YAG pulse laser used is of the wavelength of 1064 nm with a pulse width of 100 ns and a beam diameter of 0.1 mm. The thickness of the paint covered on steel is ~360 μm and a square of 40 mm × 40 mm is ablated by laser for performance evaluation of laser cleaning.
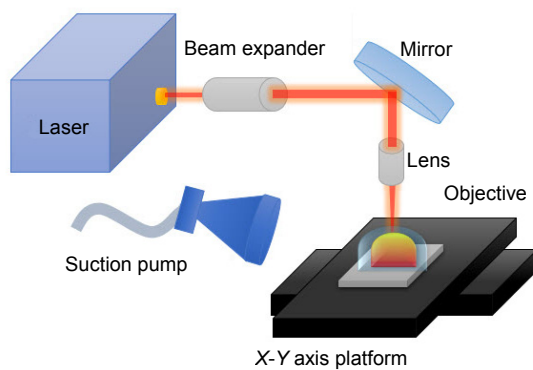

Fig. 1　Paint removal experimental setup.

Parameter setting for the first pass is used to peel off the paint from the substrate. The speed of 50 mm/s is set. The repetition rate, power and laser fluence are set to be similar to the values recommended by Brygo et al[16].

After the first pass, the suction pump absorbs most of the ablated debris with some residues left on the surface. Then the second laser pass is executed to remove the residual stray marks that may have been missed out in the first laser pass. The laser fluence used is smaller and the pulse scan speed is faster.

For the third pass, the aim is to further texture the metal surface and create another profile different from the first two passes. Hence, the laser fluence is increased. The distance between every two pulses is kept different from the first two passes so that the laser beam can process different parts from the first two passes for a different profile and thus to roughen the surface.

The samples are divided into two groups. One group processed with pass No. 1 and 2 and the other group is exposed to an additional scan with pass No. 1, 2 and 3 to verify the effect of additional scan. Specific parameters are shown in Table 1.

2.2　Repaint process

The samples are repainted using Jotamastic 87 aluminum paint which can be used in marine for external surface of hulls [17]. Paint curing is executed in room temperature and ambient pressure for one day before leaving it in an oven for three days at 105 ℃ according to the Jotamastic 87 aluminum paint data sheet [17].

2.3　Characterization

Visual assessment of surface cleanliness:

The surface cleaned by laser ablation is evaluated by ISO 8501: Preparation of steel substrates before the application of paints and related products.

Surface roughness measurement:

For each sample, the linear roughness *Ra* and the three-dimensional roughness *Sa* of the sample are randomly sampled by using a surface profiler. The linear roughness is sampled thrice and averaged. Each length is sampled at a rate of 0.05 mm/s with a sampled length of 3.04 mm while the pitch of the sampling is 0.1 μm, giving a total number of sampled points of 30400. The three-dimensional roughness is sampled once, and an area of 5 mm× 5 mm is sampled. The number of lines sampled within the area is 40, and the pitch of the sampling is 1 μm, giving the total sampled points to be 200000. The sampling speed is 0.2 mm/s.

2.4　Thickness and adhesion of re-coated paint

The adhesion test is performed according to ISO 4624 pull-off test for dry film thickness (DFT) adhesion. The dry film thickness is measured using the dry film thickness (DFT) gauge. A dolly is glued to the surface of structure first and then is pulled off after cutting the paint around it. The evaluation of the tests is based on the percentage of dolly removed paint area.

3　Results and discussion

Fig. 2(a) shows a typical ablated surface after the first pass. The surface after the first pass still contains the ablated debris materials even with the use of a suction pump. The ablated debris from the neighboring area may be dropped into the path of the laser beam during the ablation process, which causes reduction of the beam energy reaching the surface and hence affects the actual ablation process.

The second ablation pass is performed to remove re-

Table 1　Three sets of laser parameters for paint removal.

Pass No.	Average power/W	Repetition rate/kHz	Fluence/(J/cm^2)	Scan speed/(mm/s)
1	10	15	8.5	50
2	5	30	2.1	150
3	10	15	8.5	150

sidual stray marks. Fig. 2(b) shows the surface after the second pass, and it can be observed that the residual paint particles are removed compared to Fig. 2(e). For these six samples, samples 2~6 have some evidence of incomplete ablation. Streaks of the cream color undercoat are still visible even after the samples have been ablated twice. However, probably due to an inconsistent property of the paint, sample 1 has a much better result which achieves the SA2 standard of ISO 8501 as compared in Fig. 2(e). The samples 7~12 are shown in Fig. 2(c). Obviously, samples 7~12 cleaned with the triple pass have brighter surface color almost achieving ISO 8501 standard SA2. It means the third pass further cleans the surface and exposes much more surface area of the metal substrate. No damage is observed on the steel structure surface, indicating the controllable property of laser cleaning. Surface profiler records the morphology of the cleaned surface. Fig. 2(d) shows a typical 3D-profile of the surface after laser cleaning. Burrs, cavities and holes jointly contribute to the rough property of the surface, implicating a potential repainting adhesion with great friction under this textured morphology.

Fig. 3(a) presents the coated Jotamastic 87 Aluminium paint surfaces of samples 1~12. After the paint is cured in the room temperature and pressure, puff-off test is prepared. Glues are attached on the surface with tapes bonded more tightly as shown in Fig. 3(b). A tensile tester is carried out for the whole test as shown in Fig. 3(c). The

tensile stress shall be applied in a direction perpendicular to the plane of the coated substrate. The results are presented in Fig. 3(d). The force increase is stopped until the paint is partially pulled off and the adhesion value is recorded.

In Table 2, the Ra values of samples 1~6 range from 2.048~2.570 μm with extreme deviation 0.522 μm. The Ra values of samples 7~12 range from 1.691 μm to 2.859 μm with extreme deviation 1.168 μm. The extreme deviation shows that the roughness values of samples 7~12 are more inconsistent. The Sa values of samples 1~6 are around ~0.02 mm while the Sa values of samples 7~12 range from 0.019 mm to 0.043 mm also shows an inconsistency. The highest adhesion value of 20 MPa appears at Ra 2.253 μm and the lowest adhesion value of 7.6 MPa appears at Ra 2.048 μm. In this table, by comparing the Ra of the surface of double and triple passes, the third pass rarely changes the roughness. However, Ra and Sa values of the surfaces of triple pass are much more inconsistent, indicating an effect of the third pass.

The adhesion values (MPa) at different Ra are presented in Fig. 4. Though it does not show much correlation between Ra and adhesion value, it is noticed that the adhesion values obtained are significantly higher than the standard of 3 MPa set for ship hull [18]. These results infer that using laser to remove the paint is a convenient and fast method, which can simultaneously achieve a high repainting adhesion on steel.
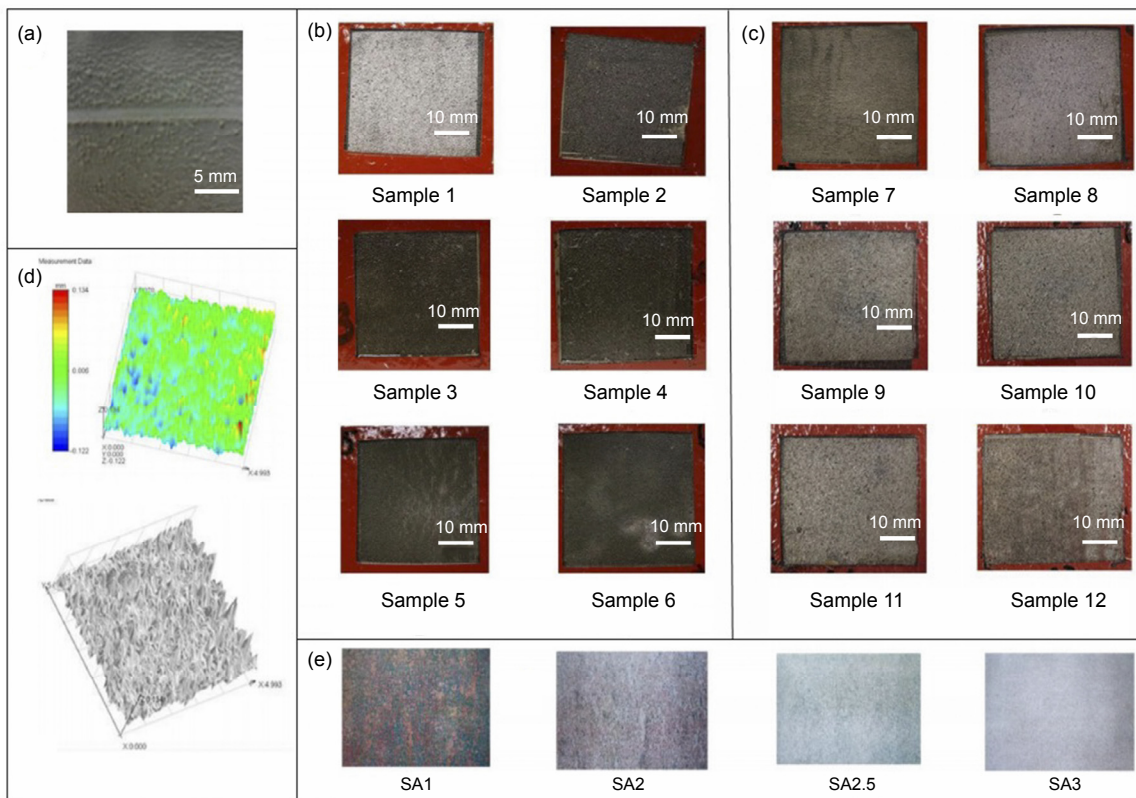

Fig. 2　Steel structure surfaces for (a) typical ablated surface after first pass, (b) six double laser cleaned samples. and (c) six triple laser cleaned samples. (d) Typical 3D-Profile after laser cleaned. (e) ISO 8501 standard.
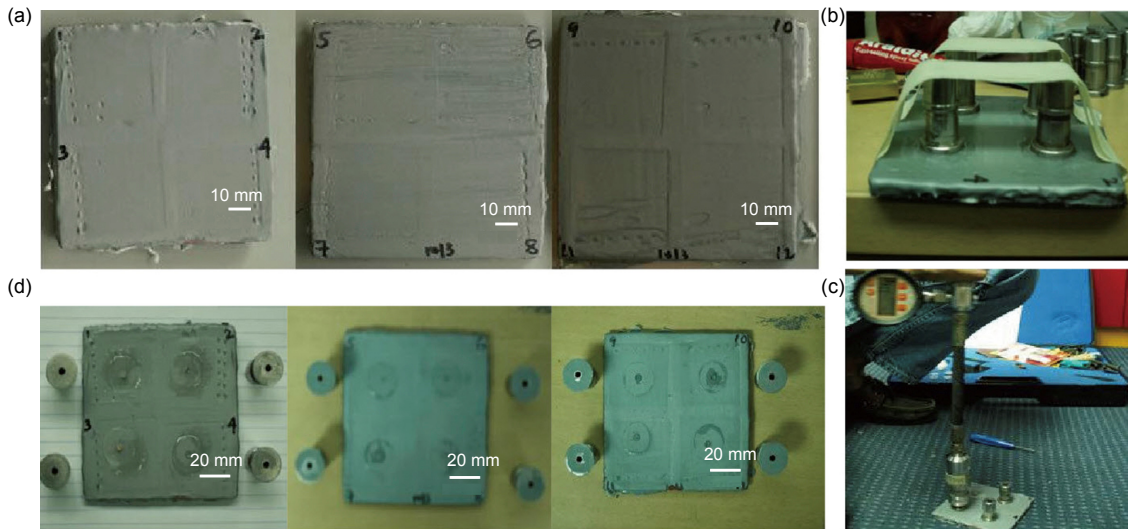
Fig. 3   (a) Repainting surface of the samples. (b) Preparation for adhesion testing. (c) Pull-off test. (d) Pull-off test results of the samples.

Table 2   Roughness and pull-off test results for double scan samples.

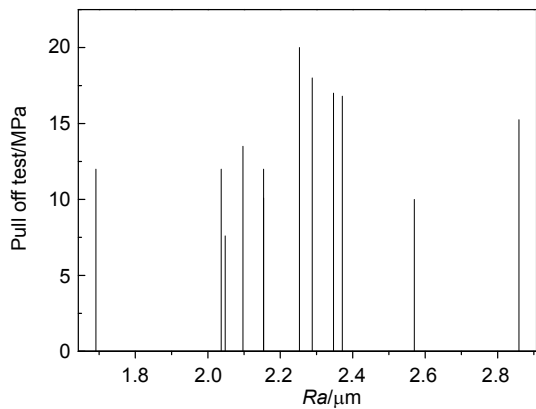| Sample	Ave. dry film thickness/μm	Ave. Ra/μm	Sa/mm	Pull-off test/MPa
1	457	2.048	0.020	7.60
2	385	2.154	0.022	10.10
3	419	2.097	0.021	13.50
4	303	2.570	0.021	10.00
5	331	2.253	0.020	20.00
6	336	2.288	0.021	18.00
7	261	1.691	0.020	12.00
8	343	2.037	0.019	12.00
9	235	2.371	0.043	16.80
10	244	2.154	0.031	12.00
11	288	2.347	0.024	17.00
12	290	2.859	0.024	15.25

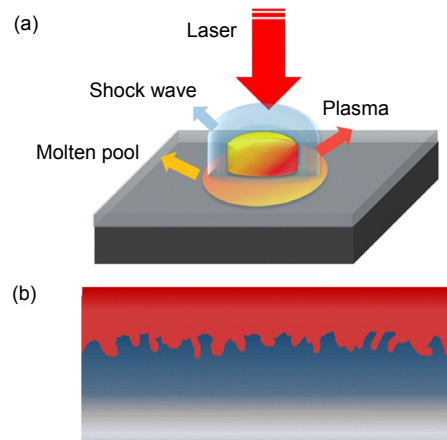Fig. 4   Adhesion at different Ra values.

Fig. 5   Schematic illustration of (a) laser ablation process and (b) repainting-substrate bonding.

Fig. 5 depicts a schematic illustration of the laser ablation of paint. Most of the laser energy is absorbed by the paint with partial of the energy being reflected. Photothermal process is involved in a very short time. For photothermal process, electrons in the materials absorb the incident laser energy, and dissipate into heat, leading to the rising of the temperature of the paint immediately. The paint is quickly vaporized. With the laser intensity further increasing, paint material is ionized to become plasma plume. Plasma contains a mixture of energetic species, including atoms, ions, molecules, and ultrafine particulates [19]. Compressive forces created by plasma and vapor, leading to expulsion of the molten pool of paint materials [20]. With the plasma expanse rapidly, shock wave is induced and propagates through the target to cause vibration. The vibration transfers momentum to debris, resulting in large acceleration of debris to be ejected from the surface [21]. Audible acoustic waves are also created with the material's thermal expansion [22].

Irregular surface is created by formation of burrs as shown in Fig. 5(b). Laser ablated surface contains plenty of small size pores, holes and voids. The paint spreads and solidifies on these microstructures to be embedded onto the surface, providing a very strong adhesion.

4   Conclusions

In summary, a simple and environmentally friendly method is proposed to remove paint on steel structure surface. The purpose of repainting of the steel structure surface is achieved with excellent adhesion of repaint. The steel exposes its initial surface after triple pass of laser scanning. The average of liner roughness *Ra* of the ablated surface is ~2 μm. The adhesion strength of 20 Mpa is achieved, which is much higher than the standard of 3 MPa for ship hull. Laser ablation is proven to be a promising alternative method for marine offshore applications.

Acknowledgements

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