LASER WELDING OF SIMILAR AND DISIMILAR LAP JOINT - PROCESS ANALYSIS

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Abstract

The article presents the results of research concerning laser lap welding of similar and dissimilar joints. Research was performed using two commonly used materials: austenitic stainless steel in grade 316L and structural ferritic-perlitic S355J2 steel. Developed joints obtained only partial penetration of the down material. Welding parameters were estimated based on numerical simulation using Simufact Welding software. Metallographic macro and microstructure were part of solution. High convergence of numerical simulation to experiments were shown. Results of calculation of maximum stresses and equivalent plastic deformations demonstrate advantages of welding dissimilar joints using stainless steel.

Keywords: Laser welding, lap joints, similar and dissimilar joints, numerical analysis, metallurgical analysis

1. INTRODUCTION AND CHARACTERISTIC OF USED MATERIALS

Laser welding of similar and dissimilar lap joint often result in different results, according to the type of welded materials and welding parameters. For solution of problem welding parameters were chosen, based on numerical simulation using Simufact Welding software. Test joints were made according to parameters from simulation and compared with each other [1]. Numerical analysis including the study of stress and strain states showed significant differences in the properties of the joints. Therefore, metallographic studies were carried out, which presented an evaluation of the macro and microstructure, as well as an analysis of the distribution of alloying elements by using electron-dispersive spectroscopy (EDS). Studies of lap joints in different configurations resulted in different conclusion. Therefore, the aim of work is to find the behavior of steel 316L and structural steel S355J2 after laser welding, especially structural differences in the distribution of stresses and strains, and significant differences in the structure of welded joints [2]. Some advantages of configuration using of stainless steel as a top material were supposed. as well as potential problems during the welding of lap joints.

Table 1 Chemical compossition of welded materials

Material	Content (%)								
	C	Mn	Si	P	S	Cr	Ni	Fe	CEV
S355J2	0.17	1.6	0.02	0.017	0.011	0.02	-	98.1	0.45%
316L	0.018	1.57	0.48	0.04	0.002	16.7	11.2	balanced	-

The materials used in the study were steel sheets 4 mm thick in S355J2 and 316L grades, with dimensions of 70 x 30 mm. S355J2 steel is a common, unalloyed, low-carbon structural steel with a ferritic-pearlitic structure. The second material was austenitic stainless steel of 316L grade. Both steels have good weldability, however, differences in chemical composition (**Table 1**) affect the welding process and joint properties, especially for dissimilar joints.

Used materials are differ, both in chemical composition and in their thermophysical properties, moreover, these properties change with temperature affected on the laser beam absorption and process dynamics. The simulations used material libraries available in Simufact Welding software.

2. NUMERICAL ANALYSIS OF LASER WELDING OF LAP JOINTS

The most important aspect of numerical simulation is defining a numerical model, which consists of welded parts geometry divided into finite elements (FE). Moreover, orientation of this part in the workspace, the heat source geometry and welding trajectory is very important as well. Therefore, the boundary and initial conditions were defined, and the type of numerical analysis was determined (**Figure 1**) [3]. In research presented in this article, numerical calculations were based on thermo-mechanical analysis.

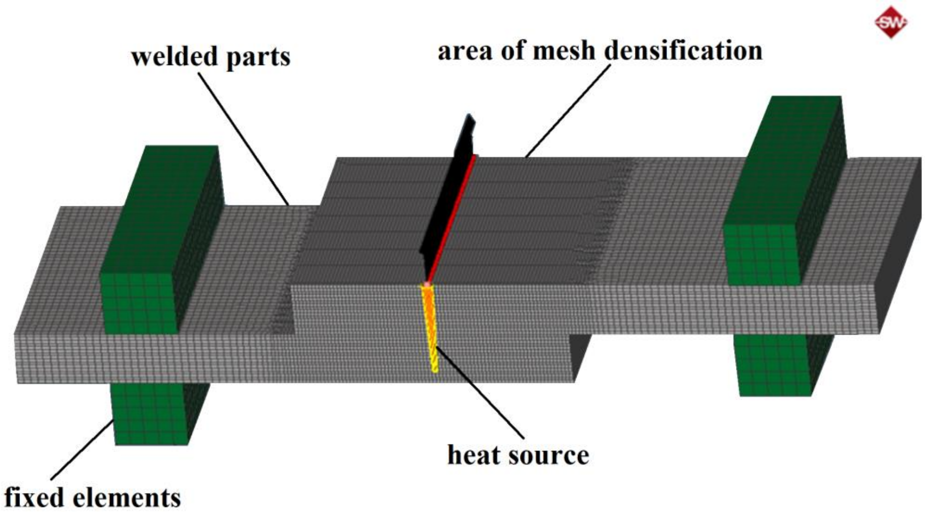

Figure 1 Numerical model

The definition of the numerical model began with a heat source calibration procedure and mesh convergence examination. A volumetric conical heat source with Gaussian power distribution was used as the heat source. In addition to the conical source, which simulates keyhole effect inside welded materials, a surface disc shape heat source was used to simulate surface absorption of the laser beam (**Figure 2**) [4].

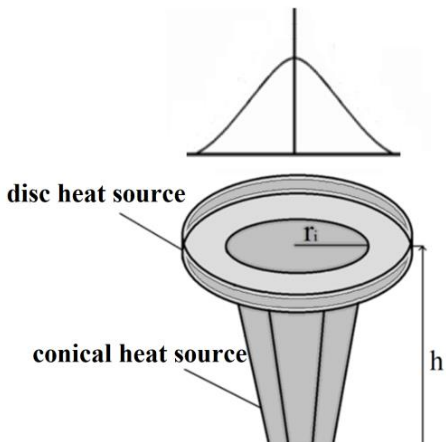

Figure 2 Heat source model

3. RESULTS OF NUMERICAL ANALYSIS

Based on the laser welding parameters, calculated by the numerical simulations, test joints were performed. To determine the correctness of the simulation results, calculated weld shapes were compared with the geometries of the experimentally obtained weld joints (**Figure 3**).

Figure 3 shows comparisons of the calculated geometry based on isotherms distribution with the shape of welds from test joints. Results was presented for three lap welds configuration: a) a similar joint of structural steel in grade S355J2, b) a dissimilar joint in the configuration of austenitic S355J2 steel as a down material and 316L as a top material, c) a dissimilar joint in the configuration of 316L steel as a down material and S355J2 as a top material. As can be seen in **Figure 3**, a high correspondence between simulation results and experimental results was achieved. The differences in the shape of the welds results from adopted simplifications of the numerical model, which consider the phenomena of convection and radiation in the energy balance, but do not consider the mixing of the liquid metal.

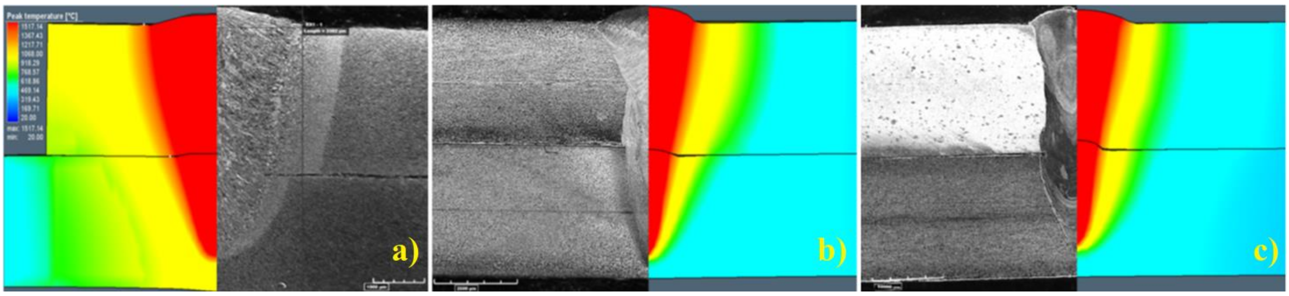

Figure 3 Comparison of simulation and experimental results

Assuming that a high correspondence between the simulation and experimental results is obtained, an analysis of the state of stresses and strains in the joint areas was carried out.

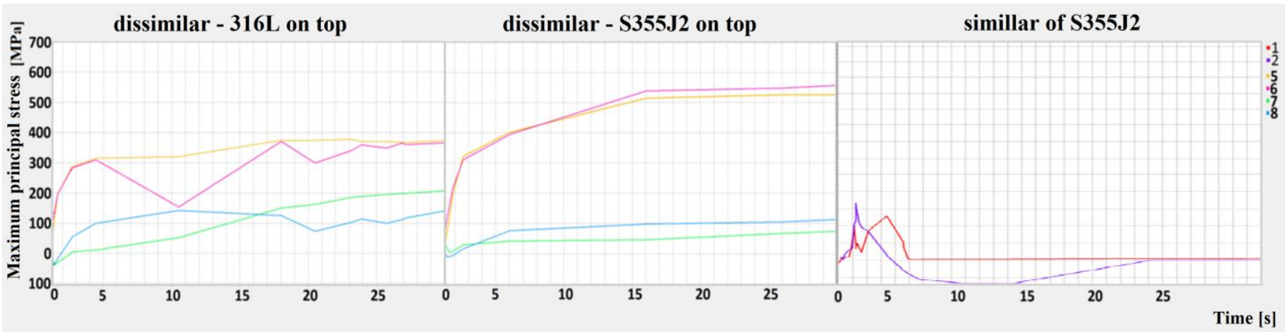

Figure 4 Graph of changes maximum principal stresses changes between welded materials inside welds

Graphs from **Figure 4** presents the maximum principal stresses values, calculated for space between sheets with points 1,2,7 and 8 referring to the weld area (1.5 mm from the weld axis), while points 5 and 6 on the graph for the dissimilar joint for a distance equal to 3mm from the weld axis. As can be seen in the stress values on the bottom surface of the plate do not exceed 180 MPa and are comparable for all considered welding variants. However, increasing distance a stress values increase, especially for austenitic steel in a dissimilar joint, when the 316L steel sheet is at the bottom of the joint (stresses like to 550 MPa) [5].

Larger differences in the results obtained were shown in the dissimilar joints, so the study of effective plastic deformation was carried out for these joints.

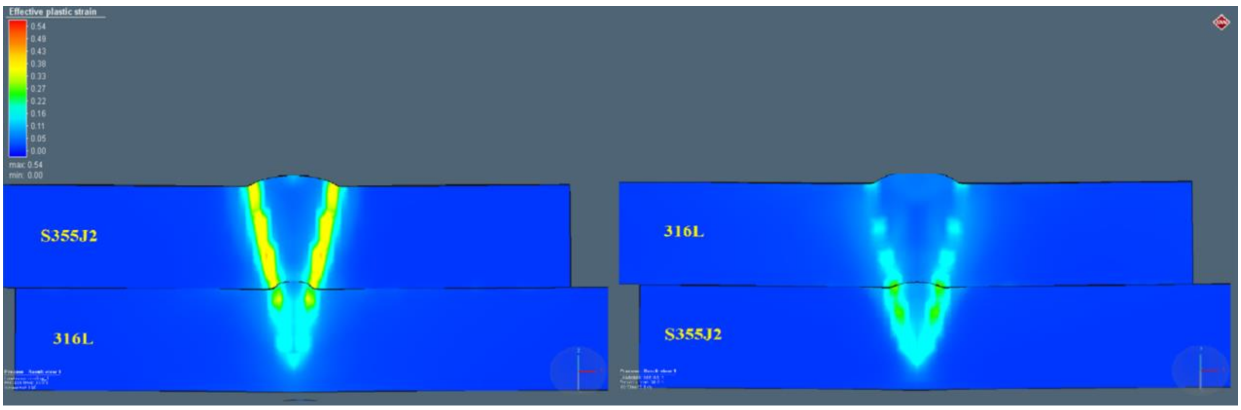

Figure 5 Effective plastic deformation map distribution in dissimilar joints

The analysis of the strain distribution maps in showed significant changes, depending on the position of the welded materials. Greater values of effective plastic strain occur in the joint when the structural steel was at the top (0.45), while when the austenitic steel was at the top, these values did not exceed 0.33. Considering stresses and strains distribution in welded joints, in the case of a dissimilar joint, the joint which austenitic steel is located as the top material, shows better properties.

4. METALLOGRAPHIC ANALYSIS

Due to inconclusive results of numerical analysis, metallographic tests were carried out in order to evaluate changes of joints structure. The tests were carried out on samples taken from the test joints, which were then polished and etched with Mi19Fe reagent. For all three welding variants, an evaluation of the characteristic areas of the joints was performed: the base material (BM), the heat affected zone (HAZ) and the weld. The microstructure results of the characteristic areas are shown in **Figure 6**.

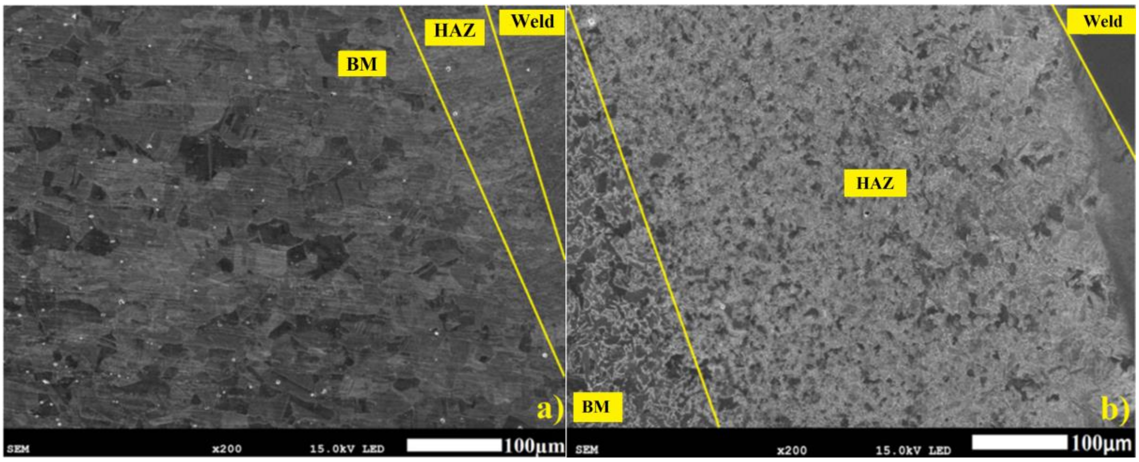

Figure 6 Microstructure of welded joints characteristic areas

Figure 6 shows the structure of characteristic joints areas, where: (a) austenitic stainless steel in grade 316L, (b) unalloyed carbon structural steel in grade S355J2 was presented. **Figure 6a)**, presents a typical austenitic structure of the base material of 316L steel, with a narrow heat-affected zone, where austenite grains forming along the fusion line in the place of ferrite concentration, and a weld. While **Figure 6b)** shown a ferritic-perlitic structure of the base material of S355J2 steel, which is characteristic of structural steels, and a wide HAZ with 3 regions: superheat (near the fusion line), normalization and partial recrystallization [6]. In both cases, the welds are characterized by a dendritic structure.

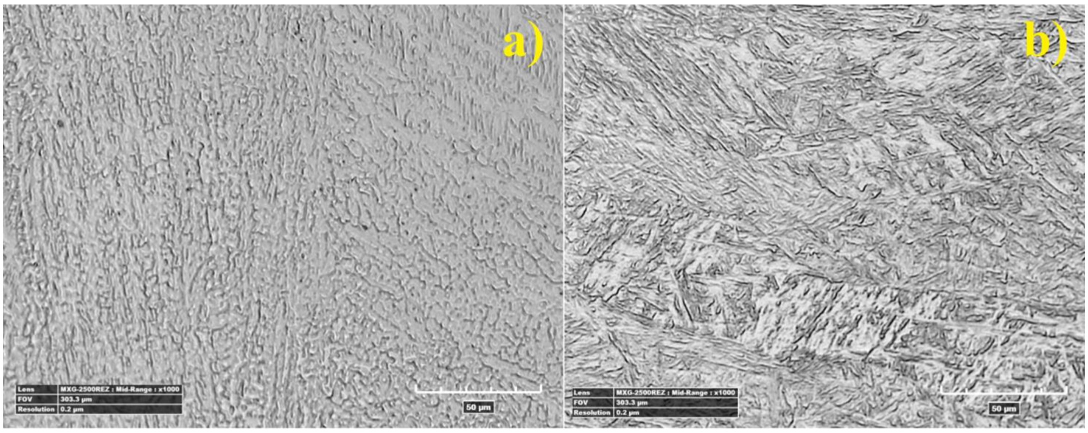

Figure 7 Microstructure of welded joints

Figure 7 shows the structure for the welded materials in top regions for both configurations. The structures are typical dendritic for both joints configuration, however with different grain size and orientation. However, during the analysis, areas of uneven mixing of alloying elements were detected, especially in the weld ridge area. Therefore, a study of the linear distribution of alloying elements such as iron, nickel and manganese were performed (**Figure 8**). Tests are presented for the lower region of the welds counting from the area between the welded sheets down to the fusion boundary at the bottom (weld ridge).

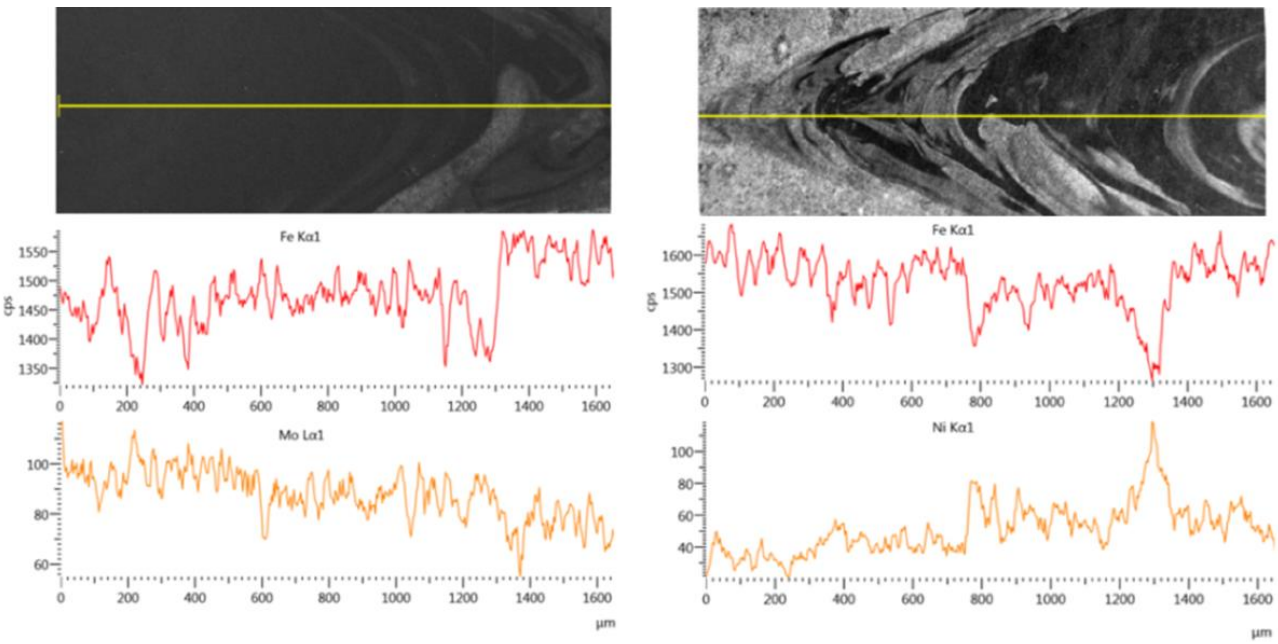

Figure 8 Graphs of the linear distribution of alloying elements in the weld axis in the ridge area

Carried out tests showed a lack of uniform mixing of the elements of the two welded materials. This is due to the disruption of the flow field of the molten material during the solidification process. The biggest difference was observed in the case of the linear distribution of nickel. More uniform mixing occurred when the top material was stainless steel.

5. CONCLUSION

The conducted tests and analyses showed high convergence of numerical simulations to experimental tests. The presented results of calculations of maximum principal stresses and equivalent plastic deformations demonstrate the advantages of welding dissimilar joints using stainless steel as the top material. Metallographic studies confirmed the advantage of using this configuration of the uniformity of mixing of alloying elements in the weld area.

ACKNOWLEDGEMENT

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LITERATURE

[1] STEEN, W. M., MAZUMDER, J. Laser Material Processing. *Springer.* 2010.

[2] SHANMUGAM, N. S. et. all. Experimental Investigation and Finite Element Simulation of laser lap welding of SS304 sheets. *International Journal of Mechanics.* 2013, vol. 7, pp. 120-127.

[3] KIK, T. Computational Techniques in Numerical Simulations of Arc and Laser Welding Processes. *Materials.* 2020, vol. 13, p. 608.

[4] DANIELEWSKI, H., SKRZYPCZYK, A., et. all. Numerical and Metallurgical Analysis of Laser Welded, Sealed Lap Joints of S355J2 and 316L Steels under Different Configurations. *Materials*. 2021, vol. 13, pp. 1-22.

[5] HIETALA, et. all. Tensile and fatigue properties of laser-welded ultra-high-strength stainless spring steel lap joints. *Procedia Manufacturing*. 2019, vol. 36, pp. 131–137.

[6] PRABAKARAN, et. all. Microstructure and mechanical properties of laser-welded dissimilar joint of AISI316 stainless steel and AISI1018 low alloy steel. *Caribbean Journal of Science*. 2019, vol. 53, pp. 978–998.