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Modeling of the scanning track formation in the selective laser melting process of 316L steel

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Abstract. Selective laser melting (SLM) is a promising additive manufacturing method that uses metal powder materials and heats them with a laser beam to the melting temperature in such a way that the metal powder layer completely melts. This paper presents a study of SLM process for austenitic 316L steel. The study focuses on single laser track formation and the effects of laser radiation parameters on melt pool size. The research aims to investigate the effects of various laser radiation parameters on the melt pool dimensions in a sample. These parameters include laser power, scanning speed, and laser focal spot diameter. A computational model, created using the COMSOL Multiphysics finite element software, is used to simulate the behavior of the sample under different processing conditions and determine the optimal processing parameters. Results show that the melt width, length and depth depend on above laser parameters. This research contributes to our understanding of SLM processes and provides valuable insights into optimizing processing parameters for achieving desired sample properties.

Keywords: selective laser melting, heat transfer modeling, finite element method, austenitic steel, melt pool

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Моделирование формирования дорожки сканирования в процессе селективного лазерного сплавления стали 316L

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Аннотация. Селективное лазерное плавление (SLM) - это перспективная технология аддитивного производства, в которой используется лазерный луч для нагрева металлического порошка до температуры плавления, что приводит к полному его расплавлению в виде нового слоя. В этой работе мы исследуем процесс SLM на примере аустенитной стали 316L. Целью данного исследования является изучение влияния различных параметров лазерного излучения, включая мощность, скорость сканирования и диаметр фокусного пятна, на размеры расплавленной ванны внутри образца. Мы используем программное обеспечение COMSOL Multiphysics для моделирования поведения образца в различных условиях и определения оптимальных параметров обработки. Результаты моделирования показывают, что ширина, длина и глубина расплава зависят от этих изменяемых параметров лазера. Это исследование расширяет наше понимание процессов SLM и дает ценные рекомендации по оптимизации параметров обработки для достижения желаемых свойств образцов.

Ключевые слова: селективное лазерное сплавление, моделирование теплопередачи, метод конечных элементов, аустенитная сталь, ванна расплава

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Introduction

Among the various technologies of additive manufacturing, selective laser melting (SLM) is one of the most widely used for the construction of metal parts [1]. The SLM process involves the layer-by-layer fusion of metal powders using laser radiation. During melting, a melt pool is formed, and the morphology of this pool affects the final microstructure of the product [2]. Products manufactured using SLM are widely used in various industries, including biomedical, aerospace, energy, and automotive [3, 4]. The quality of these parts is influenced by numerous parameters and managing them can be time-consuming. Computer modeling is used to reduce time resources.

The thermal physico-mathematical model of the SLM was developed by the authors, and with its help, a number of studies were conducted to investigate the influence of various parameters of the SLM process on the melt pool size [5–8]. In [5], it was found that with a reduction in the scanning speed, the depth of melt pool increases. A change in energy density had a greater effect on both the length and the depth of the melt pool, while the width varied slightly. In [8], different types of scanning strategies (circular and bidirectional) were examined for SLM processing of 316L steel.

Of particular interest is the study of the impact of laser radiation parameters, such as power, scan speed, and focal spot diameter, on the melt pool size. To date, several studies have been conducted in this area. These studies indicate that laser power is one of the most influential process parameters that must be taken into account. An increase in laser power and a decrease in scanning speed lead to an increase in temperature and melt pool size [9]. When using a larger laser diameter, surface quality may be compromised due to defects caused by incomplete melting of powder layers. Additionally, a smaller beam diameter can cause metal evaporation and “keyhole mode” [10].

This article investigates a wider range of laser radiation parameter values and uses modern modeling software. The aim of this work is to determine the dependence of melt pool size on laser radiation parameters such as power, scan speed, and focal spot diameter. The COMSOL Multiphysics software was used to model [11, 12] the system. The model defines all the necessary parameters of the samples (dimensions, materials, and environment conditions), as well as laser radiation parameters (scanning strategy, power, speed, focal spot size), and the thermal effects of laser radiation on the surface of the sample. Based on these simulations, a temperature distribution in the sample is obtained.

Materials and methods

The COMSOL Multiphysics finite element package was selected as the primary tool for simulating the SLM process. A 6×3×2 mm sample was constructed. 316L stainless steel was chosen as the material for the model. This alloy has improved anti-corrosion, creep resistance, and durability properties, making it suitable for use in challenging environments.

In the simulation, the thermal properties of the steel, such as its thermal conductivity and heat capacity, were set to vary with temperature. Heat transfer was modeled using the equation for thermal conductivity, and conditions for convective and radiative heat transfer were specified at the boundary of the sample. When the boiling point was reached, a flow of steam was simulated from the surface. A more in-depth mathematical description of the simulation can be found in previous publications [5, 8].

Various modes were modeled: with a laser power in the range from 100 to 800 W at a constant scanning speed of 800 mm/s and a focal spot diameter of 100 microns, with a scanning speed in the range from 100 to 800 mm/s at a constant power of 400 W and a spot diameter of 100 microns, with a focal spot diameter in the range of 50 to 300 microns at a constant power of 200 W and a scanning speed of 800 mm/s.

Results and discussion

Figure 1 shows the relationship between melt pool size and laser power. As the power increases, so does the size of the pool. This is because that the material is heated more intensely. However, further increases in the laser power lead to a decrease in the dependence on the pool size, which may be caused by boiling and subsequent evaporation of the material within the pool.

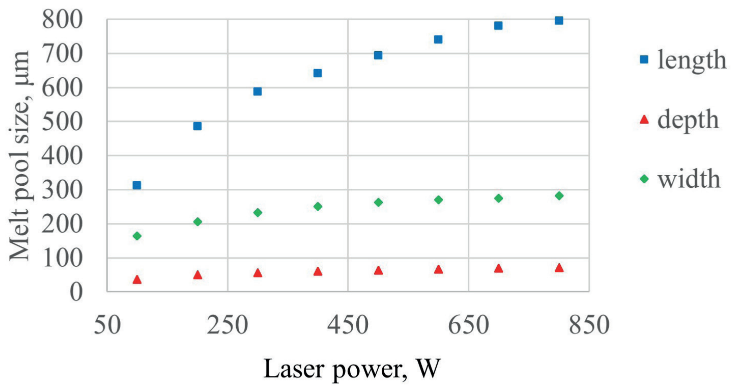

Fig. 1. Dependences of the length, width and depth of the melt pool on the laser power

Figure 2 illustrates the relationship between the size of the melt pool and the scanning speed. The low scanning speed ensures a more complete melting of the powder material. Consequently, the width and depth of the melt pool decrease with increasing scanning speed, while the length of the melt pool due to a lower solidification rate compared to the scanning speed.

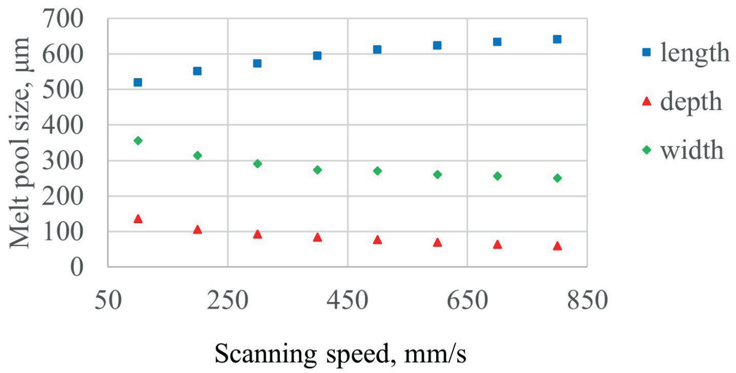

Fig. 2. Dependences of the length, width, and depth of the melt pool on scanning speed

Figure 3 shows the relationship between the size of the melted pool and the laser focal spot diameter. As the diameter of the laser beam increases (up to 200 microns), the width and length of the melted zone increase mainly due to an increase in the impact area and a slight change in energy concentration. However, the melt pool depth remains relatively constant, which can be explained by boiling of the material. Subsequently, as the diameter of the focus increases, all dimensions of the melted pool decrease due to a reduction in energy density.

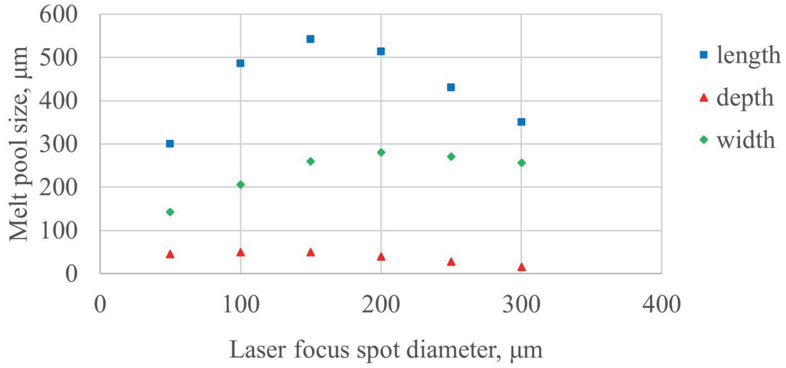

Fig. 1. Dependences of the length, width and depth of the melt pool on the laser power

Conclusion

In this article, we investigate the process of forming a scanning track during selective laser melting of 316L steel using numerical modeling. The size of the melt pool is determined by changing the laser power, scan speed, and laser focal spot diameter. Based on this study, several conclusions were drawn. Increasing laser power leads to an increase in all dimensions of the melt pool. Increasing scanning speed leads to a reduction in the width and depth of the pool, as well as an increase in its length. Minor changes in the focal spot size result in proportional changes in width and length, while depth remains relatively constant due to boiling effects. More significant changes in spot size reduce the melt pool size.

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