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ORIGINAL CONTRIBUTION

# The Laser Cleaning Process for the Removal of Surface Corrosion Developed over One Year on Stainless Steel SS304

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***Abstract***— **Stainless steel SS304 is one of the most widely employed steel alloys used in a wide variety of industries. However, under certain atmospheric and environmental conditions, it is likely to corrode. High humidity can cause damage to the native chromium oxide layer, causing rust formation. Once the corrosion develops, it becomes difficult to remove the rust layer locally and chemically treated or dry blasted. But recently, a novel application of laser surface irradiation can be employed to remove the corrosion products formed on the surface rapidly and robustly. The laser corrosion removal process is a non-mechanical technique that can remove rust from difficult to reach areas with high efficiency. However, the rust removal depends on the laser de-rusting process parameters. This work studies the effect of laser corrosion removal parameters such as power, frequency, and several loops with an optical microscope to observe surface features. Results indicate that the number of loops is a significant parameter that enhances corrosion removal significantly. Additionally, the selection of correct frequency, power and scanning speed, and hatching distance also play a significant role in corrosion removal efficiency. Using a low-power fiber laser marking machine to remove corrosion from metal samples will provide energy savings for the commercialization of such a process.**

***Index Terms***— **Laser Corrosion Removal, Laser Cleaning, Ablation, Stainless Steel, SS304**

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## I. INTRODUCTION

The fourth Industrial Revolution (IR 4.0) is currently the most sought manufacturing topic interested various researchers [1]. Laser-based manufacturing processes [2, 3] have enabled researchers to adopt advanced manufacturing techniques due to their ease of integration with IR 4.0 related technologies. Until recently, researchers are finding many applications of laser surface modification and laser cleaning processes to enhance surface characteristics. The laser cleaning process can remove unwanted contaminants such as grease oils layers or even rubber from various industrial components [4]. Additionally, the laser cleaning process can be characterized as laser corrosion removal [5]. The laser can also remove paint from various types of materials by employing different parameters for exposure duration and temperature to alter the removal rate [6]. Moreover, it is employed in sensitive cleaning applications involving archaeologically materials [7].

Austenitic stainless steel SS304 is the most widely employed engineering alloy in automotive, shipbuilding, Petro-chemical and aviation industries [8, 9]. It can be used for carrying liquid services, solids (tanks and containers), mining equipment, etc. However, SS304 can undergo severe corrosion if the environment is corrosive. Different types of corrosion can occur such as pitting corrosion, stress corrosion, cervices corrosion and grain boundary corrosion [10]. To de-corrode SS304, various conventional techniques could be employed such as chemical treatment, shot blasting, etc which are time-consuming and require component dis-assembly. However, laser corrosion removal via laser cleaning technique [11] has been reported to strip contaminants, oxides and corrosion products with the help of different types of lasers and laser sources such as femtosecond, picosecond, nanosecond, millisecond and micro-second lasers [12]. In the field of manufacturing engineering, processing parameters play an important role [13]. Laser-based manufacturing processes entirely depends on the laser processing parameters [14] and so does the laser-material interaction contributing to different cleaning efficiencies.

Various research has been carried out in regards to laser corrosion removal and laser cleaning. For instance, [15] investigated the mechanism of surface cleaning for TA15 titanium alloy using a maximum of 400W ytterbium pulsed laser and found ablation to be the main mechanism. Further to this, laser cleaning was carried out at very low power levels of 0.23 to 0.73W for bronze based archaeological corrosion products and it was reported to be of low invasiveness [16]. Lu et al [17] employed UV laser with

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a fluence of 5.30 J/cm$^2$ to remove bio-fouling signifying practical oceanic industrial applications. In another work Lu et al. [12] demonstrated that laser cleaned samples of AH36 steel for marine ships exhibited 5 times greater corrosion resistance than rusted surface signifying laser cleaning to be environmentally friendly approach. For the case of Aluminium alloy AA7024-T4 laser cleaning was carried out using diode pupped nano second pulsed fibre laser with a fluence range of 3.5 to 11.3 J/cm$^2$ [18]. It was revealed that the near surface regions chemistry changed and more corrosion resistance layers evolved that contributed to greater corrosion resistance.

Although significant work has been carried out in evaluating the corrosion rates of cleaned samples, the effect of parameters for very low power lasers in carrying out cleaning process are less acknowledged. Different laser processing parameters have accounted for variation in the amount of cleaning and corrosion removal. Pulse wave mode will be utilized in the current research since continuous-wave lasers may affect the base material properties [19]. Lastly, the aim of this study is to study the effect of laser cleaning parameters and obtain a set of parameters that would result in highest cleaning efficiency.

## II. METHODOLOGY

The laser cleaning was conducted by using the laser marking machine IPG YLM 200/30 – Q pulsed as shown in Fig. 1. The details of the machine are provided in Ref [14]. This machine has the capacity to be used in Continuous Wave (CW) and pulse wave (PW) modes. Furthermore, the machine's maximum power capacity is 30W. This machine has been attached with the laser source, focal plane adjustment system with scale (Fig. 1(b)) and the EZCAD software (Fig. 1(c)) for control and adjustment of the laser parameter. Therefore, the machine range of parameters can be adjusted according to user requirements. These adjustable parameters have major influences on the cleaning process. Meanwhile, the laser source in the machine is transferred to the laser head by using fibre optic. The distance between the focus lens and the laser focus spot is 200 mm and can be varied according to the needs.

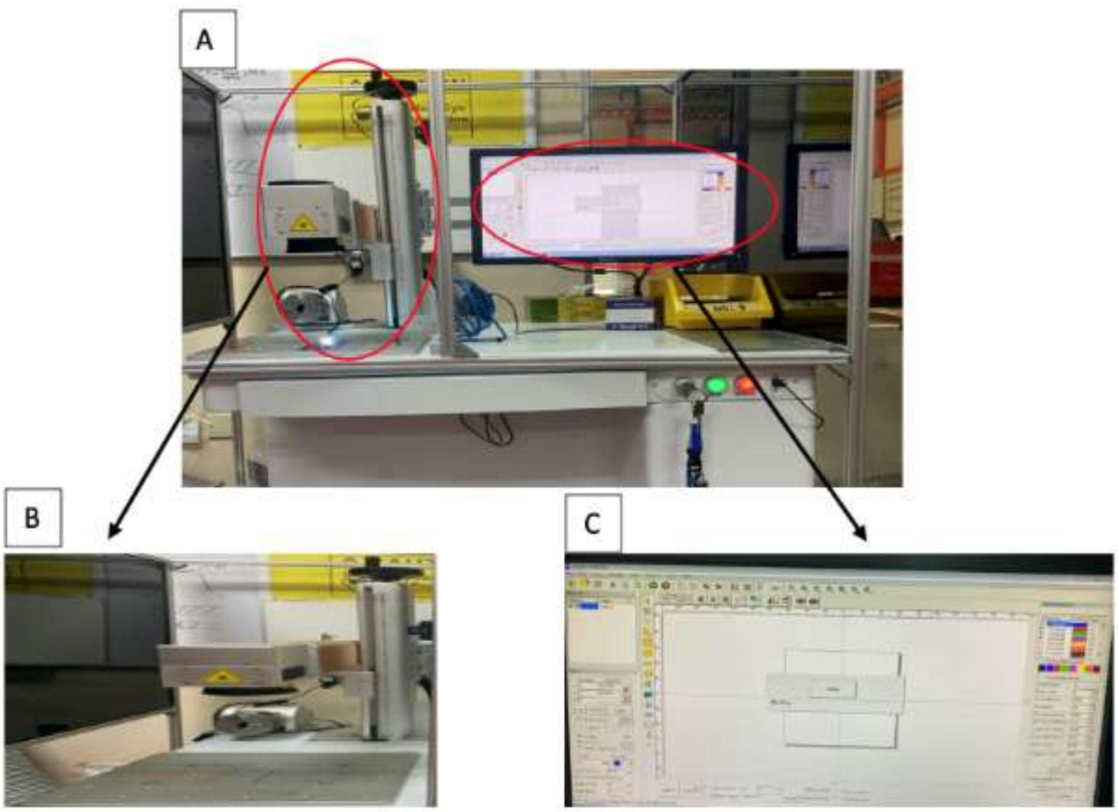



Fig. 1. a) Fiber laser machine b) Laser source with focus plane and c) software for laser cleaning machine (EZCAD)

Additionally, schematics of the laser cleaning process are given in Fig. 2(a). The coordinates of the laser scanning are controlled by a galvo-meter and the amount of surface irradiation can be controlled by the size of shape that is drawn on the software. The laser cleaning process was carried out in pulsed-wave mode and nano-second pulse width. As an example, a corroded sample de-corroded with laser cleaning process is showed in Fig. 2(b). The SS304 samples were immersed in Tap water for 7 days and thereafter were left to corrode in the open air for 1 year. Thereafter, after the laser cleaning process, the samples were characterized by an optical microscope (MEIJI TECHNO EMZ-13TR).

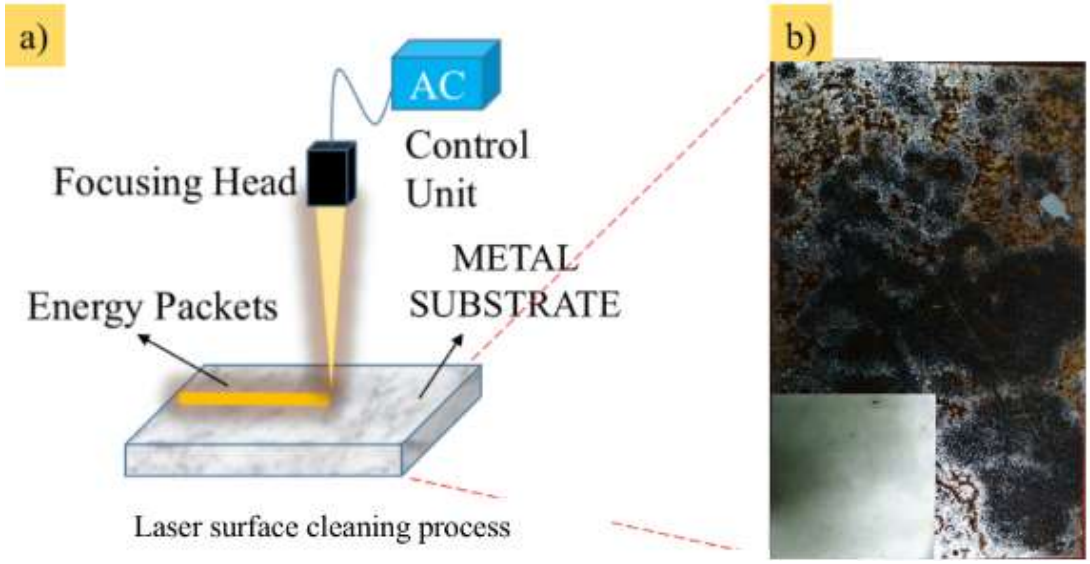



Fig. 2. a) The schematics for laser colour marking and (b) laser corrosion removal sample

## III. RESULTS AND DISCUSSION

Fig. 3(a) shows the optical microscopic image of the as-received SS304 sample and Fig. 3(b) shows the corroded surface of the SS304. As can be observed, significant corrosion took place with the characteristics of bright orangish marks and dark matter present. The effect of changes in the laser cleaning parameters on corrosion removal of SS304 is shown in Table I. A low power loop does not contribute to any amount of corrosion removal, however, some laser scanning lines because of hatching are slightly visible. With a slight increase in 20% power, these hatching lines become more prominent while all the parameters are doubled. A drastic change in corrosion removal along with some colour (blue to purple shade) was observed with a decrease in corrosion. But as the parameters were doubled and the hatching distance was reduced by half, the corrosion removal percentage declined. In experiment number 6 it was observed that for a single loop, the scanning speed of 1000 mm/s was good enough to remove corrosion products to a certain extent. After concluding that 1000 mm/s produced fruitful results with the combination of the low frequency of 20Hz, it was important to determine that which set of parameters are providing good results for a single loop to reduce the time duration of the laser cleaning process. Table II presents the variation of parameters when scanning speed and frequency are fixed and other parameters are varied. It was observed in experiment number 6 that a significant reduction in the pulse width caused the formation of colour, but the dark oxide matter was retained. As the pulse width increased, the colour formation was eliminated and both light and dark coloured corrosion mater was significantly reduced. A further reduction in power from 95% to 90% did show lesser material removal while the increase in the number of loops to 5 times produced the cleanest surface as compared to the 10 times. This could be due to the change in the intensity of surface corrosion for sample irradiated 10 times.

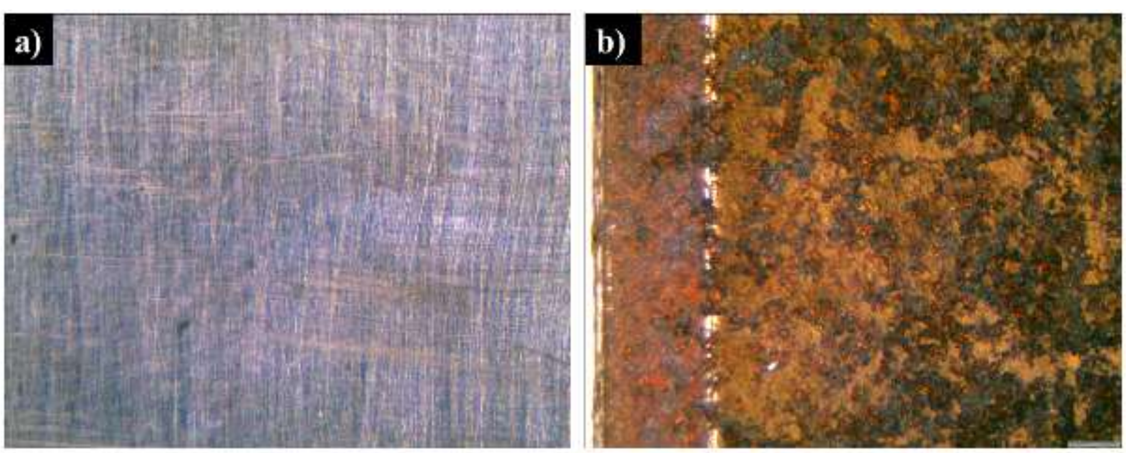



Fig. 3. Optical image of (a) as received samples and (b) corroded SS304

TABLE I
EFFECT OF LASER PARAMETERS ON MULTIPLE PASS CORROSION REMOVAL ON SS304 WITH A DEFOCUS DISTANCE OF 182MM

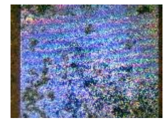
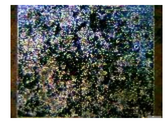
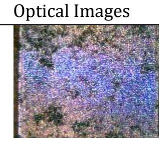
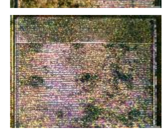
| Exp. No | Power (W) | Frequency (Hz) | Speed (mm/s) | Pulse width (9ns) | H.D (mm) | Loops | Optical Images |
|---|---|---|---|---|---|---|---|
| 1 | 10 | 10 | 100 | 10 | 0.1 | 1 |  |
| 2 | 20 | 20 | 200 | 20 | 0.2 | 2 |  |
| 3 | 40 | 40 | 400 | 40 | 0.025 | 4 |  |
| 4 | 80 | 80 | 800 | 80 | 0.013 | 8 |  |
| 5 | 60 | 20 | 1000 | 300 | 0.025 | 1 |  |

TABLE II
EFFECT OF LASER PARAMETERS ON SINGLE PASS CORROSION REMOVAL ON SS304

| Exp. No | Power | Frequency | Speed | Pulse Width | H.D | Loops | Optical Images |
|---|---|---|---|---|---|---|---|
| 6 | 95 | 20 | 1000 | 10 | 0.05 | 1 |  |
| 7 | 95 | 20 | 1000 | 100 | 0.05 | 1 |  |
| 8 | 90 | 20 | 1000 | | 0.05 | 1 |  |
| 9 | 80 | 20 | 1000 | 200 | 0.05 | 5 |  |
| 10 | 80 | 20 | 1000 | 200 | 0.05 | 10 |  |

After observing the effect of the loops, it was decided to increase the number of loops with the first two loops being with higher energy and the ensuing loops with lower power acting as a smoothening phase. The list of parameters that gave the best corrosion removal whilst maintaining the colour of the steel is given in Table III. Additionally, a comparison of corroded sample and surface areas of cleaned samples are shown in the Fig. 4. It needs to be noted that there are black spots cluster which is some form of corroded products. These could not be removed as in Fig. 4(b) and some deep pits could not be smoothened as well. It worths to mention that as the horizontal laser scanning lines are visible, they could contribute to change in the surface roughness, however, literature points out that it is possible to produce surfaces without any change in surface roughness [20]. Furthermore, it was observed that coloured surfaces were generated at lower pulse width values which have been due to the formation of chromium oxides. It is stated that due to laser cleaning process, other types of oxides are grown that can contribute to corrosion enhancement [18]. This is called re-oxidation [21] due to laser cleaning effects.

TABLE III
LASER PARAMETERS FOR MULTIPLE PASS LOOPS FOR CORROSION REMOVAL ON SS304

| Loop | Power (W) | Frequency (Hz) | Speed (mm/s) | Pulse Width (9ns) | H.D (mm) | Defocus Distance (mm) |
|---|---|---|---|---|---|---|
| #1 | 90 | 20 | 1000 | 300 | 0.05 | 184 |
| #2 | 90 | 20 | 1000 | 300 | 0.05 | 184 |
| #3 | 40 | 40 | 500 | 40 | 0.05 | 184 |
| #4 | 30 | 80 | 500 | 80 | 0.05 | 184 |

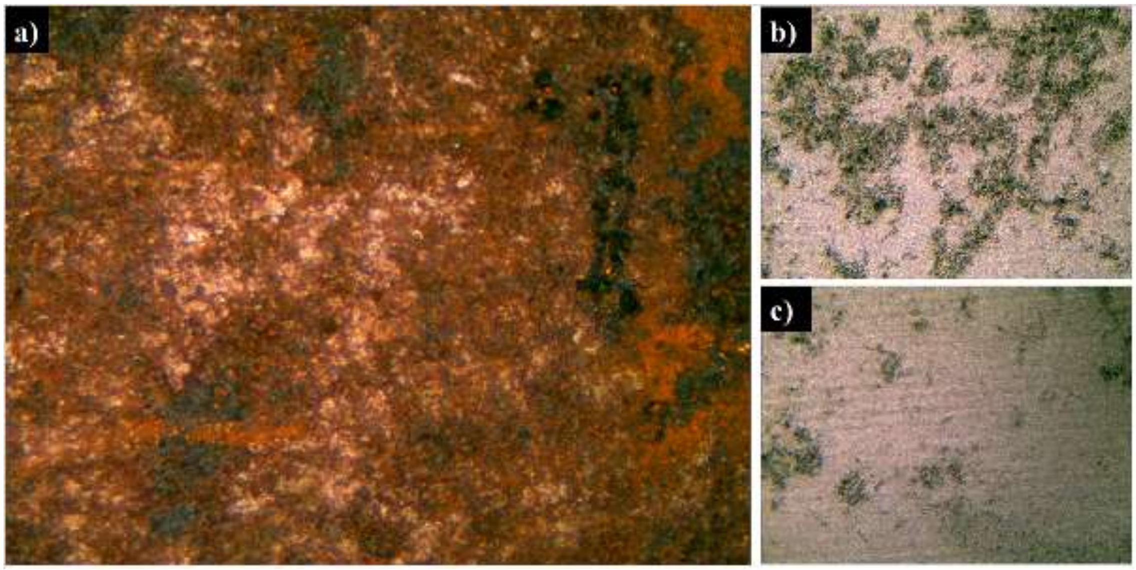



Fig. 4. Optical image of a) corroded SS304, b) LCR with retained black stains and (c) cleaner portion of LCR process

## IV. CONCLUSION

In this work, an effort is carried out in removing corrosion of SS304 developed over a long period of 1 year. The samples irradiated by laser showed that laser cleaning parameters can significantly affect the quality of corrosion removal. The laser power, scanning speed, hatching distance, repetition rate, pulse duration, number of loops are the parameters that alter the corrosion removal quality and rate. In the current research two loops of higher power and two loops of lower power amounting to a total of four loops were employed to produce the best results.

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