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PROPERTIES AND MICROSTRUCTURE OF LASER WELDED DISSIMILAR JOINTS OF TP347-HFG AND S235JR STEELS WITH ADDITIONAL MATERIAL

Paper presents results of laser welding of dissimilar joints. Flange pipe joints of austenitic TP347-HFG and low carbon S235JR steels were performed. Possibility of laser girth welding of dissimilar joints was presented. Welding of dissimilar materials are complex phenomena, chemical composition of chromium and nickel base austenitic steel with carbon amount of 0.07%, comparing to low carbon steel with trace amount of chromium, nickel and with 0.17% of carbon are different, and affect on welding result. Amount of carbon and chromium have great effect on steel phase transformation and crystallization process, which affect on material hardenability and strength characteristic. In conventional GMA welding methods solidification process of different metals is controlled by use of a selected filler material, for creating buffer zone. The main advantages of laser welding over other methods is process without an additional material, nevertheless some application may require its use. Laser welding with additional material combines advantages of both methods. To carry out weld with high strength characteristic, without welding defects, selecting chemical composition of filler wire are required. Welding parameters was obtained using numerical simulation based on Finite Element Method (FEM). Joint properties was investigated using hardness test. Metallographic analysis of obtained weld was carried out using optical microscopy and energy dispersive spectroscopy (EDS) analysis.

Keywords: Laser welding, dissimilar joints, TP347-HFG and S235JR steels, additional material, metallographic structure

1. Introduction

Laser welding is nonconventional method of joining using concentrated energy of focused photons to melt and join materials. Energetic as well as gas installation require high quality level of obtained joint. Laser technology enables obtaining dissimilar joint without additional material. Nevertheless additional material as a buffer can be used. Joint properties by selecting chemical composition of filler wire, can be changed [1-3].

Welding process are complex phenomena, especially when dissimilar joint is being considered. Analytical and numerical methods are widely used for estimating dimension of fusion zones. Simple case consider analytical solution, using Rosenthal equation to solving moving heat source problem, however, for calculating dissimilar joint, numerical methods are required. Using numerical simulation fusion zone as well as some joint properties can be calculated. In presented paper using numerical method for simulation of dissimilar stainless TP347-HFG and low carbon S235JR steel welding, with additional material was proposed. Welding dissimilar joint with additional material require considering phase transformation of three different materials, creating fusion zone. Simulation of laser welding was used for estimating parameters of complete weld penetration in flange pipe configuration [4-6]. Numerous study of laser welding of dissimilar joint is conducted by researchers, nevertheless laser welding with additional material is not completely explored, specially for changing joint properties. Moreover numerical simulation of laser welding with additional material are complex phenomena, where programming of heat source geometry and boundary conditions are problematic, therefore, investigation of this problem was obtained via this paper [7-10]. Results of numerical simulation were investigated experimentally. To define structure of obtained joint, metallographic analysis was performed. Paper presents results of numerical simulation and experimental validation of LBW of flange pipe dissimilar joint, with filler wire as an additional material (Fig. 1).

Materials in joint configuration are characterized as good weldable, nevertheless welding austenitic with ferritic-pearlitic steels is problematic, and research of using additional material for this application is presented.

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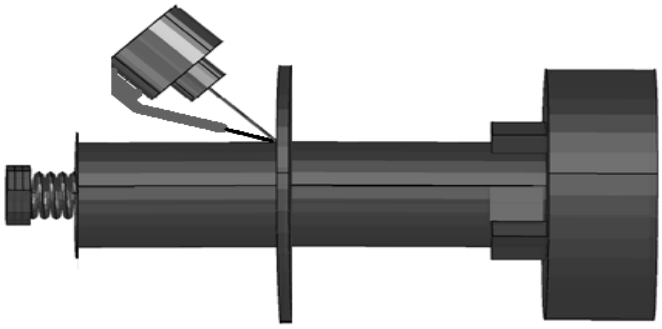

Fig. 1. Experimental scheme of flange fillerrotary joint

2. Numerical simulation of welding dissimilar joint

Parameters of laser welding with complete penetration, using numerical simulation were estimated. Trial joint welding, using high power CO_2 laser was performed. Process parameters were based on laser machine specification, assumed output power, as maximum power generated by welding system, equal to 6 kW. Speed rate of welding was tested in range 600-2000 mm/min, with step 200 mm/min. For simulation SimufactWelding software, dedicated for welding applications was used. SimufactWelding based on Marc solver engine use simplifying in calculation of some physics phenomena, therefore, relatively quick results can be received. For laser welding simulation two volumetric heat sources were used. Conical heat source, simulating keyhole effect and disc shape heat source, simulating laser beam absorption via surface (Fig. 2).

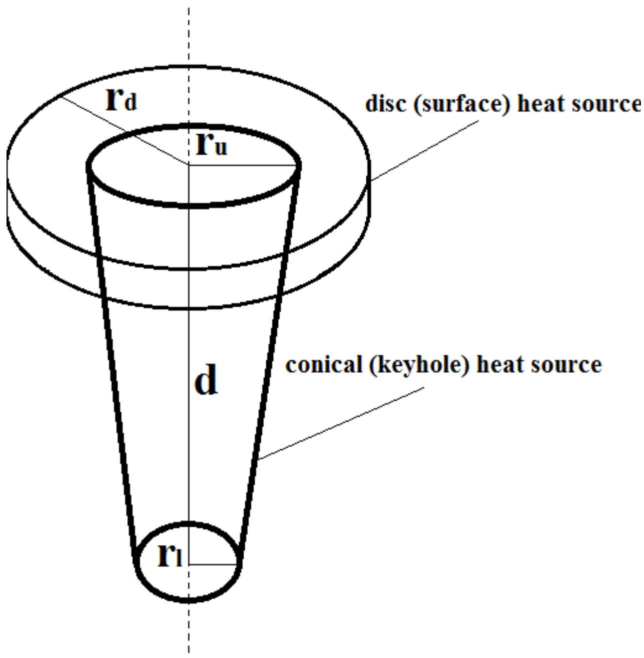

Fig. 2. Laser welding heat sourcesgeometries

Using thermo-mechanical simulation with phase transformation fusion zone, as well as joint properties such as stress-strain, hardness distribution and fraction of material structure, can be calculated. In boundary condition rigid fixing geometries were used, material library of steels and additional material, with properties changing with temperature were programmed. Meshing of components (steel pipe with outer diameter 50 mm, and wall thickness 6mm, and sheet with thickness of 6 mm) was performed using ring mesh method and refining of the finite element size, near the fusion zone area. According to programmed boundary conditions, simulation of laser welding of dissimilar joint was performed (Fig. 3).

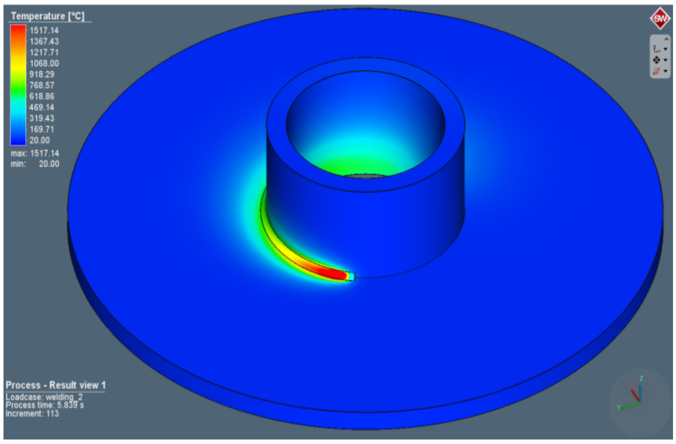

Fig. 3. Numerical simulation of laser flange pipe joints welding

Based on carried out laser welding simulation, parameters for complete penetration were calculated. For output power equal to 6 kW and welding speed of 900 mm/min, complete penetration of flange pipe joint with filler fire was obtained (Fig. 4).

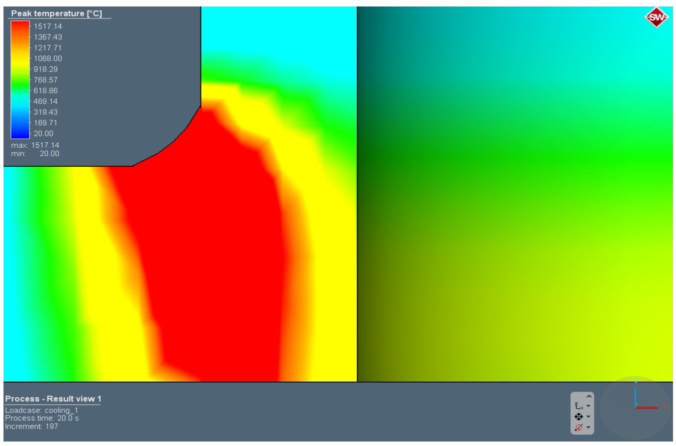

Fig. 4. Fusion zone in cross section obtained from simulation

Using numerical simulation based on thermo-mechanical solution, material properties, such as hardness can be calculated. For dissimilar joint of TP347-HFG and S235JR steels with additional material in grade 309L, hardness distribution was calculated (Fig. 5).

Simulation results shown differences in hardness of welded materials, heat affected zone (HAZ) are differ, higher conductivity of low carbon steel affect in wider hardening area.

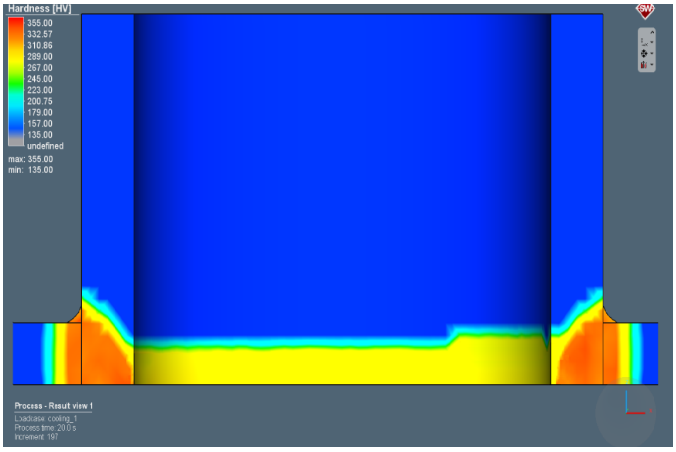

Fig. 5. Hardness distribution of obtained joint based on numerical simulation

3. Laser welding of dissimilar joint

Laser circumferential welding of TP347-HFG and S235JR steels with 309L filler wire of 1.2 mm diameter, used as an additional material was performed. Welding device was high power CO_2 laser Trumpf TruFlow 6000 with maximum power of 6 kW, integrated with TruLasercell 1005 work center, with rotary axis and filler wire feeder system.

TABLE 2

Laser welding parameters

Welded materials	Type of laser	Power [kW]	Velocity [mm/min]	Wire feed rate [mm/min]	Frequency [kHz]
TP347-HFG S235JR	CO_2	6	900	900	50

Pipe and disc shape sheet plate was fix on developed positioner, with one side spring clamp. In order to reduce ionization effect as a shielding gas, helium conveyed coaxially in welding head, with flow rate 20 l/min, and argon for shielding root of weld were used [11]. Trial joint was performed using welding head with focal length equal to 270 mm. Welding was performed in forced position, due to limitation of welding head orientation (Fig. 6). In table 2 welding parameters were presented. Metallographic structure of used material were differ, therefore, threat of solidification instability were reduced using additional material, which changing weld properties. No preheating treatment was performed.

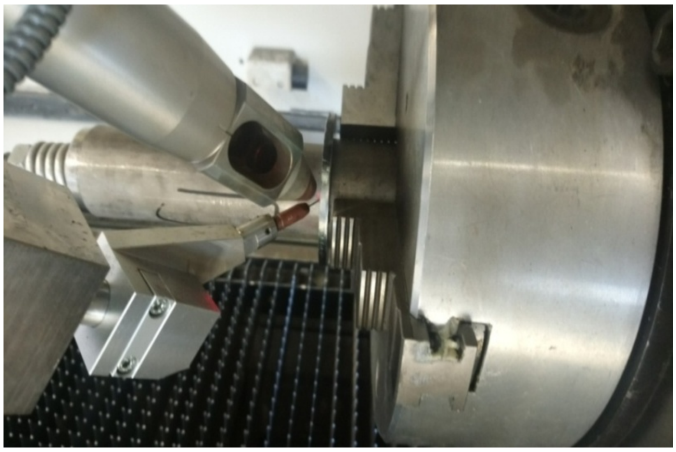

Fig. 6. Circumferential laser welding offlange filler joint

Obtained results refer to joints without postweld heat treatment. Weld with proper build, no visual defects and dimension similar to simulation result was obtained (Fig. 7).

Macrostructure analysis of obtained joint was performed using confocal digital microscope Hirox KH-8700, with magnification of ×35. High fusion zone mixture ratio (Fig. 7) with no visual defects, neither lack of fusion or cracking detection was obtained. Results of trial joint and numerical simulation shown some differences in weld shape, face of weld geometry are similar as well as root of weld width, nevertheless, weld waist are differ and it can be related to assumed heat source energy distribution factor and properties of welded materials.

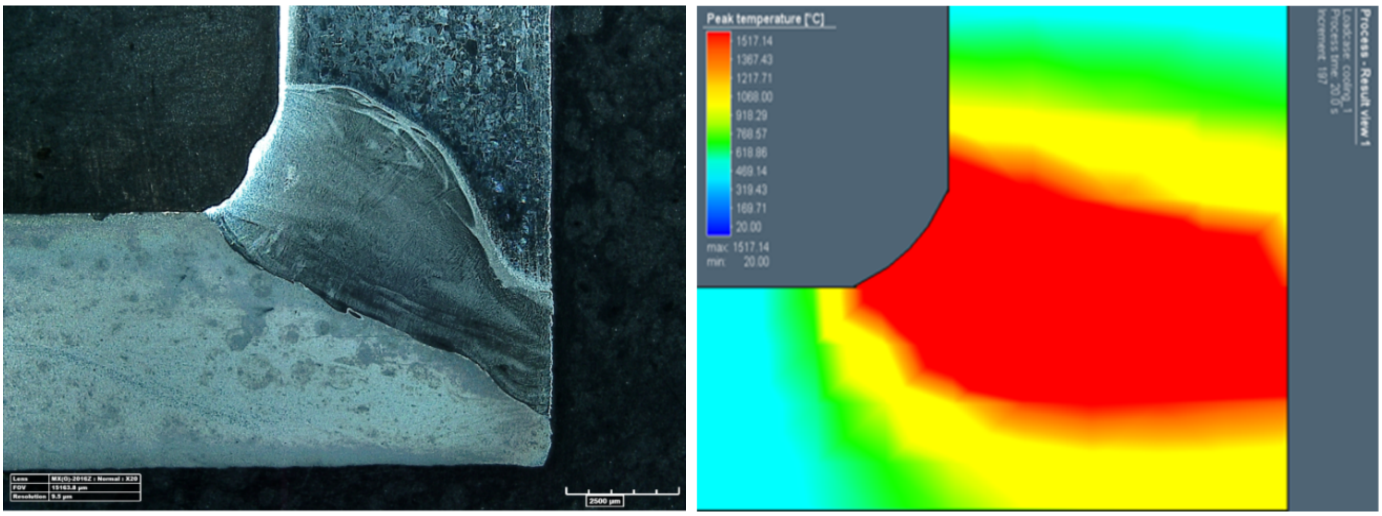

Fig. 7. Fusion zone in cross section – experimental and simulation result

4. Hardness distribution test

In order to investigate hardness, according to PN-EN ISO 6507-1 [12] test was performed. Fig. 8 shown measurement point distribution and hardness results.

Hardness test shown substantial strengthening in weld, and small in HAZ. Hardness distribution is slightly different, for austenitic steel are almost linear in BM and HAZ, in low carbon steel some strengthening in HAZ was observed. Simulation results of hardness distribution shown values not exceed 320 HV, nevertheless, fusion mechanism of base and additional materials affect on crystallization process, chemical compounds such as chromium, molybdenum, iron, carbon and manganese affect on hardenability, and strength characteristic of obtained joint. According to PN-EN ISO 15614-11, maximum allowable limit of Vickers hardness HV10 after welding is 380, however results shown values approximating 445 HV10. According to standards obtained maximum value of hardness exceed allowable hardness, and for B quality level post welded heat treatment are required.

5. Metallographic test

Metallographic analysis was performed according to PN-EN ISO 17639 [13], where micro and macroscopic tests using Hirox KH-8700 confocal digital microscope and JSM 50 scanning electron microscope were carried out. Microstructure of obtained joint was presented.

Images of BM, HAZ and weld microstructures for laser welded TP347-HFG and S235JR dissimilar joint were presented. Fig. 9 shown microstructure of TP347-HFG and S235JR – BM, Fig. 10 shown microstructure of HAZ. Typical dendritic structure of weld was observed (Fig. 11), where grain refining in structure of austenitic steel and grain growth in ferritic-pearlitic steel in HAZ were shown [14,15].

Metallographic structure are related to fusion mechanism and phase transformation of additional and base materials, and their chemical compositions. Therefore, microstructure of weld results from multiphase mixture of ferritic-pearlitic and austenitic steels as well as 309L grade filler wire. To confirm uniform weld structure, quality and quantity EDS analysis were carried out (Fig. 12-20).

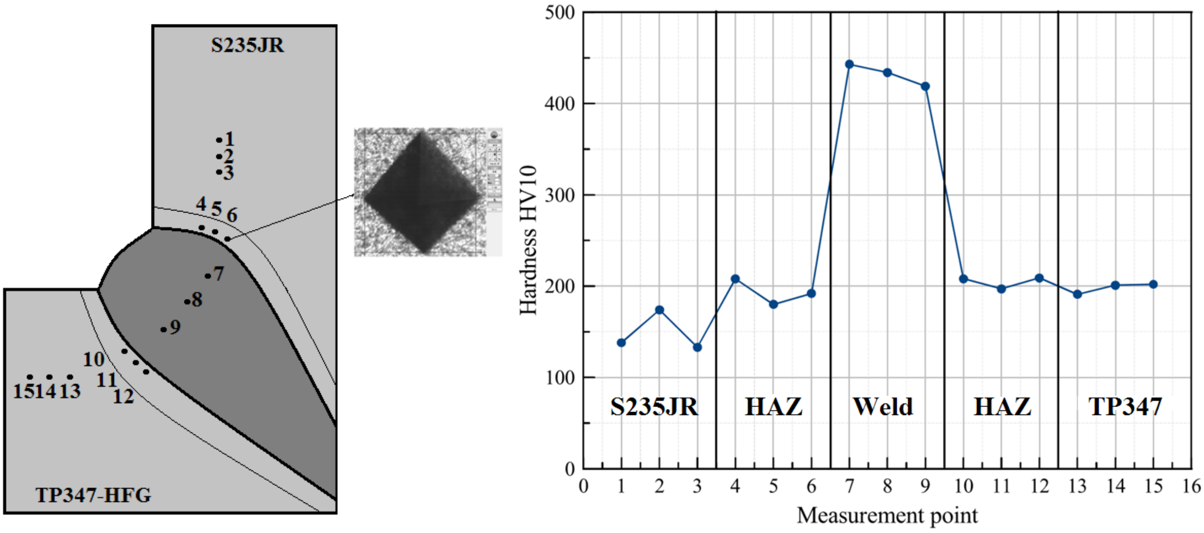

Fig. 8. Hardness distribution in cross-section of weld

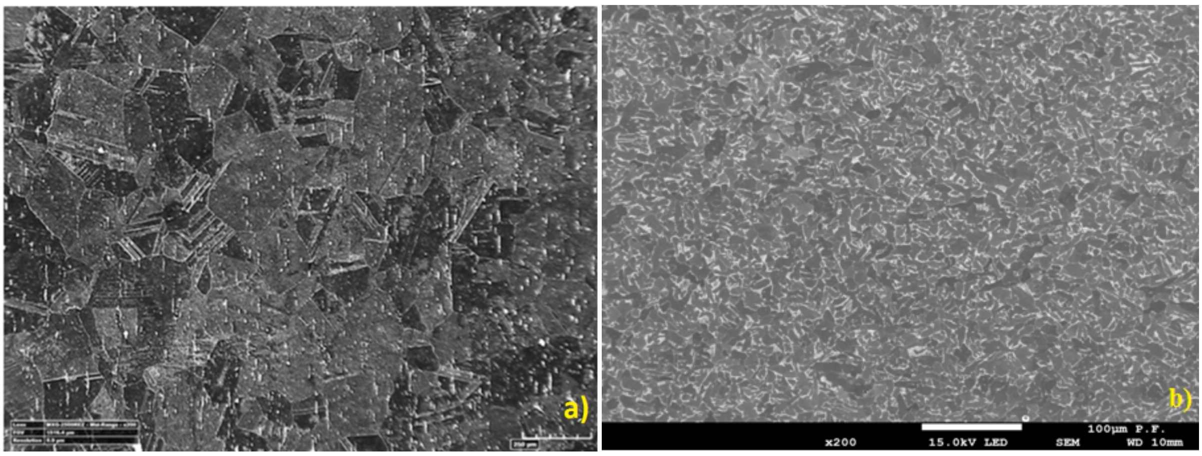

Fig. 9. BM microstructure: a) TP347-HFG, b) S235JR, magnification of ×200

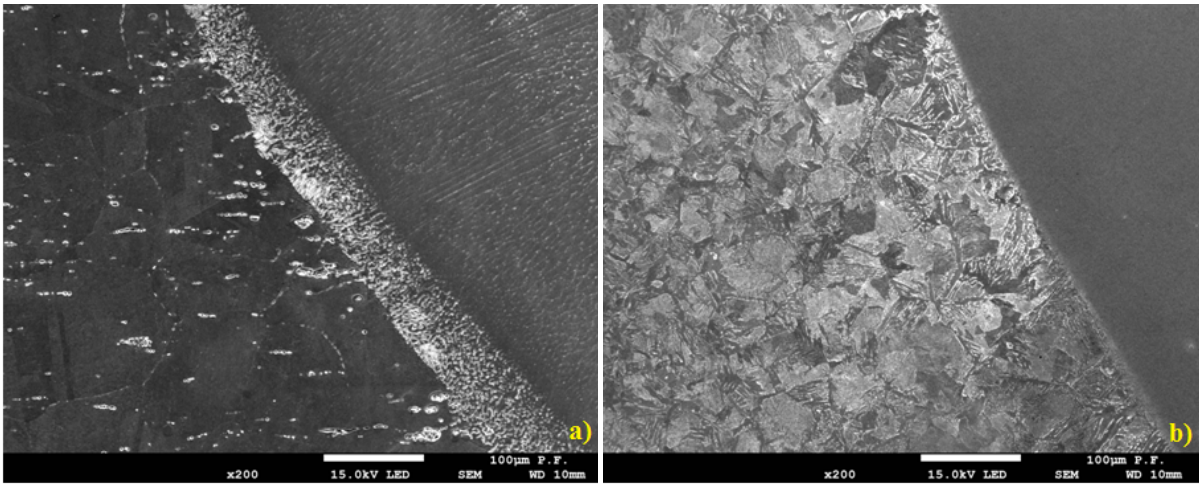

Fig. 10. HAZ microstructure: a) TP347-HFG, b) S235JR, magnification of ×200

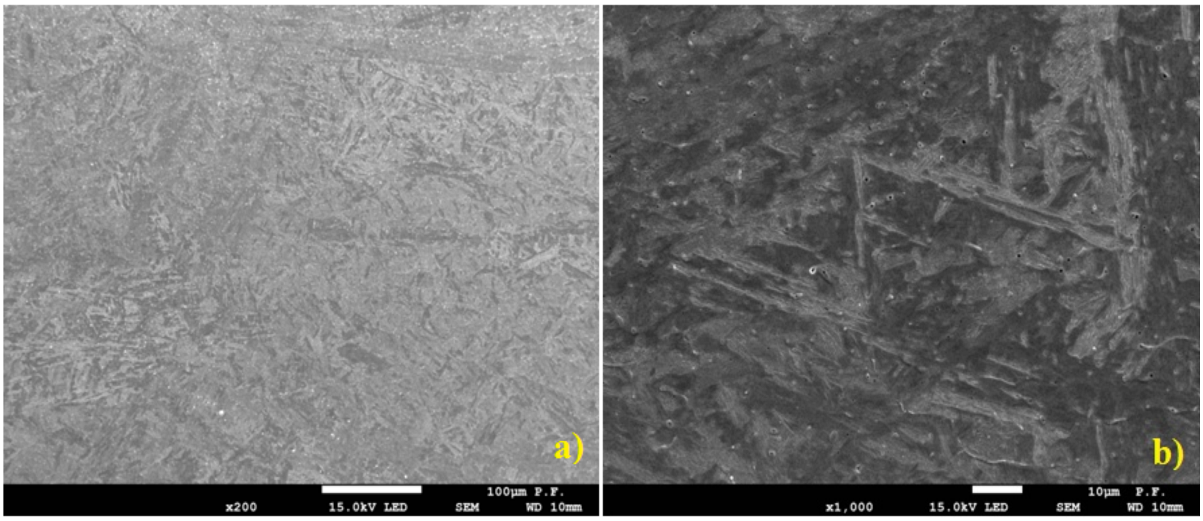

Fig. 11. Weld microstructure: a) magnification of ×200, b) magnification ×1000

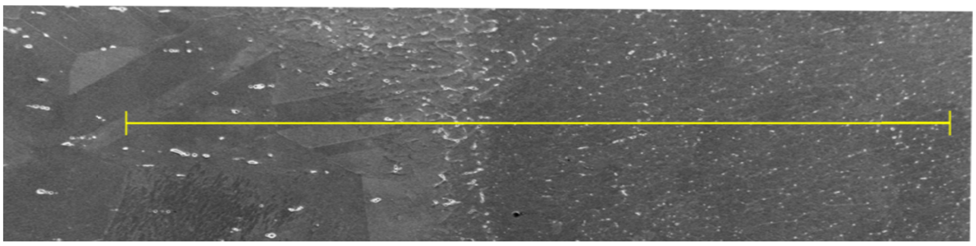

Fig. 12. EDS analysis measure line in cross section of TP347-HFG HAZ and weld

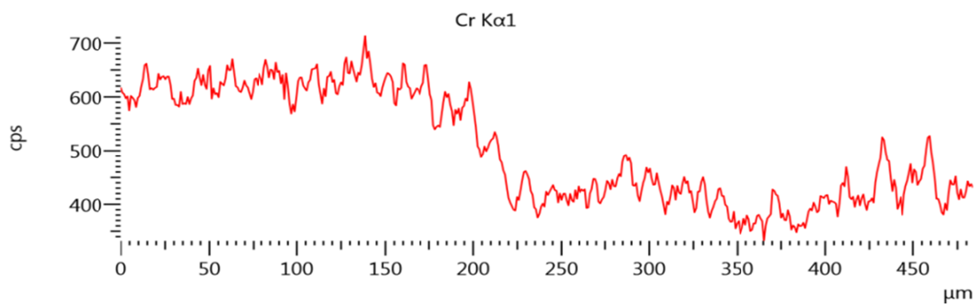

Fig. 13. Chromium counts alongside measurement line

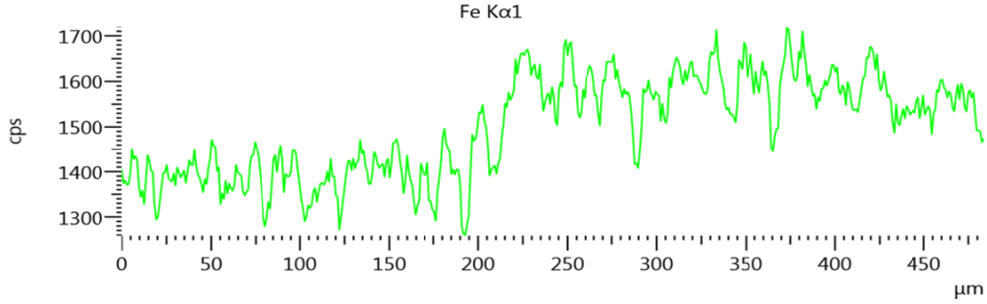

Fig. 14. Ferrite counts alongside measurement line

Chemical composition of fusion line of low carbon steel was presented (Fig. 15-17).

Additional material in grade 309L are dedicated for welding of austenitic steels as well as carbon steels, and was selected as a buffer material. Analysis of fusion zone was performed (Fig. 18-20).

Structure of obtained weld are uniform, moreover, no visual defects were detected. Nevertheless, metallographic analysis shown some impurities in weld, and further study was performed (Fig. 21).

Precipitation analysis shown impurities in form of manganese sulfide in fusion zone.

6. Summary

Numerical simulation for estimating laser welding parameters for flange filler rotary joint, with additional material was carried out. Therefore fusion zone, HAZ and hardness distribution were calculated. Based on simulation trial joint was performed.

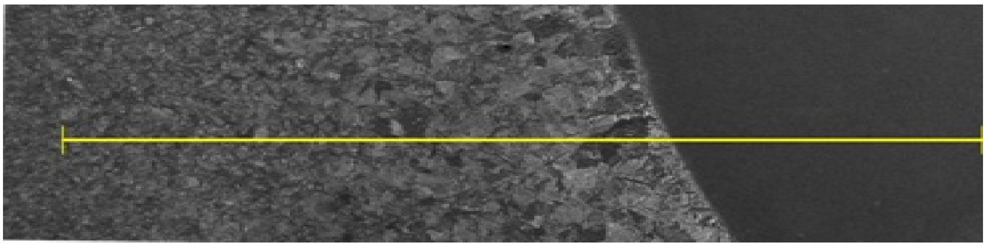

Fig. 15. EDS analysis measure line of S235JR HAZ and weld

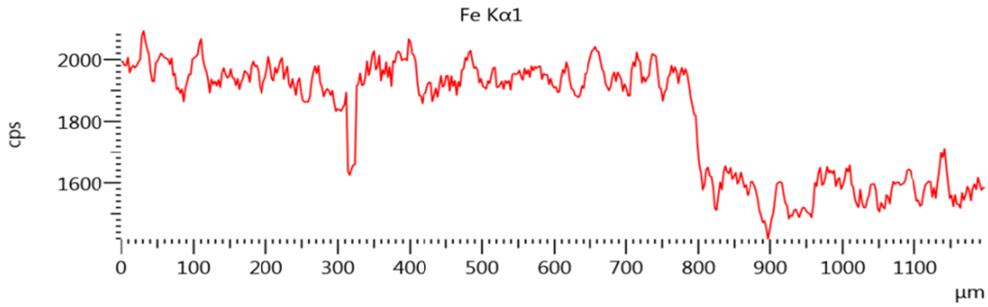

Fig. 16. Ferrite counts alongside measurement line

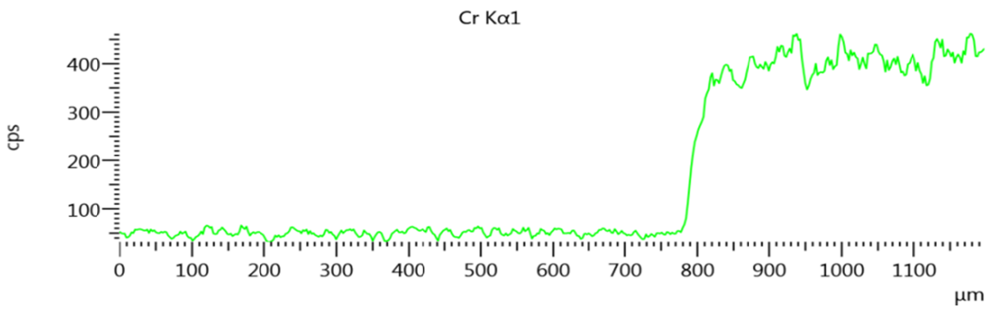

Fig. 17. Chromium counts alongside measurement line

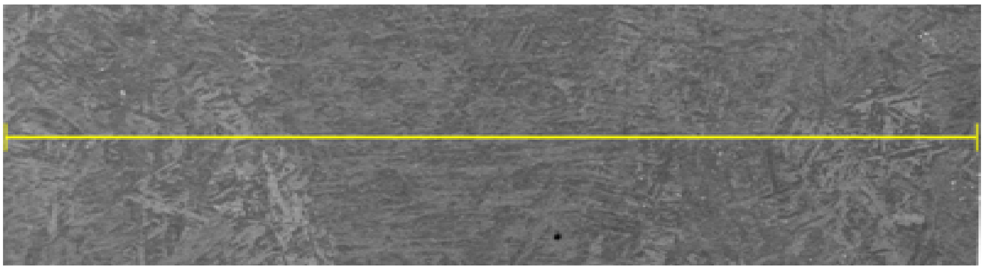

Fig. 18. EDS analysis measure line of fusion zone

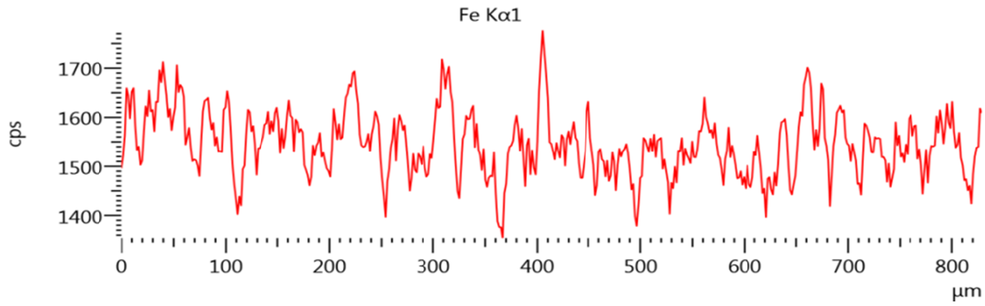

Fig. 19. Ferrite count alongside measurement line

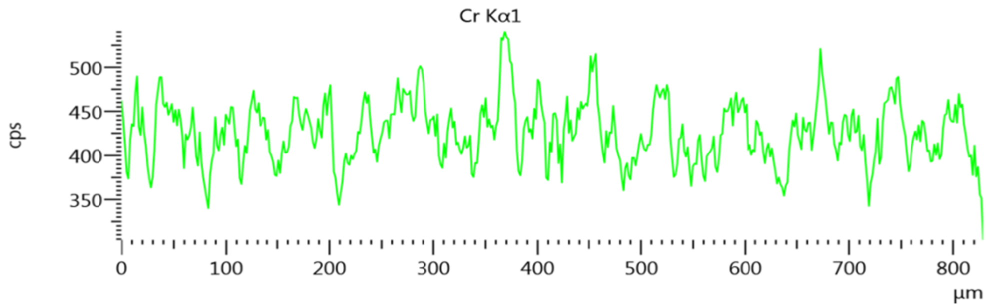

Fig. 20. Chromiumcount alongside measurement line

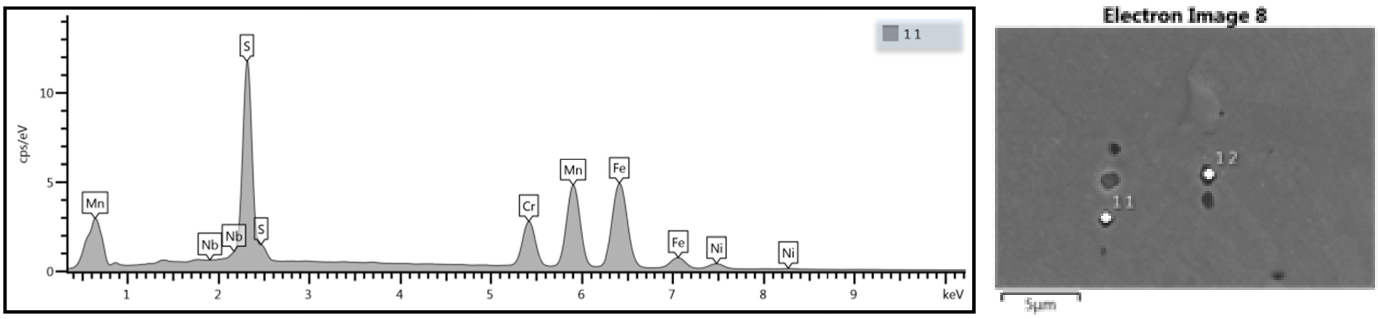

Fig. 21. EDS analysis of detected impurities

Hardness distribution was measured. Results of calculated and measured hardness are differ, highest hardness value HV10 occur in trial joint. To confirm strength characteristic, some additional destructive tests need to be performed. Moreover, due to obtained hardness number, postweld heat treatment are recommended.

Metallographic analysis shown uniform fusion zone mixture, and typical microstructure of BM, HAZ for welding of used materials. Weld have uniform, dendritic structure. Chemical composition of weld is combination of additional and base materials equivalent. No visual defects of obtained joints were detected, nevertheless, some manganese sulfide in fusion zone occur. Additional test, in order to characterized strength of obtained joint are required, performing equivalent welding in butt joint configuration provide possibility for tensile and bending tests. Carried out of research of selected low carbon S235JR and austenitic TP347-HFG steels, welding with another grades of additional materials, for changing joint properties are planned, and required further analysis.

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