

Abstract

In times of increasing technical diversity and product specialisation, there is a growing demand for flexible manufacturing systems that would be able to provide the required level of individualisation and withstand ever shorter manufacturing cycles. One effective tool for ensuring individualisation is the use of generative technologies, a method that can also be used to manufacture thin-walled prototype products in the automotive industry. However, they have the disadvantage of creating a material with homogeneous properties, whereas the specific functionality of thin-walled components usually results from their differentiation at specific locations (e.g. by means of local stamping). An effective tool for diversifying material properties can be the utilisation of techniques of local modification to adjust the functionality of existing components. Laser technologies are ideally suited for this purpose due to their selectivity and high energy concentration, which makes it possible to process even very small areas. In the case of additively manufactured steels, a possible modification type is local hardening, which can be successfully implemented using laser hardening technology.

The process of designing a local modification method is currently supported by numerical methods by determining the effect of a given reinforcement shape on the functionality of the component and by calculating the optimal reinforcement shape for a given application. However, the geometries of the analysed and proposed local modification areas are challenging in terms of both the technological feasibility of manufacturing and the ability to characterise the actual processing results for the analysis of their functionality. A promising solution to this issue could be the characterisation of the reinforced area based on a virtual laser processing model. The use of multiphysics simulations of the laser hardening process for this purpose makes it possible to predict the results of real processing in the form of calculations of the shape of the reinforced area. In addition, the multiphysics simulations provide data on the hardening geometry in digital form, which can be directly adapted in the simulation of nonlinear dynamics.

In this study, a number of research activities were undertaken with the aim of simulation characterisation of the material transformation zone representing reinforcement in experimental, additively manufactured steel (StaVari) for the purpose of developing local reinforcement by laser hardening.

In order to obtain the desired results, a detailed analysis of the laser hardening technology topic, its numerical modelling methodology and the characterisation of the material grade were carried out. Extensive material tests were performed to determine the thermophysical parameters for numerical simulation and to characterise the state of the material before and after laser treatment. Four sets of processing parameters were developed through experimental investigations which represent the process window and allow reinforcement to be achieved. Proper measurements were also taken for future validation of the simulation model. A virtual model, representing the hardening process, was developed in the COMSOL Multiphysics environment, which allows a combined description of the various phenomena occurring during processing (e.g. heat flow and phase transitions). As part of the simulation work, a main model of the heat flow within the component was developed and a substitution model of the oscillating beam was created. The method for its validation was also developed. The main simulation model of the heat flow was validated based on process measurements and extended with the functionality of determining the area of full and partial reinforcement, corresponding with the transition zone. Three reinforcement models were proposed: one-, two- and multi-parametric, differing in the complexity of description (number of analysed variables describing the reinforcement). For the two-parametric model, a method for substitution determination of the dependence of A_{c1} and A_{c3} temperatures on the heating rate was developed. For the multi-parametric

model, a method of describing material transformations defined by the CTPc diagram through diffusion transformation equations based on the Leblond-Devoux model was developed.

After analysing the results of simulations with different reinforcement models, the two-parameter model (based on the temperature dependence of A_{c1} and A_{c3} on the heating rate) was selected as the most favourable one in terms of accuracy of shape prediction of the reinforced area. A qualitative analysis based on hardness distribution maps was also carried out, representing the actual reinforcement distribution compared to the simulation results. Based on the selected model, an extended characterisation of the results of the hardening process was carried out, describing processing results that would have been unavailable for examination if analysed by experimental testing.

The results of the work have also found their application. The developed laser hardening technology was adapted and used for local reinforcement of a thin-walled crashbox type component within the AM-Crash project. Simulation models developed as part of this research have been checked for use in such a technological task. They were also used for the determination of a power course to reduce the length of the transition region of hardness increase and for the development of a virtual laser hardening laboratory based on simulation applications with dedicated functionality. The results of the work are also a starting point for the development of more advanced methods of local reinforcement, based on the use of virtual models of reinforced areas and simulation support for the selection of laser processing parameters.