FEA ANALYSIS OF THIN STEEL SHEET WITH DIFFERENT LOCATIONS OF REINFORCING RIBS CREATED BY LOCAL LASER TREATMENT

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Abstract

The main purpose of the research was to determine the effect of local laser heating on the tensile stress under load. The simulation results show that the different locations and the number of laser tracks (internal reinforcing ribs) on a thin-sheet surface had a great influence on the stress distribution during tensile loads. The finite element analysis of equivalent Von-Mises stresses and stretching of thin-sheet steals acknowledge that the samples with the internal reinforcing ribs have a greater resistance to tensile load.

Keywords: Thin steel sheet, reinforcing ribs, laser treatment, FEA modelling

1. INTRODUCTION

In most ways, existing methods to increase the stiffness and strength of thin-sheet metal plates are present in the relationship between construction geometry and their stiffness. To increase stiffness can be created additional ribs or thick areas, but at the same time, it will increase the size and weight of the thin-sheet metal plate [1].

Every year, the development of new technologies for processing metal materials allows better control and to improve of the metals properties. Local laser heating is a new modern technique that allows a change and creation of certain zones within the material, the general properties of which will differ significantly from the basic metal structure [2]. Local laser heat treatment is a heating process with or without the melting of the base material. Due to laser treatment, the microstructure and properties of the materials can be controlled changed; for example, it's possible to increase their stiffness or hardness. To influence the stiffness of the metal structure and significantly increase its tensile strength it is enough to know the distribution and values of internal stresses that arise in the structure during loading. Thus, using local laser heating, we will be able to create special zones with internal stiffeners, which will significantly increase the mechanical properties of the structure while maintaining the original weight and dimensions [3].

Finite element analysis (FEA) is an effective, common, forceful numerical method and design tool for the nonlinear analysis of different structures.

The article discusses the use efficiency of local laser heating for creating reinforcing ribs in thin sheet steel. A finite element analysis of the effect of different locations and distances between laser paths on the stress distribution under tensile loads has been carried out.

2. AIM OF THE STUDY

The main goal of this study was to evaluate the effect of laser treatment on tensile loads as well as to determine a sufficient number of laser tracks to increase the tensile strength of the material.

The FEA modelling and nonlinear mechanical analysis of tensile stress distribution of thin steel sheets treated by laser for their strengthening are presented in this work.

Another goal of this research was to assess how the different locations and sizes of laser tracks influence the tensile stress of sheet material.

The experiment used the Ansys Workbench 2020 R1 software for modelling steel sheet tensile tests under workloads.

3. OBJECT OF THE STUDY

According to the International Organization of Motor Vehicle Manufacturers, 77.6 million vehicles were produced in 2020. [4] On average, 900 kg of steel is used per vehicle. Depending on the total mass of the vehicle, the steel in the vehicle is distributed in different ways, but we are interested in the part that is used in the body structure, panels, doors and trunk closure to ensure high strength and energy absorption in the event of an accident - which is approximately 40 % of the total weight car. New grades of Advanced High-Strength Steels (for example S550MC) enable carmakers to reduce vehicle component weight by 25-39 % and total vehicle weight by 8-10 % compared to conventional steel. When applied to a typical five-passenger family car, the overall weight of the vehicle is reduced by 100-150 kg, which corresponds to a lifetime saving of 2-3 tonnes of greenhouse gases over the vehicle's total life cycle. This saving in emissions can be more than the total amount of CO_2 emitted during the production of all the steel in the vehicle. [5] The use of local laser processing of thin sheet steels can help to further reduce the overall entire weight of the structure while maintaining high strength characteristics of the material.

Structural hot rolled carbon steel (1.0986, S550MC) containing less than 0.3% carbon was used in this work (**Table 1**).Chemical composition of steel 1.0986 (wt%): 0.12C; 0.5Si; 1.8Mn; 0.015S; 0.025 P; 0.2V; 0.09 Nb; 0.15Ti; 0.015Al.

Table 1 Mechanical properties of steel 1.0986 [6]

Elastic modulus E, (GPa)	Yield strength $R_{0.2}$, (Mpa)	Tensile strength Rm, (Mpa)	Relative extension (%)	Hardness (HBW)
190-220	550	600	Min 12	341

4. METHODOLOGY OF RESEARCH

An Ansys Workbench software was used for FEA simulation of the tensile stress of laser-treated thin sheet metal plate. Appropriate mesh models of laser-treated thin sheet metal plates was done with element quality more than 0.13 for each specimens without highly distorted elements.

The dimensions of the thin sheet metal (100 x 5 x 2 mm and 100 x 20 x 2), area of laser-treatment (20 x 5 mm), depth of treatment (0.35 mm) are identical in all the FEA models created (**Figure 1**).

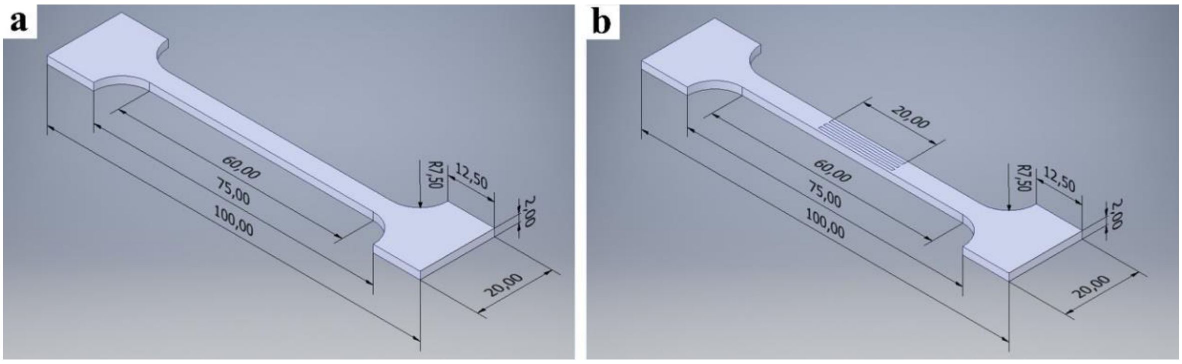

Figure 1 General view of 3D model: a – untreated plate; b - location of laser-treated area

Three options are presented for the location of the laser-treated area on a sheet sample (strips horizontally, vertically and at an angle of 45 degrees). Three options are also used for the distances between the laser-treated tracks (with overlap, distances of 0.35 mm and 0.7 mm) (**Figure 2, Table 2**).

Table 2 Variants of FEA model geometry

Location of laser-treated area	Distances between the laser-treated tracks (mm)	Number of laser tracks in treated area (pcs)	Abbreviation of case
Reinforced strips horizontally	0.7	6	I-I
	0.35	8	I-II
	Overlap	12	I-III
Reinforced strips vertically	0.7	28	II-I
	0.35	36	II-II
	Overlap	54	II-III
Reinforced strip at an angle of 45 degrees	0.7	24	III-I
	0.35	32	III-II
	Overlap	54	III-III
Untreated plate	-	0	X

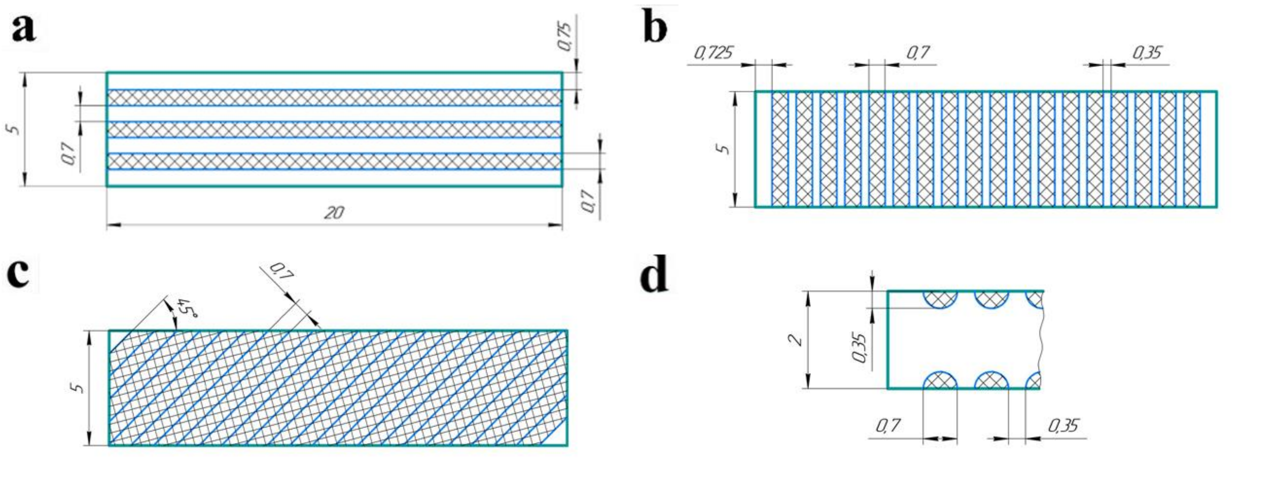

Figure 2 General view of laser treated area: a – case I-I; b – case II-II; c – case III-III; d – cross-section view of laser track case III-II

Two different material properties (for base material and laser-treated tracks) were used for the FEA model (**Table 3**). Tensile test was done according to ISO 6892-1:2019 [7]. Boundary conditions of the modelling scenarios: one side of the plate, fixed, 0 degree of freedom; second side of the plate – displacement, 1 degree of freedom. The maximum applied force was 3750N (**Figures 3, 4**).

Table 3 Mechanical properties of base metal and laser treated layer used to FEA simulation [9,10,11]

Material	Modulus of Elasticity E (GPa)	Shear Modulus G (GPa)	Yield strength $\sigma_{0.2}$ (MPa)	Ultimate Strength σ_B (MPa)
Base metal	212	82.1	550	600
Laser treated layer	262	101.7	660	720

Tetrahedral elements were used to mesh the model of the metal thin sheet plate. The mesh size was from 0.55 to 0.95 mm. The numerical investigation of the physically nonlinear problem was solved for the bending case. A relatively simple plasticity model (Bilinear Isotropic Hardening model) was used [8,12].

The stress-strain curves of the basic metal and the treated layer are provided from experimental data, but the dependences of the nonlinear part of the curves are simplified to linear, as is customary with the Bilinear Isotropic Hardening model. [8].

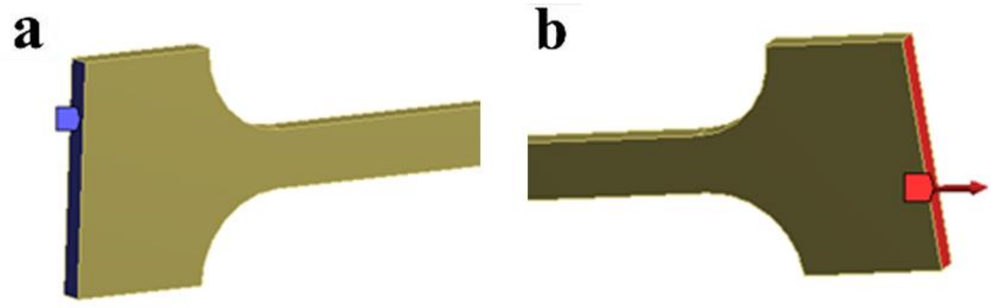

Figure 3 a – fixed support; b – applied force loads

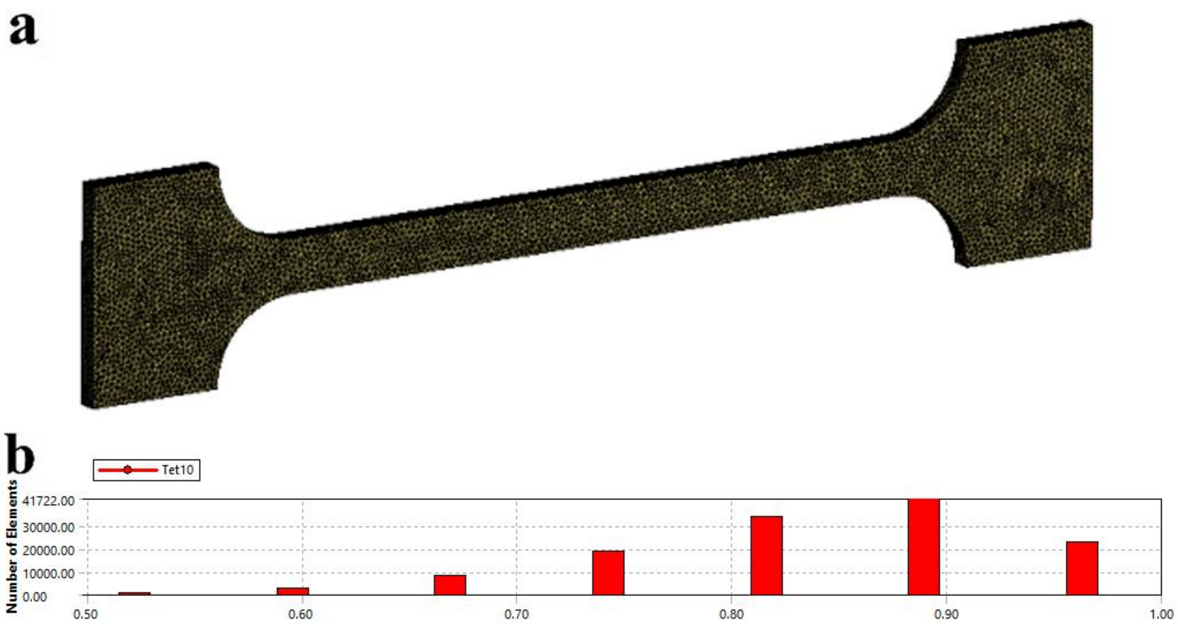

Figure 4 a **-** 3D meshing model; b – number of meshing elements

5. RESULTS

The results of the FEA simulationand their analysis (**Figures 5-8**, **Table 4)** shows that the greatest strengthening effect was achieved when the sheet steel was laser treated with overlapping laser tracks under 45 degrees. The difference of achieved maximal Von Mises equivalent stresses in the treated samples to comparison with an untreated thin sheet plate was from 30 % up to 38 %. Differences in the efficiency of the application of laser treatment with overlapping and discontinuous surface treatment (with different distances between laser tracks) were only 2 - 3.5 %. Thus, it is more reasonable to use laser processing with a distance between the tracks of about 0.35 - 0.7 mm, since it requires significantly less energy consumption, which makes the method more economical.

Table 4 Results of FEA simulation of the elastoplastic deformation

Sample	Max.Deformation (mm)	Von Mises equivalent stress (MPa)
Untreated sample (X)	5.7807	410.88
Treated sample I-I	5.5065	543.06
Treated sample I-II	5.4128	550.21
Treated sample I-III	5.2318	553.74
Treated sample II-I	5.4727	535.2
Treated sample II-II	5.3732	537.69
Treated sample II-III	5.1663	548.84
Treated sample III-I	5.2725	546.64
Treated sample III-II	5.2493	551.76
Treated sample III-III	5.1337	565.76

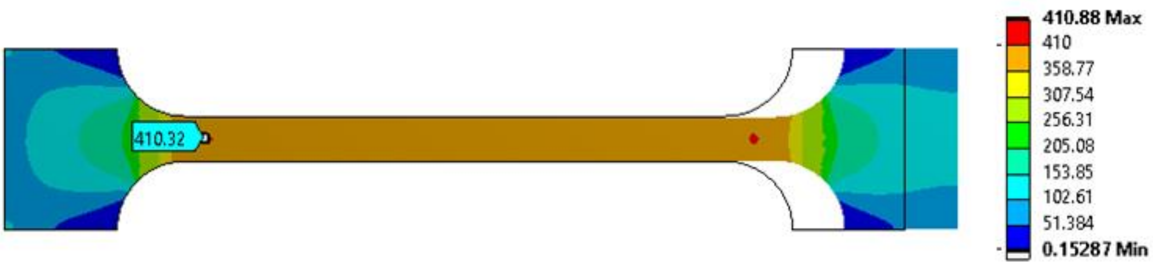

Figure 5 Test sample X: Max. Deformation 5.7807 mm; Von Mises equivalent stress 410.88 MPa

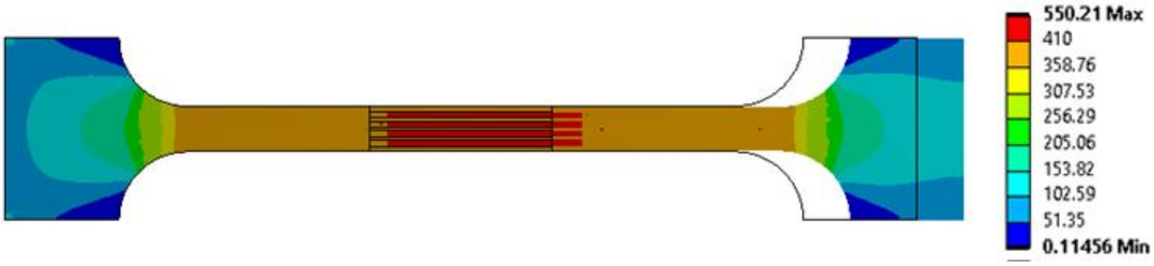

Figure 6 Test sample I-II: Max. Deformation 5.4128 mm; Von Mises equivalent stress 550.21 MPa

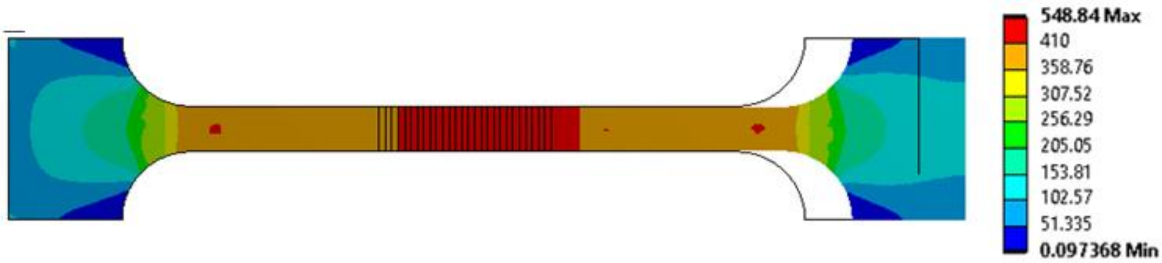

Figure 7 Test sample II-III: Max. Deformation 5.1663 mm; Von Mises equivalent stress 548.84 MPa

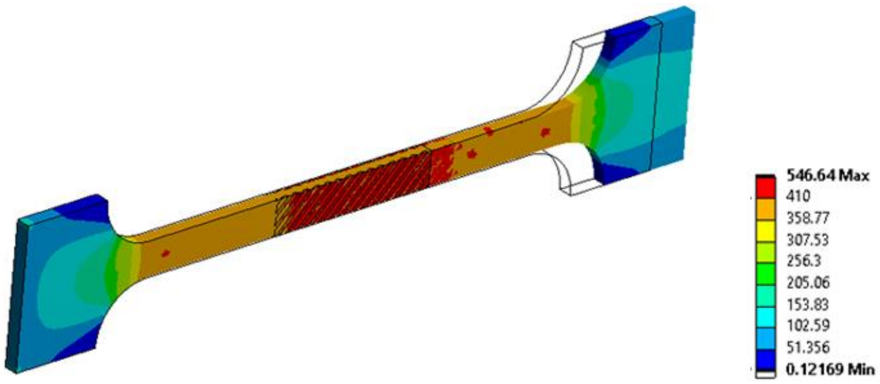

Figure 8 Test sample III-I: Max. Deformation 5.2725 mm; Von Mises equivalent stress 546.64 MPa

6. CONCLUSIONS

The results of FEA simulations of the tensile test established that local laser processing can be used to resist tensile loads thin sheet steel S550MC by up to 38 %, as an alternative to the application of complex geometric shapes or additional strengthening elements.

The FEA method can be used for the prediction of the required laser treatment area - geometry and localization of processed area, depth of laser penetration, orientation, and quantity of laser tracks.

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