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Laser Welding of Girth Joint – Numerical Simulation and Experimental Investigation

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Abstract. Laser welding of similar girth joints is a commonly used method of permanent joining process. Parameters can be easily analytically estimated. Nevertheless, performing more advanced types of joints, such as girth joints, is more complex. Estimating process parameters using numerical simulation can be performed. Assuming laser beam energy absorption in material heat expansion isotherms of a melting point can be calculated. Performing girth joint requires adequate angle process head orientation and welding parameters. Laser welding process is an unconventional method and does not require any additional material. The arc welding of a flange joint requires a multi run welding, and a single run welding can be performed using a laser beam. The article presents the possibility of numerical modeling laser welding of girth joints using the SimufactWelding software. Thermal and thermo-mechanical analysis were performed. The parameters estimated in the laser welding simulation are the following: output power, feed rate, efficiency and intensity distribution - Gaussian parameter. Low carbon construction steel S235JR is the material used for the process simulation. Double cylindrical simulated laser beam absorption and keyhole effect are the heat source used for the laser welding simulation. Thermal and thermo-mechanical properties such as fusion zone, distortion, displacement and hardness distribution were calculated [1, 2]. Experimental laser welding of lap joints was performed based on estimating parameters. Welding process using 6 kW CO_2 laser with simulated parameters in order to compare numerical and experimental results was performed.

Introduction

Laser welding uses concentrated photons beam for melting material. Heat source moves and starts the solidification and crystallization process of a material. Using the concentrated energy of focused electrons or photons, high energy density can be obtained. High velocity of the welding process combined with high energy density affects in relative low thermal energy absorbed in the material. Welding parameter investigations for application like girth joints are problematic, require many technological trials and some knowledge of the welding process. Simple calculations of welding based on solving conduction equation which are proposed by Rosenthal (1) can be used [3, 4].

$$T - T_0 = \frac{q}{2\pi k r} e^{\frac{-v(r-x)}{2\alpha}} \qquad (1)$$

The evolution of computation is based on mathematic description of heat sources evolution. A resolving moving heat sources equation shape of weld can be estimated. In the article, the possibility of a numerical simulation of girth joint using SimufactWelding software are presented.

Numerical simulation of laser girth joints welding

An estimation of weld dimension by solving moving heat source equation can be performed. Material phase transformation affects material properties. Using the numerical analysis of a thermo- mechanical simulation, a simplified material metallographic structure can be estimated. A numerical simulation using a volumetric cylindrical heat source model was calculated. For estimating the laser radiation absorption surface disc and for the simulated keyhole effect, conical cylindrical heat source is used [5-8]. Dimensions of volumetric heat sources were defined. In the simulation of a welding process fusion zone and properties of welded joint were calculated. In boundary conditions, rigid restraint for welded elements are used. A disc-shaped sheet plate with a thickness of 4mm and pipe shape cylindrical elements were meshed using a ringmesh with hexahedral finite elements. The weld trajectory across the contact line is determined. A simulation of welding is conducted for S235JR steel, and complete multi-phase material library is used. A numerical simulation of complete joint penetration was performed (Fig 1.). To perform a phase transformation, the adequate cooling time was established as 30s.

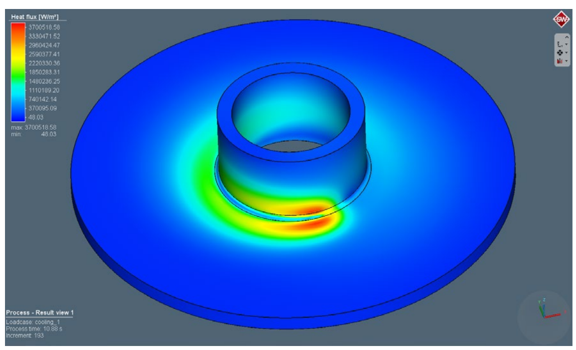

Fig. 1. Numerical simulation of laser welding girth joint - heat expansion in closing of the weld.

A welding simulation for estimated parameters of laser complete penetration was performed. Simulations with constant speed rate equal to 1m/min, efficiency of 0.95 and Gaussian parameter of disc and conical heat source equal to 3 were programmed. Laser output power was changing from 3 to 6kW with the step of 500W. Complete welding penetration was obtained at 6kW (Fig.2).

Welding of circumferential girth joints is problematic, as the forced position of welding head orientation gives some limitation and has great impact on the process. Thermo-mechanical analysis with phase transformation gives realistic results of the welding process with the convex face of a weld and material deformation. Fillet joints such as girth joints have considerably high welding stress and deformation, some applications require additional heat treatment, nevertheless a stress-strain analysis is required. The results of numerical analysis of stress and strain indicated in welded material (Fig. 5) showed concentration in HAZ and fusion zone. The crystallographic structure of a welded material (Fig. 3, 4, 5) is related to phase transformations during the laser welding process.

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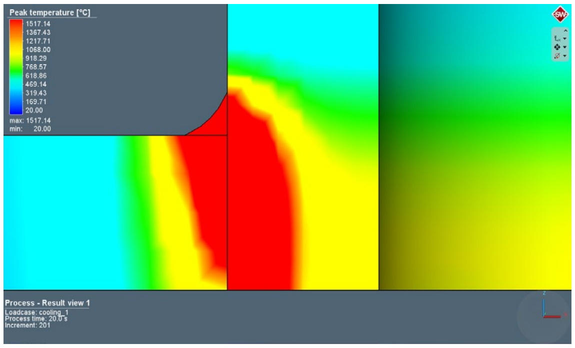

Fig. 2. Simulated results of fusion zone geometry in cross section.

The numerical simulation showed phase transformation of fusion zone, primary a ferritic-pearlitic crystallographic structure change. The results of numerical simulation showed a transformation into a bainitic structure with ferritic-pearlitic inclusions (Fig. 3). Low carbon construction steel S235JR used in numerical simulation is a typical ferritic material with precipitation of pearlite.

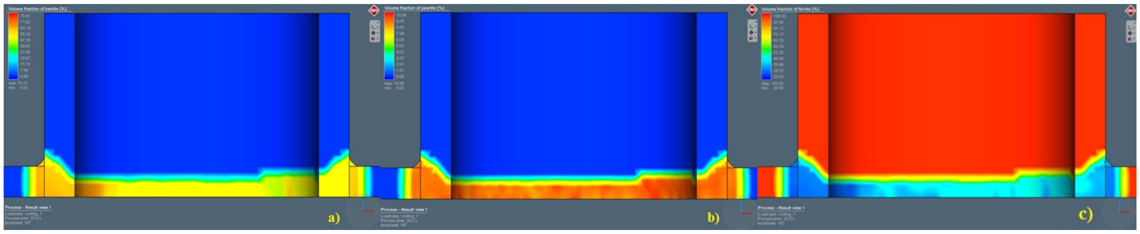

Fig. 3. Distribution of a) bainite, b) pearlite and ferrite in simulated girth joint.

The structure of a material defines material properties. Strength characteristic can be tested using tensile tests and hardness tests. Strength analysis requires destructive methods, nevertheless hardness based on phase transformation and thermal cycles in material can be calculated (Fig. 4).

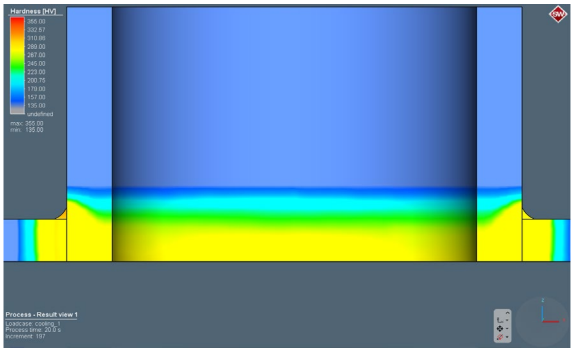

Fig. 4. Distribution of hardness in a simulated laser welded girth joint.

The phase transformation of welded material and heat expansion generated thermal stress. State of stress can be reduced by an additional heat treatment. Due to defined value of occurring stresses, an experimental strain gauge measurement or numerical simulation can be performed (Fig. 5). If stress exceeds maximum acceptable value defined by element usage, stress relaxation is recommended.

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The value of stress calculated in the numerical simulation does not exceed 340 MPa. The greatest stress concentration occurred in the weld and HAZ. Stress in base materials is relatively low. Due to high energy density in the laser welding process, stress and strain in material are lower comparing to conventional welding methods [9-12]. Nevertheless, stress state in welded joint needs to be controlled.

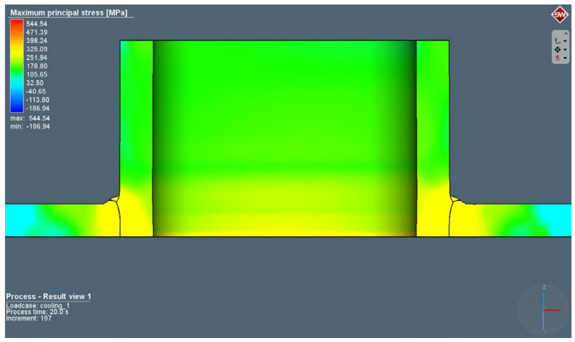

Fig. 5. Stress distribution in simulated girth joint.

Laser welding of the test girth joint

Process parameters of the laser girth joint welding using numerical simulation were estimated. Laser welding trial girth joint was performed using a high power CO_2 laser Trumpf TruFlow 6000 with 6 axis work centre LaserCell 1005. Estimated parameters for trial joint to obtain complete penetration were performed [13-15]. 6kW output power with speed ratio equal to 1m/min and welding heat with a focal length of 270 was used. To reduce the plasma effect, helium as a shielding with a coaxial flow rate of 15l/min gas was used.

The results of trial welding girth circumferential joint were observed (Fig.6). A complete penetration was obtained; nevertheless, due to the forced position, the length of edge fusion zone was obtained only partially [16, 17].

Fig. 6. Macrostructures of partial lap joint weld in cross section.

Hardness test of laser welded lap joint

Welding process affects the crystallographic structure of welded materials. To confirm simulation results, joint hardness test using Innovatest Nexus 4304 was performed (Fig 7). The hardness test was carried out according to PN-EN ISO 6507-1 [18].

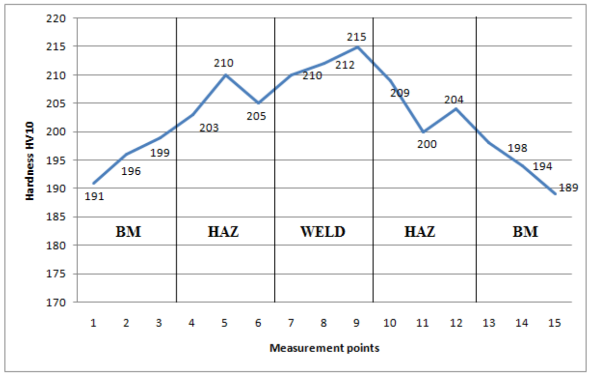

Fig. 7. Hardness distribution in weld cross-section

Hardness test results showed strengthening in the weld and HAZ. The measured hardness in the weld has the value of approximately 210HV10, and does not exceed 215HV10, HAZ are lower and take value from 200 to 210HV10. According to PN-EN ISO 15614-11, maximum allowable limit of Vickers hardness HV10 after welding process is 350. No additional post weld heat treatment is required.

Summary

Numerical simulation of laser welding allows for estimating process parameters of full penetration. A simulation of girth joint processes to assume welding parameters was performed. The results of simulation and experimental trial joint showed similarity. Caused by force welding head position, no full edge fusion zone in the welded material was performed. To define properties of the weld, hardness test was performed. The results showed good strength characteristics. Stress analysis based on numerical simulation showed low stress concentration, located only in the weld and HAZ. The hardness test showed hardening in the weld and HAZ, but no additional heat treatment was required.

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