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An application of neural network solutions to laser assisted paint stripping process of hybrid epoxy-polyester coatings on aluminum substrates

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Abstract

A neural network approach is used to model a paint stripping process performed using a 1.5 kW continuous diode laser source on an aluminum substrate coated with approximately 80 μm of a hybrid epoxy-polyester resin. Two different coating colors, namely RAL 8087 (dark) and RAL 1013 (bright), are examined in order to analyze the influence of the difference in absorption of the laser energy by the surface on process.

Experimental analysis was performed first in order to find the trend of paint stripping factor (PSF) according to leading process parameters such as laser power, scan speed, defocus length, and number of passes. A statistical approach is used to discuss the experimental data found. Two neural network models are investigated, namely Multi-Layer Perceptron (MLP) and Radial Basic Function (RBF), with MLP being more reliable and effective in modeling experimental results.

A sensitivity analysis on the MLP model is used to show the significance of all the input data employed. As a result of sensitivity analysis, a check between experimental and calculated trends for each investigated variable was performed, which revealed an appreciable fit between data displayed. Following this, a regression model to predict the trend of PSF according to laser fluence was developed. Finally, the regression model and the MLP model were compared and showed the high degree of accuracy of neural network solution in predicting the experimental results.

Keywords: Laser cleaning; Diode laser; Epoxy-polyester coating; Neural network model

1. Introduction

Laser cleaning (LC) is an emerging laser process with great potential for use in stripping paint and coatings, in surface cleaning (i.e. contaminant and soil removal), and in metal polishing (i.e. oxides and stain removal) [1].

The process selectively vaporizes the undesired layers clinging onto the workpiece surface by using controlled irradiation emitted by a focused laser beam. Unlike mechanical and chemical stripping, laser cleaning is a 'free contact' and 'free tool' process, with no significant liquid and solid residuals being generated during operations and no 'tool' wear or need for 'tool' regeneration. Therefore, the main reason for the increasing diffusion of LC is that the undesired layers can be removed from workpiece surface avoiding techniques [2–5] which, making use of solvents [2,3], abrasives or tools [4,5], severely impact on the environment, thereby failing to respect the ever more stringent legislation and regulations.

A few mechanisms have been identified which explain the leading phenomena in LC, accounting for various part geometries, laser process conditions, and the complex interaction of many thermal and mechanical factors [6,7]. Although these interactions are not fully understood yet, improving knowledge of the process in terms of theoretical models and control strategies [8], as well as continued development of adaptive and/or predictive LC systems [9], means the process will offer the industry an ever increasing and a significant potential value in overcoming traditional operational cleaning problems.

2. Background and motivation

Several applications of different laser systems to paint and coating stripping process can be found in the literature [10–14]. Most applied techniques are based on a pulsed ArF system using photolytic and photoacoustic effects [10,11]. Very few relevant applications of continuous laser sources have been

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reported in the literature [12–14], namely a cw CO_2 system and a HPDL system.

The experimental findings show that in spite of the fastest removal process being produced by a CO_2 laser medium, the most accurate and controllable removal process is obtained from a laser with a pulsed energy source [11]. Diode laser systems have potential for paint stripping process as they are the most economical system of the three in terms of comparable power ratings [13], and for control over the removal depth [14,15].

Although some applied examples of laser removal of organic residuals, contaminants, and oxide layers already exists, the detailed relationships between laser parameters and cleaning performance are still not particularly clear. Consequently, several unresolved issues and unanswered concerns relating to the use of lasers in cleaning processes still exist. The wide variety of laser system uses in cleaning processes depends on the undesired layer typology, the amount of contaminants being removed, the differing nature of substrates, and the bonds between undesired layers and substrates, which all make the process set-up extremely delicate. Furthermore, for any laser source, due to the process characteristics, the working time required is still too high (working time is expressed as ratio of treated surface to unit of time). Finally, the fields of process applicability are still very limited as too large a laser power is a major cause of surface damage (deterioration of roughness, mechanical performance, and resistance to corrosion of the cleaned surface), and too low a power is associated with a seriously ineffective cleaning process. Therefore, there has been an ever and strongly increasing demand for more controllable and self-calibrating techniques.

In this context, the development of a sophisticated prediction and control instrument to determine the most appropriate operational parameters in advance according to the properties of the undesired layers, their thickness, and the substrate characteristics, would be extremely convenient. Above all, this would improve productivity because it would significantly reduce set-up time and process calibration in different operational conditions. Moreover, the employment of neural network solutions as an alternative to traditional prediction and control instruments based on statistical analyses and regression models seems to be emerging as an answer to the increasing demand for new techniques, as indicated by several successful applications in laser material processing [16–19] (i.e. laser hardening [16], laser welding [17], and laser forming [18,19]), as well as in manufacturing processes [20].

3. Outline of the work

The present paper presents the application of a neural network solution to the modeling of a 1.5 kW continuous diode laser source used in a paint stripping process performed on an aluminum substrate coated with approximately 80 mm of a hybrid epoxy-polyester resin.

The amount of paint stripped from aluminum substrates can be deduced experimentally by concurrently varying leading process parameters such as laser power, scan speed, number of passes and focal length. A statistical approach is used to study and interpret the influence of all the operational variables on the experimental data. Using this, different neural network solutions for each painting color are developed to estimate Paint Stripping Factor (PSF). Since the choice of the network architecture is of fundamental importance in the development of a predictive model, two different solutions are investigated: Multi Layer Perceptron (MLP) and Radial Basis Function Networks (RBFN), with the former being more reliable and effective in predicting experimental results. On this basis, sensitivity of laser operational parameters is performed in order to extract the cause and effect relationship between the network inputs and outputs. The significance of each process parameter is also estimated.

Lastly, a regression model based on experimental data correlating PSF to laser fluence was developed and used as baseline to estimate the performance of neural network solutions, thereby revealing the remarkable potential of MLP model as a prediction and control instrument for laser cleaning processes.

4. Materials and methods

4.1. Materials

Paint stripping experiments were performed on aluminum substrates (AA 2024 T3 alloy). 44 specimens (125 mm wide and 150 mm long) were cut from 1 mm thick aluminum sheets (2 m long, 1 m wide). After this, the specimens underwent a series of surface pre-treatments to prepare the electrostatic deposition of the paint on them. Next, a vapor degreasing cleaning with common solvents to remove oil, grease, loose metal chips, and other surface contaminants was applied. Then, following deionised water rinsing, zinc phosphating was carried out during which both the coating weight and the crystal size were accurately controlled. Finally, after a rinsing and a drying cycle, an epoxy-polyester hybrid powder was applied by using an electrostatic spray gun.

As mentioned above, two different painting colors were employed: the first 24 specimens were coated by using brown colored EP powders RAL 8087 (higher expected values of absorption coefficient); the other 20 specimens were coated by using pearl colored EP powders RAL1013 (lower expected values of absorption coefficient). Coated specimens were subsequently baked in an electric oven for 20 min at 170 °C and post-cured for 72 h at 50 °C. Dry film thickness was closely monitored by using a MEGACHECK 5F-ST instrument, based on magnetic field. A map was composed using 81 measurements taken on the surface of each specimen, uniformly distributed in threes at 27 locations, which were later irradiated using laser. All the manufactured specimens with coating thickness not falling in the range between 75 and 85 μm were discarded and remade in order to obtain greater reproducibility of paint stripping conditions.