FEA ANALYSIS UNDER BENDING LOADS OF THIN STEEL SHEET PLATE WITH DOUBLE SIDE REINFORCING RIBS CREATED BY LASER TREATMENT

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Abstract

The main goal of the study was to determine the effect of local laser treatment on bending stresses under load. The simulation results show that the different locations and number of laser tracks (internal rigidity ribs) on the thin-sheet surface had a influence on the stress distribution under bending loads. Finite element analysis of the equivalent von Mises stresses and bending of thin sheet steels confirms that specimens with internal stiffeners are more resistant to bending loading.

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

1. INTRODUCTION

There is a correlation between the geometry of the structure and the stiffness of thin sheet metal plates in many of these available methods for improving rigidity and strength. More ribs or thickened portions can be added to the thin-sheet metal plate to enhance stiffness, increasing the plate's size and weight. [1].

New metal processing methods emerge annually, allowing for more control and improved metal characteristics. When a new current method called local laser heating is used on a material, it may transform and create zones inside the material with different general characteristics than the rest of the metal structure [2]. The base material can either be melted or heated without melting when using a local laser heat treatment. Laser treatment may be used to modify the microstructure and characteristics of materials, such as increasing their rigidity or toughness [3]. Simply knowing where the stresses are located in a metal structure may have a major impact on its stiffness and bending strength when subjected to a load. Due to the ability to build internal stiffeners through the use of local laser heating, we can greatly enhance mechanical qualities while keeping weight and dimensions constant [4].

The effectiveness of producing reinforcing ribs in thin sheet steel with local laser heating is discussed in the article. The stress distribution under bending loads was studied using a finite element analysis of varied positions and lengths between laser paths.

2. AIM OF THE STUDY

The goal of this study was to establish the influence of laser treatment on bending loads and the number of laser tracks required to significantly improve the bending strength of the material under consideration. This paper presents the results of an FEA simulation and a nonlinear mechanical analysis of the bending stress distribution of thin steel sheets that have been treated with a laser to strengthen them. Steel sheet bending tests under load were modelled in the experiment using the Ansys Workbench 2020 R1 software, which was used in this case.

3. OBJECT OF THE STUDY

The International Organization of Motor Vehicle Manufacturers reported that 80.1 million automobiles would be produced in 2021 [5]. Each vehicle consumes around 900 kg of steel on average. The steel in the vehicle is distributed in a variety of ways depending on the total mass of the vehicle, but we are most interested in the portion of the steel that is used in the body structure, to maintain high strength and energy absorption in the case of an accident - which accounts for approximately 40% of the total weight of the vehicle. When compared to ordinary steel, new grades of Advanced High-Strength Steels (for example, S550MC [6]) enable automakers to cut vehicle component weight by 25-39 % and total vehicle weight by 8-10 %. As a result, the overall weight of a conventional five-passenger family automobile is lowered by 100-150 kg, resulting in an annual savings of 2-3 tonnes in greenhouse gas emissions during the vehicle's entire lifetime. There is a possibility that the reduction in emissions will be greater than the whole quantity of CO_2 released during the manufacturing of all of the steel in the vehicle [7]. Incorporating local laser processing of thin sheet steels into a structure can assist in further reducing its overall weight while retaining the high strength qualities 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 [8]

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

4. METHODOLOGY OF RESEARCH

The bending stress of a laser-treated thin sheet metal plate was simulated using the Ansys Workbench software. The dimensions of the thin sheet metal (100x5x2 mm), the region of laser treatment (20x5 mm) – double side, and the depth of treatment (0.3 mm) are the same in all of the FEA models that have been produced for this project (**Figure 1**). For each specimen, appropriate mesh models of laser-treated thin sheet metal plates were created, with an element quality of more than 0.13 for each specimen and no significantly deformed elements (**Figure 2**).

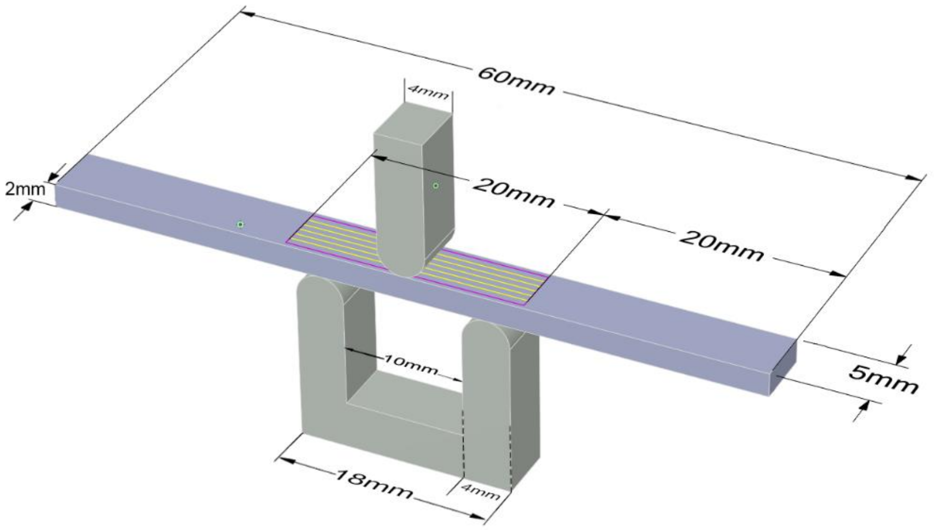

Figure 1 General view of 3D model and bending device

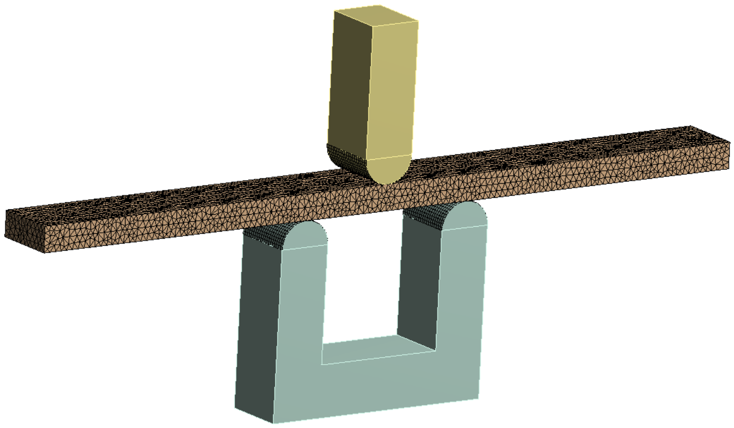

Figure 2 - 3D meshing model.

Three possibilities for positioning the laser-treated region on a sheet sample are shown (strips horizontally, vertically and at an angle of 45 degrees). There are additionally three possibilities for the distances between the laser-treated tracks, which are as follows: (distances of 0 mm, 0.35 mm and 0.7 mm) (**Figure 3, 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
	0	12	I-III
Reinforced strips vertically	0.7	28	II-I
	0.35	36	II-II
	0	54	II-III
Reinforced strip at an angle of 45 degrees	0.7	34	III-I
	0.35	36	III-II
	0	42	III-III
Untreated plate	-	0	X

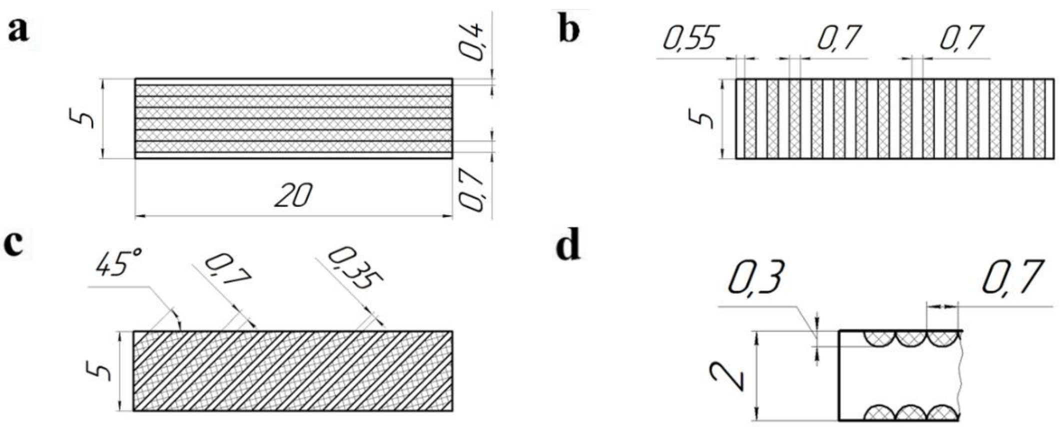

Figure 3 General view of laser treated area: a – case I-III; b – case II-I; c – case III-II; d – cross-section view of laser track case I-III

For the FEA model, two separate properties of the material (for the base material and the laser-treated tracks) were used to represent the tracks (**Table 3**). The bending test was carried out in accordance with ISO 6892-1:2019 [9].

Table 3 Mechanical properties of base metal and laser treated layer used to FEA simulation

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

To mesh the model of the metal thin sheet plate, tetrahedral components were used. The mesh size ranged between 0.55 and 0.95 mm. For the bending instance, the numerical examination of the physically nonlinear problem was solved. The Bilinear Isotropic Hardening model was used as a very simple plasticity model [10,11].

Experimental data are used to generate the stress-strain curves for the basic metal and the treated layer. However, in order to simplify the nonlinear part of the curves to linear dependences, as is customary with the Bilinear Isotropic Hardening model, the nonlinear part of the curves is simplified to linear dependences [10].

5. RESULTS

FEA simulation and analysis (**Figures 4-6**, **Table 4**) revealed that the maximum strengthening effect was obtained when the sheet steel was laser-treated with the reinforced strip at an angle of 45 degrees and a 0 mm distance between them. The difference between the maximum Von Mises equivalent stresses achieved in the treated samples, and the maximum Von Mises equivalent stresses achieved in an untreated thin sheet plate ranged from 15% to 26%. Almost all samples showed the same deflection distance, but the force with which to press on the metal plate increased by 33% (1375 N) compared to the untreated plate (1033 N)

Table 4 Results of FEA simulation of the elastoplastic deformation

Sample	Max. Deformation (mm)	Von Mises equivalent stress (MPa)	Force reaction from bending tool (N)
Untreated sample (X)	6.46	870	1033
Treated sample I-I	6.46	1005	1092
Treated sample I-II	6.45	1026	1124
Treated sample I-III	6.44	1079	1165
Treated sample II-I	6.46	1039	1118
Treated sample II-II	6.45	1060	1130
Treated sample II-III	6.44	1075	1178
Treated sample III-I	6.46	1072	1154
Treated sample III-II	6.45	1074	1155
Treated sample III-III	6.43	1100	1375

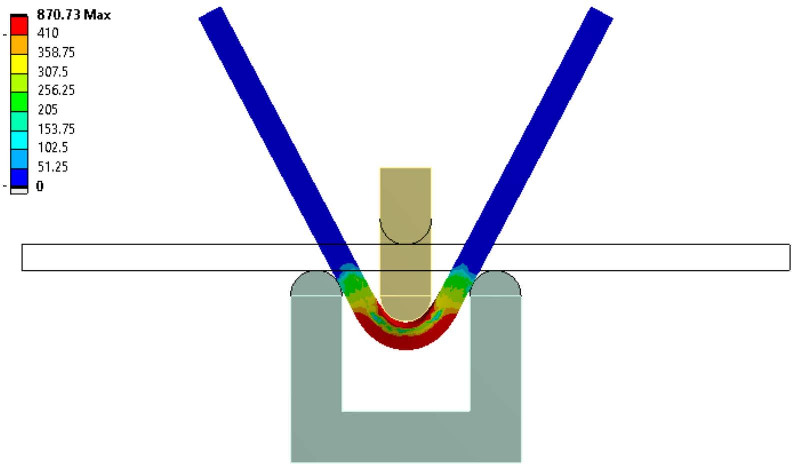

Figure 4 Test sample X: Max. Deformation 6.46 mm; Von Mises equivalent stress 870 MPa; Force reaction from bending tool 1033 N.

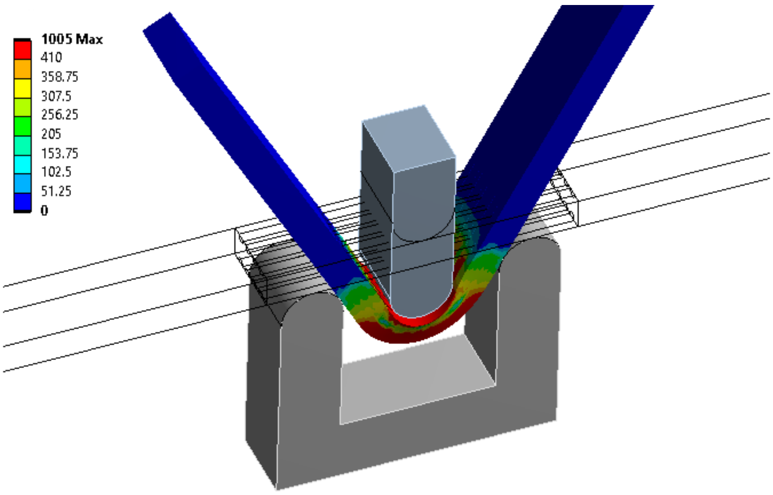

Figure 5 Test sample I-I: Max. Deformation 6.46 mm; Von Mises equivalent stress 1005 MPa; Force reaction from bending tool 1092 N.

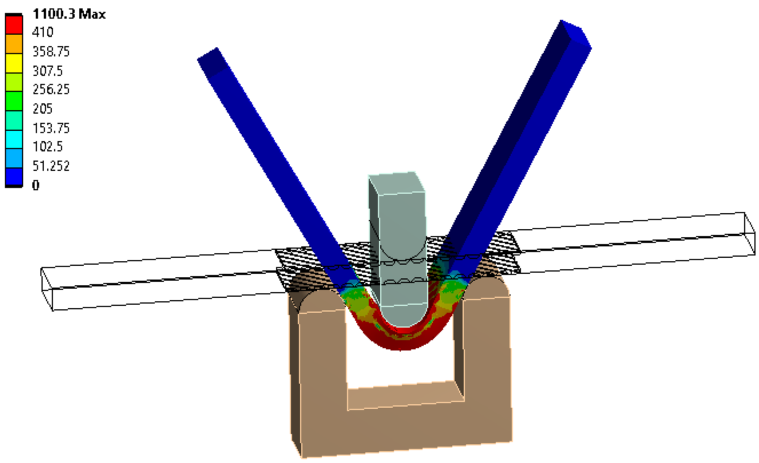

Figure 6 Test sample III-III: Max. Deformation 6.43 mm; Von Mises equivalent stress 1100 MPa; Force reaction from bending tool 1375 N.

6. CONCLUSIONS

After performing finite element analyses on thin sheet steel S550MC bending test results, it was discovered that local laser processing could increase the resistance to bending loads by up to 26% as an alternative to the application of complex geometric shapes or the addition of additional strengthening elements.

The FEA approach may be used to determine the needed laser treatment area, including the geometry and location of the treated area, the depth of laser penetration, the orientation of the laser tracks, and the number of laser tracks.

REFERENCES

[1] JÄRVENPÄÄ, A., JASKARI, M., HIETALA, M., MÄNTYJÄRVI, K. Local Laser Heat Treatments of Steel Sheets. *Physics Procedia*. 2015, vol. 78, pp. 296-304.

[2] KAPUSTYNSKYI, O., VIŠNIAKOV, N. Laser treatment for strengthening of thin sheet steel. *Advances in materials science and engineering, Hindawi.* 2020, pp. 1-13. Available from: https://doi.org/10.1155/2020/5963012.

[3] ZHANG, W., TAO, J., JING, L., LIQIANG, L. Effect of Laser Heat Treatment on the Microstructure and Properties of Alloy 800h. *Metals 9, no. 3*. 2019. https://doi.org/10.3390/met9030379.

[4] KAPUSTYNSKYI, O., VIŠNIAKOV, N., ČERNAŠĖJUS, O., GOLOVKO, L., CHAYEUSKI, V. Optimization of the Parameters of Local Laser Treatment for the Creation of Reinforcing Ribs in Thin Metal Sheets. *Proceedings of 24th International Conference "MECHANIKA 2019".* 2019, pp. 71-75.

[5] Oica.net. *2021 Statistics* [online]. [viewed 2022-04-25] Available from: https://www.oica.net/category/production-statistics/2021-statistics/.

[6] BIAN, J., HARDY, M., JIAN-SU, Z., YUN-TANG, Z., HONG-ZHOU, L., HAN, D. Application Potential of High Performance Steels for Weight Reduction and Efficiency Increase in Commercial Vehicles. *Advances in Manufacturing 3*, *no. 1*. 2015, pp. 27–36. https://doi.org/10.1007/s40436-015-0102-9.

[7] Worldsteel.org. *Steel In Automotive* [online]. [viewed 2022-04-25] Available from: https://www.worldsteel.org/steel-by-topic/steel-markets/automotive.html.

[8] European Committee for Standardization. EN 10149-2:1996: *Specification for hot-rolled flat products made of high yield strength steels for cold forming*. CEN: Brussels, Belgium, 1996.

[9] International Organization for Standardization. ISO 6892-1:2019: *Metallic materials—Bending Testing.* International Organization for Standardization: Geneva, Switzerland, 2019.

[10] Fea-cae-engineering.com. *Element Types* [online]. [viewed 2022-04-25] Available from: http://fea-cae-engineering.com/FEA-CAE-Engineering/element_types.htm.

[11] JONES, R. *Deformation Theory of Plasticity*. Blacksburg, Va.: Bull Ridge Pub, 2009.