Software package for modeling and optimizing parameters of laser processing of brittle non-metallic materials using laser splitting methods

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***Abstract**. In this work, with help of a software package implemented in Python, at the first stage, a finite element calculation of the temperature fields and thermoelastic stress fields formed during the processing of quartz glass plates by laser splitting was performed. At the second stage, based on the data obtained as a result of finite element modeling, the parameters of laser cutting of quartz plates were approximated using artificial neural networks. Neural networks and their training algorithms were implemented using the Keras library. At the third stage, the search for optimal laser cutting parameters was carried out using the author's genetic algorithm using the constructed neural network approximators. Finite element modeling in the developed software package was implemented using the FEniCS library and verified by comparing the obtained results with the corresponding values of maximum temperatures and thermoelastic stresses in the laser processing zone of quartz plates, determined using the APDL programming language in the Ansys software package.*

I. Introduction

Laser splitting is an effective method for processing a variety of brittle non-metallic materials, including silicate glasses and various crystals. Cutting using the laser splitting method is realized as a result of the formation of a dividing crack when the material is heated by laser radiation, followed by cooling of the processed surface with a refrigerant. This processing method has significant advantages, including high separation accuracy and high processing speed [1-3]. Currently, finite element analysis and neural network modeling are widely used to calculate temperature fields and thermoelastic stress fields when modeling processes of laser splitting of brittle non-metallic materials [4-6]. To improve the efficiency of laser technologies, it is important to optimize the relevant process parameters. Examples of determining the effective parameters of laser splitting using genetic algorithms are presented in [7-8].

Currently, Python is a popular programming language that has many libraries and tools designed for modeling physical processes. At the same time, Python is widely used for machine learning and artificial intelligence research. Combining both features opens up opportunities for the use of artificial intelligence methods in laser processing modeling. Using Python in laser processing modeling provides researchers with flexible, open-source and efficient tools for developing and optimizing laser material processing parameters. Thus, the development of tools for automated search for optimal parameters for laser processing of brittle non-metallic materials using laser splitting methods implemented in the Python language is an important scientific and practical problem.

II. Finite element modeling of the laser cutting process

Finite element modeling was implemented using the FEniCS library [9]. The modeling was carried for a thermoelasticity problem in a quasi-static formulation with weak thermomechanical coupling for a plate with geometric dimensions of 30×20×4 mm. The calculations used the layout of the laser beam and coolant and the properties of quartz glasses given in [6].

The processing speed for problem was equal to V=0.015 m/s. The following values of the laser beam parameters were used: radius of the beam radiation spot R=0.0015 m for a beam with radiation wavelength λ=10.6 µm and radiation power P=20 W. A heat transfer coefficient of 8000 W/m^2K was used for the area affected by refrigerant.

The obtained results were verified by comparison with the corresponding values of the maximum temperatures T and maximum thermoelastic tensile stresses σ_{yy} in the laser processing zone, calculated using the APDL programming language in the Ansys software package (see Table 1). The relative error in obtained maximum temperatures and maximum stresses in the laser processing zone did not exceed 1.5%.

Table 1. Verification of the results

Parameter	Ansys	FEniCS
σ_{yy}, MPa	4,53	4,48
T, K	1085	1073

II. Neural network modeling of laser cutting parameters

Neural network modeling was used to approximate the responses σ_{yy} and T. Two approximators were built that predict σ_{yy} and T based on the cutting speed V, laser radiation power P and time t. The initial data for training neural networks was obtained as a result of finite element modeling with different variations of factor values. Neural network models and their training are implemented in Python using Keras library [10]. When choosing optimal neural network architectures for approximating the responses σ_{yy} and T, three-layer perceptrons of various configurations were evaluated and compared. The number of neurons in the first and second hidden layers was selected in the range from 10 to 50 with a step of 10. For each candidate- architecture, an evaluation was carried out based on cross-validation using the MSE and R^2 metrics. Figure 1 shows heat maps of the MSE distributions for the approximators for responces σ_{yy} and T.

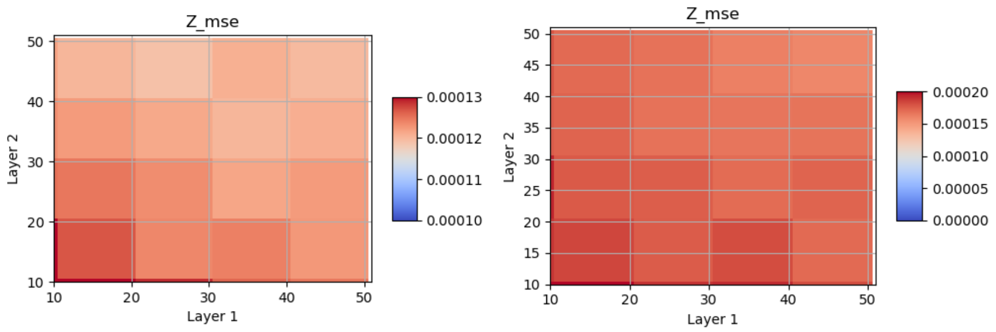

Fig.1. Heat maps of mean square error (MSE) distributions for three-layer candidate architectures of neural network response approximators T (left) σ_{yy} (right)

III. Search for optimal laser cutting parameters

Using the selected neural network architectures [40-40-1] and [50-20-1], approximators for σ_{yy} and T, respectively, were constructed. As a result of applying the genetic algorithm [4] and the constructed approximators, a search was carried out for the optimal values of the factors V and P according to the criteria of maximum tensile stresses $\sigma_{yy} \rightarrow max$ and maximum processing speed $V \rightarrow max$ when setting the maximum temperature limit in the processing zone $T \leq 1473\ K$.

As a result of applying the genetic algorithm, the optimal values of the factors were determined as shown in Table 2. The values of the parameters obtained as a result of finite element calculations in the ANSYS software package are given in parentheses. The values of stresses σ_{yy} and temperatures T, obtained using the developed software package, are calculated with errors not exceeding 2% and 2.5%, respectively.

Table 2. Optimization results

P, W	V, m/s	T, K	σ_{yy}, MPa
23,5	0,011	1397 (1371)	7,08 (6,92)

IV. Conclusion

In this work, a software package implemented in Python was used to model and optimnize the parameters of laser cutting of a quartz plate using laser splitting methods. The finite element modeling and neural network modeling in the developed package ware implemented using the FEniCS and Keras libraries. Multicriteria optimization of laser processing parameters was carried out using a modified genetic algorithm implemented in Python.

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