Characterization of laser welding of steel 30ХГСН2А by combining artificial neural networks and finite element method

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Abstract

The paper presents the calculation of the temperature fields, created at different depths, via artificial neural networks and the finite element method during laser welding of steel 30ХГСН2А. The training data array and the array data for testing neural networks were created using ANSYS.

Introduction

The manufacture of structural steel products using electric arc and gas-flame welding is sometimes complicated by high residual stresses and deformations. Laser welding is used to produce joints of various metallic materials. In this case, using laser welding provides minimal deformation of welded joints due to the high energy density, high rate of the process, and narrow fusion zone [1, 2]. In [3], the dynamics of forming thermal cycles during pulsed laser welding and surfacing of high-strength structural steel 30ХГСН2А was determined based on the results of finite element modeling. Artificial neural networks are widely used in science and technology, including simulating laser processing [4]. Paper [5] uses neural network simulation to predict the laser welding parameters. It has been found that the developed neural network provides more accurate predictions compared to the regression model. This study determines the values of temperatures, formed at different depths during laser processing of steel 30ХГСН2А, using the artificial neural network.

Finite Element Analysis

The training data array and data for testing the neural network were performed with ANSYS. The simulation was carried out for a plate with geometric dimensions of 2×3×0.6 mm. The calculations took into account the temperature dependences of the thermophysical properties of 30ХГСН2А steel. The time dependence of the heat flux was set in the form of rectangular pulses [3]. During finite element modeling, the duration of laser pulses t varied from 1 to 10 ms, the power density of laser radiation P_0 was from 10^8 to 10^9 W/m². The calculations were performed for 100 variants of input parameters, 90 of which were used to train the neural network. The input parameters and the calculation results of the test set are presented in Table 1. T_1, T_2, T_3 are the temperatures on the sample surface at a depth of 250 μm and 500 μm, respectively.

Table 1. Input parameters of the finite element model and temperature values in the laser processing zone

N	P_0, 10^8 W/m²	t, ms	T_1, C	T_2, C	T_3, C	N	P_0, 10^8 W/m²	t, ms	T_1, C	T_2, C	T_3, C
1	7	8	1689.1	1170.6	803.4	6	1	3	196.7	144.9	108.0
2	1	5	204.9	152.8	115.6	7	2	10	415.1	306.5	228.9
3	8	2	1556.2	1036.2	673.6	8	2	7	405.3	297.3	220.1
4	3	8	623.8	452.2	329.7	9	9	5	2255.6	1506.7	982.7
5	8	10	2141.0	1462.8	984.2	10	2	8	409.1	300.9	223.5

The use of artificial neural networks

A fully connected feedforward neural network with the architecture [2-10-5-3], created in the open software library for computer-assisted instruction TensorFlow, was used to determine the temperature values during laser welding [6]. The activation function ReLu (Rectified Linear Unit) was used when creating the networks. The optimizer was Adam, which is an extension of the stochastic gradient descent algorithm. The network was compiled with the mse (mean squared error) loss function, which calculates the squared difference between the predicted and target values. The number of epochs in training the networks was 50. The results of the created neural network are shown in Table 2. The relative errors were considered as the values characterizing the accuracy of determining the required parameters. The values of the largest relative errors in determining the temperatures T_1, T_2, T_3 were 14.2%, 20.6%, and 8.9%, respectively.

Table 2. Temperature values in the laser processing zone, defined by neural network

N	T_1, C	e, %	T_2, C	e, %	T_3, C	e, %
1	1571.9	6.9	1162.1	0.7	812.1	1.1
2	196.1	4.3	155.9	2.0	125.9	8.9
3	1424.1	8.5	927.1	10.5	605.3	10.1
4	620.1	0.6	454.8	0.6	314.4	4.6
5	2016.3	5.8	1461.1	0.1	1002.7	1.9
6	168.7	14.2	114.9	20.6	98.3	8.9
7	418.3	0.8	326.1	6.4	223.3	2.4
8	411.8	1.6	318.7	7.2	231	5.0
9	2257.8	0.1	1494.5	0.8	971.5	1.1
10	419.1	2.4	325.6	8.2	231.9	3.8

Conclusion

The paper shows the possibility of determining the modes of laser welding of structural steels based on a combination of the finite element method and artificial neural networks. The results can be used in developing technological processes for pulsed laser welding and metal surfacing.

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