

Analysis of Rust Removal Performance of Q235 Steel by Laser Rust Removal Process based on Ridge Regression and Lasso Regression

Feng Jiang

Zhejiang Normal University, Jinhua 321001, China

Abstract

Laser rust removal is an effective method for eliminating rust from steel surfaces. The performance of rust removal is crucial for steel reuse, necessitating accurate prediction of laser derusting effects. This study evaluates the rust removal performance by analyzing the rust ratio before and after laser treatment on Q235 steel. Ridge regression and Lasso regression were employed to address multicollinearity among influencing factors, establishing two modified multiple regression models to predict derusting performance. These predictions were compared with actual experimental results. The findings reveal that the ridge regression model achieved an RMSE of 0.2379, while the Lasso regression model yielded an RMSE of 0.2460. The Lasso regression model demonstrated superior fitting performance, with predicted values closer to the actual results.

Keywords

Laser Rust Removal; Ridge Regression; Lasso Regression; Predict.

1. Introduction

Steel is one of the most widely used materials in various industries around the world, and is the basis for the construction of a great nation. China's annual production of steel ranks first in the world, and it is an indispensable material for pipelines, equipment and bridges^[1]. However, the corrosion and rust of steel can be seen everywhere, and the economic loss caused by corrosion and rust every year is incalculable, which may lead to the damage of equipment, or threaten the safety of people's lives and properties^[2]. In the use of steel, the removal of the corrosion layer is essential to meet its surface cleanliness at the same time, but also to extend the service life of steel equipment^[3-4].

The current rust removal methods mainly include mechanical and chemical methods. Mechanical method is divided into manual grinding and sandblasting two measures, manual grinding workload, rust removal effect is not obvious, but also will cause irreversible damage to the steel equipment. The sandblasting method is difficult to control the direction of sand particles due to the large size of the equipment, so it can not cover the narrow area of rust, and it is easy to damage and pollute the parts around the rusted equipment. Although the chemical method will not cause damage to the material, the solvent will bring secondary pollution and affect the surrounding of the rusted area, which is not applicable to localized rust removal^[5]. Therefore, it is crucial to explore an economical, environmentally friendly and controllable method for steel rust removal.

Laser cleaning and rust removal technology is a novel technology, through the high peak power of continuous or pulsed laser irradiation corrosion parts, the corrosion layer absorbs the laser energy after a series of physicochemical changes such as gasification, melting, thermal vibration, and ultimately make the corrosion layer out of the carbon steel substrate^[6]. Laser cleaning technology has the outstanding advantages of green environmental protection, good cleaning effect, non-contact and

controllable substrate loss, etc. It is widely used in aerospace, automobile and shipbuilding, ancient cultural relics protection and other fields^[7-9].

At present, most of the research on laser cleaning and rust removal technology mainly focuses on the way of rust removal and the optimization of process parameters. Tian bin^[10] and others through the laser dry rust removal method, the preliminary laser cleaning threshold, cleaning efficiency, cleaning cost cleaning effect and other data. Mateo and others^[11] found that by adjusting the laser energy and pulse frequency can be on the brass surface of the varnish film to get a high cleaning effect. Li Wei^[12] proposed the simultaneous cleaning and passivation conditions of floating rust layer and double beam wet cleaning rust removal and passivation method. Zhang^[13] found that the laser repetition frequency in 1KHz and 2KHz conditions, the repetition frequency of low cratering caused by the surface of the material is shallower, the impact is more uniform, the roughness is lower. Sheng^[14] in the class B corrosion degree of Q235 steel rust removal process tests found that the surface roughness of the sample increased with the increase of laser power and scanning number, and decreased with the increase of scanning speed. Although there are more research on the optimization of laser rust removal methods and process parameters, there is no research on the prediction of rust removal effect, if it can be combined with machine learning to determine the prediction of the rust removal effect of each parameter, it will greatly improve the efficiency of rust removal, which will bring certain economic benefits to the rust removal of steel equipment.

In this paper, a nanosecond laser with adjustable re-frequency of 1-15Hz is used to descale Q235 steel, and the research on the rust removal performance of each parameter is carried out. The surface morphology obtained by cleaning under different parameter processes is analyzed, and the analyzed surface imaging map is used to carry out image recognition to extract the rusted areas on the surface, and combined with the percentage of rust before and after laser treatment, ridge regression and Lasso regression are used to combined with the corrosion percentage before and after laser treatment, ridge regression and Lasso regression were used to predict the rust removal performance of the laser treatment parameters, providing new methods and techniques for the subsequent research and application of laser rust removal technology.

2. Experimental Section

2.1 Sample Preparation

Fifty Q235 steel plates with thickness of 1mm and a length and width of 10mm were selected as experimental materials. Using 600 mesh, 1000 mesh, 2000 mesh sandpaper step by step sanding to the surface of the bright state, and then cleaned with deionized water ultrasonic cleaner, natural drying in a cool place. After drying, an equal amount of rusting agent was dropped on its surface with a pipette gun and then coated well.

2.2 Laser Device

The nanosecond laser with adjustable re-frequency from 1 to 15 Hz manufactured by Continuum was used for the preparation of the samples, and in order to ensure sufficient processing efficiency, all the experiments were carried out at the maximum re-frequency of 15 Hz, and its appearance is shown in Fig. 1(a). The laser is capable of generating Nd: YAG laser with a center wavelength of 1064 nm, and the polarization direction is parallel to the emitting end of the laser, and it is also capable of generating 532 nm and 355 nm pulses through frequency doubling, and the polarization directions are perpendicular and parallel to the emitting end of the laser, respectively. The maximum energy of a single pulse is up to 28mJ, and the energy of the output pulse can be continuously regulated by the energy attenuator of the laser, with a pulse width of 5-7ns, and a spot energy distribution approximating a Gaussian distribution. After pretreatment, the samples were placed on Altechna's microdisplacement platform for precision machining, and the main view of the platform is shown in Fig. 1(b). The platform can be moved in any direction in the horizontal plane, with a minimum displacement accuracy of 1 nm, the focusing objective lens is mounted on the Z-axis perpendicular to the machining plane, and different depths of focus can be realized by moving the objective lens

holder, in addition to the platform can be rotated in two dimensions around the X, Y axis on the horizontal plane, and the processing area can be monitored by the monitoring system of the platform in real time in the software. The platform comes with a processing monitoring system, which can monitor the status of the processing area in real time in the software. The focusing lens used in the experiment has a magnification of 4 times and a numerical aperture of 0.1, and the power meter used to measure the laser power is the 11XLP12-3S-H2 type produced by Standa, with a measurement accuracy of $1 \times 10^{-12} \text{W}$.

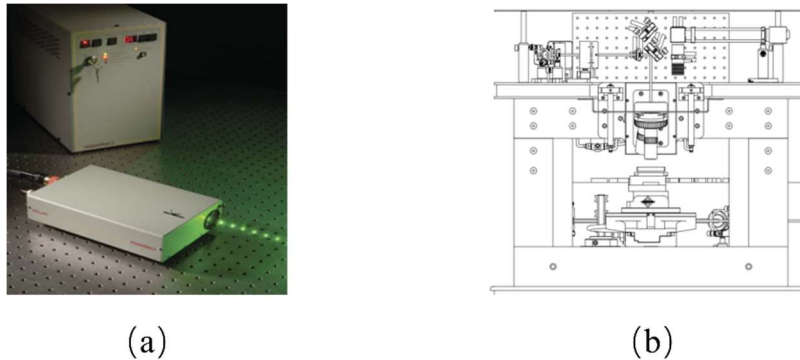


Fig. 1 (a) Appearance of Nd: YAG pulsed laser; (b) Main view of micro-displacement machining platform

2.3 Characterization Method

The observation of the surface morphology of the samples was carried out by the VK-X200 shape analysis laser microscope manufactured by KEYENCE. The microscope has four magnifications: $10\times$, $20\times$, $50\times$ and $150\times$, and its accompanying shape analysis software can measure and analyze the surface roughness of the sample surface in single line, multi-line and area, with a measurement accuracy of 1 nm, and finally, the diffraction image of the sample is collected by the imaging system, and the illumination is a white LED, with a color temperature of 6000-6500K, and a rated current of 700 mA. The rated current is 700mA and the brightness is 160-180LM.

2.4 Experimental Program

In the development of the experimental program to select the laser power, engraving speed, engraving spacing, pulse frequency and pulse density of a series of process parameters, as shown in Table 1, when one of the parameters of the regular change, the rest of the parameters randomly selected, as shown in Table 2. laser rust removal spot scanning movement process as shown in Fig. 2, the upper 50% of the region as a laser process, and the lower 50% of the region as the original rust area, do not do the laser process, the upper and lower regions of rust as an assessment of the performance of the rust removal. The corrosion ratio of the upper and lower regions is used as an assessment of the rust removal performance, because analyzing the same steel plate can effectively reduce the error due to the different degrees of corrosion caused by the two steel plates.

After laser rust removal, VK-X200 shape analysis laser microscope is used for characterization, and the characterized rusted areas are extracted by combining image processing, the rusted areas of the upper and lower regions are calculated respectively, and finally, the ratio of the rusted areas of the upper and lower regions is used as the performance of rust removal, which is evaluated by combining machine learning.

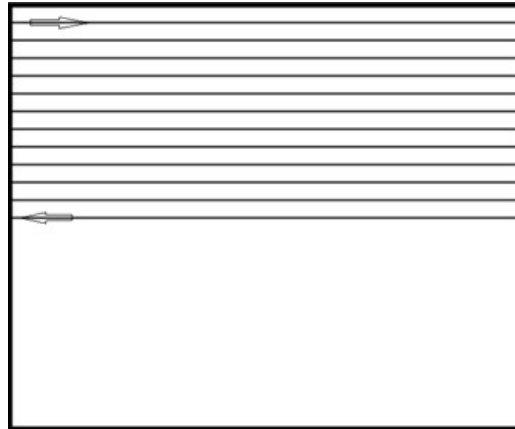


Fig. 2 Schematic diagram of spot scanning trajectory in laser rust removal process

Table 1. Experimental scheme of laser rust removal

Parameter type	Value									
laser power	10%	20%	30%	40%	50%	60%	70%	80%	90%	90%
engraving speed	10	15	20	25	30	35	40	45	50	55
engraving spacing	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1
pulse frequency	6	7	8	9	10	11	12	13	14	15
pulse density	6	7	8	9	10	11	12	13	14	15

Table 2. Laser machining parameter selection scheme

laser power	engraving speed	engraving spacing	pulse frequency	pulse density
10%	-	-	-	-
20%	-	-	-	-
30%	-	-	-	-
40%	-	-	-	-
50%	-	-	-	-
60%	-	-	-	-
70%	-	-	-	-
80%	-	-	-	-
90%	-	-	-	-
100%	-	-	-	-

3. Experimental Results and Discussion

3.1 Material Surface Morphology

VK-X200 shape analysis laser microscope was used for characterization to extract the area of laser-treated and untreated rust, as shown in Fig. 3(a), which is the top 50% part of 1 of the 50 steel plates prepared for the experiment, the topographic characterization of a certain laser parameter treatment, and Fig. 3(b), which is the bottom 50% part of the same plate, the bottom 50% part of the same plate, the topographic characterization of the original rust that has not been treated with the laser treatment, in which the yellow, brown, and red color are the image processing is to extract the area of yellow,

brown and red color in the figure to calculate the area of corrosion. As shown in Fig. 3(c), the figure shows the rusted part extracted by image processing after laser treatment, and Fig. 3(d) shows the rusted part extracted by image processing of the original rust.

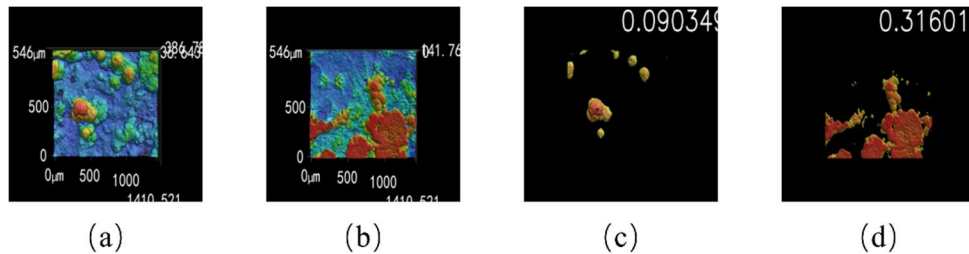


Fig. 3 (a)Surface morphology after laser treatment, (b) Laser untreated original morphology, (c)Rust extraction after laser treatment, (d) Laser untreated rust extraction

3.2 Selection of Training and Test Sets

The training and test sets are divided by randomly selecting 80% of the samples as the training set and the remaining 20% as the test set, with the laser power, engraving speed, engraving spacing, pulse frequency and pulse density as the eigenvalues. It is important to point out here that the selection of training and test sets is random, and when different training and test sets are selected, the final RMSE will be different. So in this experiment, we will repeat the algorithm several times independently and use the average RMSE as a measure.

3.3 Ridge Regression

Ridge regression is a kind of biased estimation regression method specially used for the analysis of covariate data, which is essentially a modified least squares estimation method, by abandoning the unbiased estimation of least squares, we can obtain more practical and reliable regression coefficients at the cost of losing part of the information and decreasing the precision, Ridge regression is to introduce a matrix into the parameter estimation of ordinary least squares, $\hat{\beta} = (x'x)^{-1}x'y$, and get $\hat{\beta}(k) = (x'x + kI)^{-1}x'y$, which gives the following result kI ($k > 0$, I is the unit matrix), where $\hat{\beta}(k)$ is the ridge regression estimate and k is the ridge parameter. Since the ridge parameter is not unique, the obtained $\hat{\beta}(k)$ is a family of estimates of the parameter β . In this paper, we combine the ridge plot of the regression coefficients and the basic principles of the ridge parameter values to determine the most appropriate values of the ridge parameter, and the ridge plot is shown in Fig. 4.

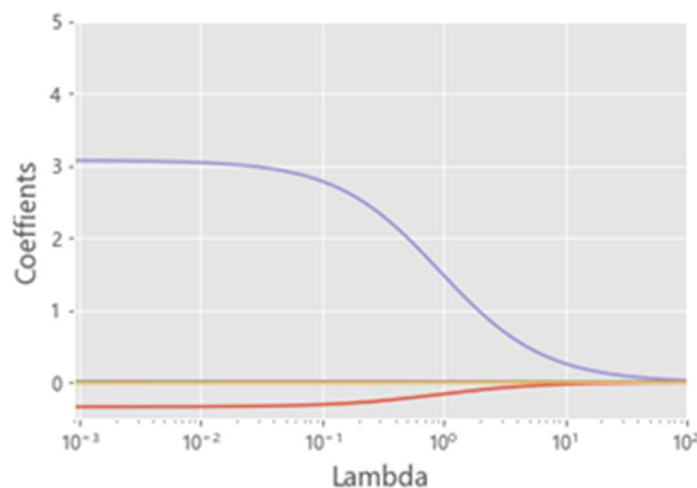


Fig. 4 Ridge trace

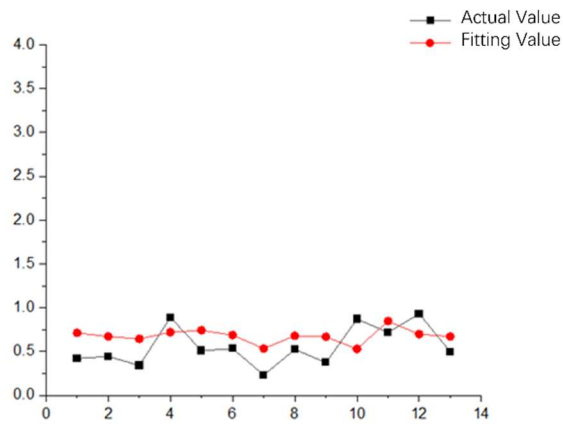


Fig. 5 Comparison between ridge regression fitting value and actual value

By analyzing the results given by the returned ridge best Lambda, the ridge regression parameter is 0.21214517849106276, combining the coefficients of each parameter and the intercept value, the ridge regression model obtained is:

$$Y=0.886579-0.339347X_1-0.002275X_2+3.067548X_3+0.004623X_4-0.008949X_5 \quad (1)$$

3.4 Lasso Regression

Lasso regression is a relatively new method, the principle is to add a paradigm as a penalty constraint in the calculation of RSS minimization, which is widely used in parameter estimation and variable selection, and it is a regularization method that is carried out in the process of variable selection and parameter estimation at the same time. Similar to ridge regression, Lasso regression transforms a constrained optimization problem into an unconstrained penalty function optimization problem by adding a penalty term. The difference is that, although Lasso regression cannot obtain an analytical solution, its regression results help to make a suitable feature selection, which is superior, and its definition is as follows:

$$\hat{\beta} \text{ (lasso)} = \underset{\beta}{\operatorname{argmin}} \left\| y - \sum_{i=1}^p x_i \beta_i \right\| + \lambda \sum_{i=1}^p |\beta_i| \quad (2)$$

Where λ is a non-negative regularity parameter and $\sum_{i=1}^p |\beta_i|$ is a penalty term.

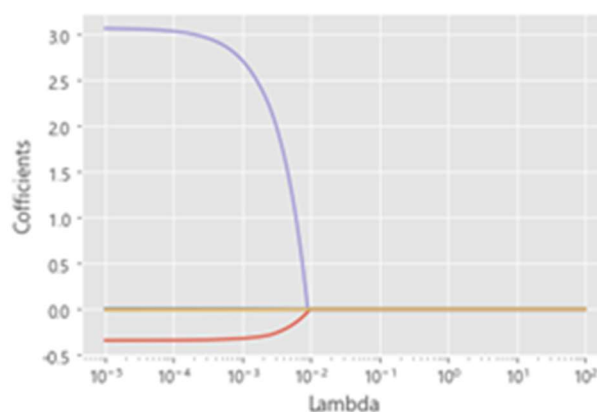


Fig. 6 Lasso regression figure

Combining the list of coefficients derived from the algorithm and the lasso regression plot shows that the corresponding non-zero coefficients are power -0.339347, -0.002275, 3.067548, 0.004623, and -0.008949. Therefore, we get the Lasso regression model as:

$$Y=0.886579-0.339347-0.002275+3.067548+0.004623-0.008949 \quad (3)$$

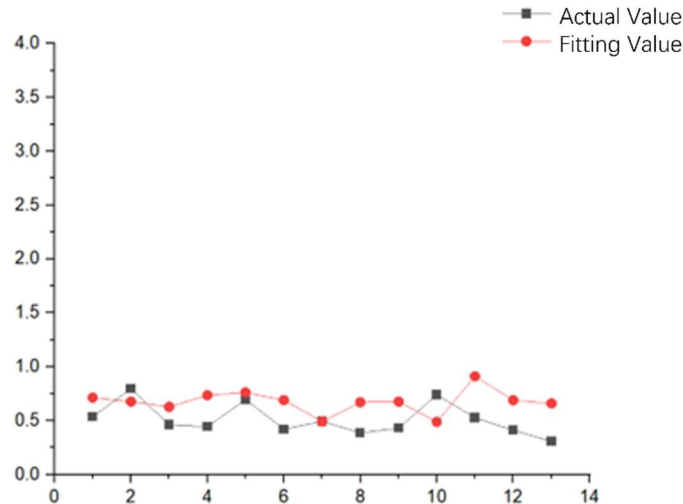


Fig. 7 Comparison between lasso regression fitting value and actual value

4. Summary

In this paper, the rust removal performance of Q235 steel was analyzed and predicted using ridge regression and lasso regression combined with laser rust removal technology. The RMSE of ridge regression is 0.2379, and the RMSE of lasso regression is 0.2460. Comparing the predicted values with the real values obtained from the two models, the prediction results are better and the prediction effect of lasso regression model is better. As a whole, the RMSE obtained by both methods is close to 0.2, the prediction effect is better, the fitting effect is good, and it has practical application value.

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