The use of artificial neural networks for determining the parameters of laser processing of fused quartz

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Abstract
This paper provides the simulation of the laser splitting process of fused quartz using artificial neural networks. The calculations of temperatures and thermoelastic stresses were performed by the finite element method in the ANSYS program to create a training data array and an array data for testing neural networks. The paper studies the influence of neural network architecture, the size of the training data array, and the training time on the accuracy of determining thermoelastic stresses and temperatures in the zone of laser processing of quartz sol-gel glass.

Introduction
The implementation of the fused quartz processing is based on the use of a diamond tool, a water-jet, or laser radiation for cutting in the mode of material evaporation [1]. Laser splitting is one of the most effective methods for processing glass, ceramics and crystals. The main advantages of laser splitting are high separation accuracy, high processing speed and increased strength of the resulting products [2]. Paper [3] presents the research results of the laser splitting process of glass sol-gel plates. Artificial neural networks are widely used in

science and technology, including simulating laser processing processes [4]. Paper [5] provides a comparison of the modeling efficiency using an artificial neural network and finite-element modeling of the laser splitting process of glass. This paper uses an artificial neural network to calculate the values of temperatures and thermoelastic stresses generated by laser splitting of quartz plates.

Finite element analysis

The training data array and data for testing the neural network were performed with ANSYS. Simulation was carried out for a plate with geometric dimensions of 20x10x0.5 mm. The calculations used the properties of fused quartz obtained with the help of a colloidal version of the sol-gel method [3]. When simulating, the cutting speed varied from 40 to 70 mm/s; the laser power was from 100 to 300 W; the semi-major axis of the elliptical laser beam was from 1 to 3 mm; the semi-minor axis of the elliptical laser beam was from 0.5 to 1.5 mm. Table 1 presents some of the input parameters and calculation results.

Table 1. Input parameters of the finite element model and calculated values of maximum temperatures and thermoelastic stresses in the laser processing zone

N	V, mm/s	A, mm	B, mm	P, W	σ, Pa	T, K
1	60	1	1.25	100	2134379	609
2	40	3	1	100	2651899	587
3	60	2.5	1.5	100	1516934	468
4	50	1	1.25	300	7304059	1335
5	55	1.5	0.75	250	7047292	1388

The use of artificial neural networks

Fully connected feedforward neural networks with various architectures created in the open software library for computer-assisted instruction TensorFlow were used to determine the parameters of laser processing of sol-gel glass [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. There was a change in the number of epochs in training networks and their architecture. Mean Absolute Percentage Error (MAPE) was used to assess the efficiency of neural networks

$$\mathrm{MAPE} = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{d_i - y_i}{d_i}\right| \times 100,$$

where d_i is the desired network output, y_i is the actual network output [7]

The MAPE values when determining the maximum thermoelastic tensile stresses and maximum temperatures in the treatment zone did not exceed 8% and 5% for the worst option of the neural network (option 1). In general, option 3 of the neural network configuration seems preferable to be used, which provides the MAPE values of 3.7% and 2.5%, respectively, when determining the maximum tensile stresses and maximum temperatures in the treatment zone (Table 2).

Table 2. Results of training and testing neural networks

N	Data	Architecture	Epochs	σ	T
				MAPE	MAPE
1	800	[4-5-3]	50	7.7 %	4.9 %
2	800	[4-15-10-3]	50	5.4 %	3.3 %
3	800	[4-15-10-3]	100	3.7 %	2.5 %

Conclusion

The results have shown that it is possible to determine the modes of laser splitting of quartz sol-gel glass based on a combination of the finite element method and artificial neural networks. The numerical experiment helped to identify the architectures of neural networks, which give the best result in determining the thermoelastic stresses and temperatures in the laser processing zone.

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