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Theoretical and experimental study of laser treatment of nickel using a diode laser

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Abstract. In recent years, laser surface treatment (LST) has widely used to improve the properties of nickel coatings. LST has many advantages, however, different coating thicknesses require different modes, which can be selected using simulation. In this study, the modeling process is considered and an experiment is conducted to study the effect of LST process parameters on melt pool sizes. The aim of this research was therefore to reveal the dependence of the melt pool depth, namely the thickness of the layer in which the mixing process of components takes place, on the scan speed using a diode laser. With LST by diode laser, the thickness of the processed layer reaches about 500 μm, and the width of the processed surface is about 6 mm.

Keywords: laser surface treatment, thermal modeling, finite element method, nickel, melt pool, cold spraying

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Теоретическое и экспериментальное исследование лазерной обработки никеля с использованием диодного лазера

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Аннотация. Для улучшения свойств никелевых покрытий широко применяется лазерная обработка поверхности. Процесс лазерной обработки имеет много достоинств, однако разная толщина покрытия требует использования разных режимов обработки, которые можно подобрать с помощью моделирования. В этом исследовании изучается влияние параметров процесса лазерной обработки на размеры ванны расплава. Таким образом, целью данного исследования является определение зависимости глубины ванны расплава, а именно толщины слоя, в котором происходит процесс перемешивания материала покрытия и подложки, от скорости сканирования. Установлено, что при лазерной обработке с помощью диодного лазера толщина обрабатываемого слоя достигает порядка 500 мкм, а ширина обрабатываемой поверхности 6 мм.

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Ключевые слова: лазерная обработка поверхности, тепловое моделирование, метод конечных элементов, никель, ванна расплава, холодное напыление

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Introduction

At present, a large number of materials are used in the world to solve various problems [1–4]. Nickel has been widely applied in aerospace, navigation, and military industries, due to excellent corrosion and oxidation resistance, high thermal conductivity, and high-temperature stability [5, 6].

Among various surface modification techniques, laser surface treatment (LST) has attracted significant interests. The main feature of this process is localized laser-assisted melting and solidification within a short time and shallow depth, resulting in changes in the microstructure and the material properties [7, 8]. LST improves the mechanical and chemical properties of the material, such as adhesion, microhardness and corrosion resistance due to microstructural changes in the laser impact zone [9–11].

Lasers diode modules are used for processing large surfaces. They make it possible to achieve a uniform coating thickness and accelerate the laser processing process.

The microstructure and thickness of coating obtained by the LST depends on many technological parameters, for example, the scanning speed. This paper studies the process of modeling and conducts the experiment to analyze the effect of LST process parameters on the melt pool sizes.

Materials and Methods

The Comsol Multiphysics package and 3D finite element method are used to model thermal effects [12, 13]. A three-dimensional numerical model was built with dimensions of 20 mm ×8 mm ×4 mm. Nickel was chosen as the coating material, and St3 steel as the substrate material. Steel St3 was chosen for modeling, since its physical properties are known from open sources, and it is similar to steel 09G2S. The studies were carried out for speeds of 7.5 mm/s – 15 mm/s and for the thickness of the nickel coating 70 μm and 140 μm. Table presents the studied modes.

Table

Parameters of laser treatment modes

Mode	Thickness PC, μm	Scanning speed, mm/s	Power, *W*
1	70	7.5	1680
2		10	1680
3		12.5	1680
4		15	1680
5	140	7.5	1680
6		10	1680
7		12.5	1680
8		15	1680

The main mechanisms of heat transfer in the LST process in the thermal model are the thermal conductivity of the sample, laser heating of the coating, and thermal convection between the boundaries of the coating and the ambient (Fig. 1) [11].

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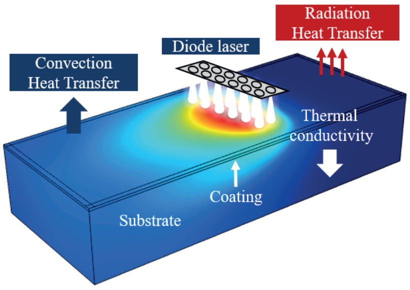

Fig. 1. Schematic illustration of the LST process

To LST, a PLD-6 diode laser was used, consisting of 12 point sources arranged in two rows of 6 pcs. The laser beam diameter of each point source was 0.9 mm. In each case, when treatment the coating surface, the total laser power was 1680 W. Nickel powder with the addition of corundum was used as the initial powder material. Sheets of steel grade 09G2S were used as a substrate. Several treatment modes were performed with different speeds of the laser beam movement.

The experiment consists of two stages. At the first stage, the cold spraying method forms a nickel coating with a thickness of 70 and 140 μm. For applying coatings by cold spraying, a Dimet-403 installation was used. The 09G2S steel substrate was coated with different thicknesses: 70 and 140 μm.

The second stage includes laser surface treatment to form a coating with improved characteristics. LST is performed at PLD-6 using a diode laser in a protective argon atmosphere.

Results and Discussion

Thermal modeling of LST using a modular diode laser was carried out for the modes indicated in Table 1. The simulation results showed that the melt pool has an elongated shape, which makes it possible to process a 6 mm wide surface in one pass of the laser beam.

As a result of the study, the dependence of the melt pool depth on the scanning speed was established. With an increase in speed from 7.5 to 15 mm/s, an almost linear decrease in the depth of the melt pool was observed (Fig. 2).

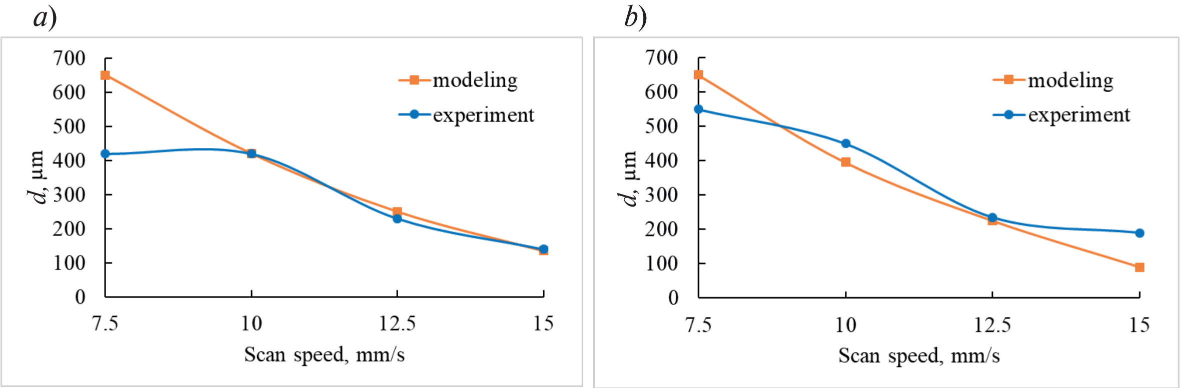

Fig. 2. Comparison of the melt pool depth obtained from simulation and experimental study for nikel thickness 70 μm (*a*) and 140 μm (*b*)

For the 70 μm coating thickness in all modes from 1 to 4 the coating and the substrate are fused, since the melt pool depth exceeds the coating thickness. For the 140 μm coating thickness for modes 5–7 fusion occurs, but the study of mode 8 showed that the coating does not have time to completely melt at a scanning speed of 15 mm/s. Figure 2 shows the results of calculating the melt pool depth for different scanning speeds.

Based on the LST modeling, representations on the modes selecting for conducting the experiment were formed. As a result of the study, the dependence of the melt mixing zone size on the scanning mode (different scanning speeds and coating depth) was established.

Figure 3 shows the coating thickness distribution after cold spraying (Fig. 3, *a*) and modified

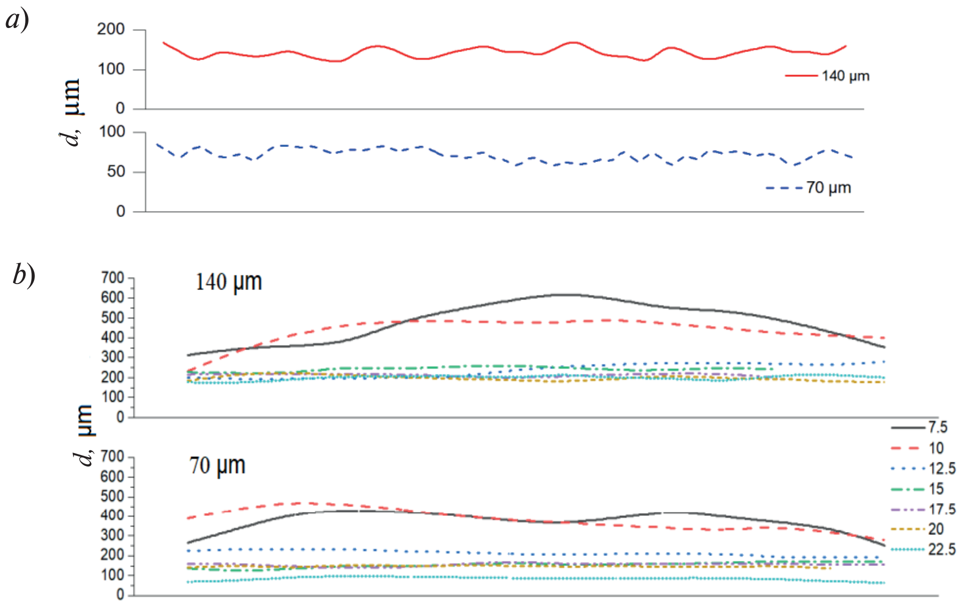

Fig. 3. Coating thickness distribution (*a*) modified layer thickness after LST (*b*) of 140 μm and 70 μm nickel coating thickness

layer thickness after subsequent laser treatment for different coating thicknesses and scanning speeds (Fig. 3, *b*).

As can be seen from Fig. 3, *a*, the surface profile of the nickel coating is inhomogeneous. Therefore, the average coating thickness was measured. It was 70 μm and 140 μm.

A distinct peak at speeds of 7.5 m/s and 10.0 mm/s indicate that the input energy has propagated into the interior of the substrate. There was a deeper melting, which is typical for the impact of a fiber-optic laser with a Gaussian power distribution. These processing modes make it possible to obtain a thickness of the treated layer of more than 500 μm.

Measurements of the coating thickness of the manufactured samples also showed that at speeds above 15 mm/s there is no mutual mixing of the coating components and the substrate.

Conclusion

With an increase in scanning speed from 7.5 mm/s to 15 mm/s, the melt pool depth almost linear decreases. Speeds at which the melt pool depth does not reach the substrate and there is no mutual mixing of the components of the coating and the substrate were found. For a coating thickness of 70 μm, this speed is 22.5 mm/s and 25 mm/s, and for a coating thickness of 140 μm it is over 15 mm/s.

Experimental results have shown that the use of a diode laser for LST makes it possible to ensure a uniform distribution of the alloying component in the processing area. At a scanning speed of 7.5 mm/s and 10.0 mm/s, the thickness of the processed layer reaches about 500 μm, and the width of the processed surface is about 6 mm.

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