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# Thermal Analysis of 316Ln Stainless Steel Butt Joint

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## Abstract:

This study focuses on the thermal analysis of laser welding using SYSWELD software for autogenous welding of 316LN stainless steel with a thickness of 1.5 mm. The objective is to analyse the temperature distribution, thermal cycles, and potential heat-induced issues in the welded joint.Using SYSWELD software, a finite element analysis approach is employed to simulate and predict the thermal behaviour of the laser welding process. The software incorporates material properties, laser parameters, and boundary conditions to accurately model the welding process. The simulation provides insights into the temperature distribution within the workpiece during welding, allowing for the evaluation of solidification behaviour, heat-affected zone formation, and potential issues related to excessive thermal stress.

*Keywords* **—Laser welding, SYSWELD, 316Ln, Thermal Analysis.**

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## I. INTRODUCTION

Laser welding is a modern welding technique that utilizes laser beams to join materials together. It is a highly precise and controlled welding process that offers numerous advantages over traditional welding methods. Laser welding is widely used in various industries, including automotive, aerospace, electronics, medical devices, and manufacturing.

In laser welding, a laser beam is generated and focused onto the workpiece, delivering a concentrated heat source that melts and fuses the materials. The laser beam provides a high-energy density, allowing for efficient and localized heating, which results in precise and accurate welds. Laser welding can be performed in either a continuous wave (CW) or pulsed mode, depending on the specific requirements of the application.

One of the key advantages of laser welding is its ability to produce narrow and deep welds with minimal heat-affected zones (HAZ). The focused laser beam generates a small and intense heat source, minimizing the thermal impact on the surrounding material. These results in reduced distortion, improved weld quality, and enhanced mechanical properties of the joint.

Laser welding offers excellent control over the weld parameters, including power density, spot size, and travel speed. This enables precise control over the weld depth, width, and overall geometry, making it suitable for welding complex shapes and thin materials. Laser welding can achieve high welding speeds, leading to increased productivity and efficiency in manufacturing processes.

Furthermore, laser welding provides a non-contact welding process, as the laser beam does not physically touch the workpiece. This eliminates the need for any consumables or direct contact with the material, minimizing the risk of contamination and ensuring a clean and precise weld. Laser welding is particularly advantageous for welding sensitive or delicate materials that require minimal thermal distortion.

Laser welding is compatible with a wide range of materials, including metals, alloys, plastics, ceramics, and composites. It can join similar or dissimilar materials with different melting points, allowing for the welding of dissimilar metals and composite structures. Laser welding is capable of joining materials of varying thicknesses, from thin foils to thick plates, providing versatility in welding applications.

The use of laser welding offers several benefits, including high welding speed, precise control, minimal distortion, enhanced joint strength, and the ability to weld a wide range of materials. These advantages have made laser welding a preferred choice in industries where high precision, efficiency, and quality are critical.

## II. THERMAL ANALYSIS

Thermal analysis plays a crucial role in understanding and optimizing the laser welding process for austenitic stainless steel. Austenitic stainless steels are commonly used in various industries due to their excellent corrosion resistance, high strength, and good weldability. However, their welding characteristics, such as high thermal conductivity and susceptibility to solidification cracking, present unique challenges that can be effectively addressed through thermal analysis.

Thermal analysis of laser welding for austenitic stainless steel involves studying the heat transfer and temperature distribution during the welding process. This analysis provides insights into the weld pool formation, solidification behaviour, and the resulting microstructure and mechanical properties of the weld joint.

One of the key aspects of thermal analysis is the modelling of the heat source, which is the laser beam in this case. The laser beam's intensity, power, and distribution need to be accurately represented in the simulation to predict the temperature distribution in the workpiece. The laser beam's energy is absorbed by the material, generating a localized heat source that melts the stainless steel, leading to the formation of a molten pool and subsequent solidification.

During thermal analysis, the heat conduction equation is solved using numerical methods, such as Finite Element Analysis (FEA) or Finite Difference Method (FDM). These methods discretise the workpiece into small elements or nodes, allowing for the calculation of temperature distribution over time. The simulation takes into account factors such as the laser power, scanning speed, beam diameter, and material properties to accurately predict the temperature field during welding.

Thermal analysis provides valuable information about the temperature gradients, cooling rates, and thermal cycles experienced by the austenitic stainless steel during laser welding. It helps in understanding the solidification behaviour, including the formation of dendritic structures, segregation of alloying elements, and the potential for the formation of undesirable phases or defects.

Furthermore, thermal analysis aids in predicting and managing the potential issues associated with austenitic stainless steel welding, such as solidification cracking and distortion. By simulating the temperature distribution and thermal history, engineers can optimize the welding parameters, such as laser power, welding speed, and heat input, to minimize the risk of these issues and ensure the production of sound and high-quality welds.

Finite Element Analysis (FEA) of laser welding for stainless steel is a powerful numerical simulation technique used to predict and analyse the behaviour of stainless steel components during the welding process. FEA allows engineers to assess various aspects of laser welding, including temperature distribution, thermal stress, and distortion. Here is an overview of the steps involved in performing a Finite Element Analysis of laser welding for stainless steel.

1. Geometry Modelling: Create a three-dimensional (3D) model of the stainless steel components to be welded. The model should accurately represent the geometry, dimensions, and material properties of the workpiece.

2. Mesh Generation: Divide the geometry into a finite number of smaller elements, creating a mesh. The size and density of the mesh should be chosen carefully to ensure an accurate representation of the physics involved in the welding process. The mesh should capture the thermal gradients and structural behaviour of the welded joint.
3. Material Properties: Assign the appropriate material properties to the stainless steel material. This includes thermal conductivity, specific heat capacity, density, and mechanical properties such as yield strength and Young's modulus. The material properties can be obtained from experimental data or from material databases.
4. Boundary Conditions: Define the appropriate boundary conditions for the simulation. This includes specifying the laser beam characteristics, such as intensity, spot size, and movement. Additionally, the constraints and fixations of the workpiece should be defined to represent the actual welding setup.
5. Heat Transfer Analysis: Perform a transient heat transfer analysis to simulate the laser heating process. Apply the defined laser heat source to the model and solve the heat conduction equation to calculate the temperature distribution within the workpiece. Consider the absorption of laser energy, heat conduction, and convective cooling effects during the analysis.
6. Thermomechanical Analysis: Incorporate thermomechanical effects into the simulation to analyse the thermal stress and distortion during and after welding. This includes accounting for the temperature-dependent material properties, expansion and contraction of the material, and phase transformations that occur during the welding process.
7. Post-processing and Analysis: Analyse the results of the simulation, including temperature profiles, thermal stress distributions, and distortion patterns. Compare the simulation results with design specifications and acceptance criteria to assess the weld quality and structural integrity of the welded components.

M. Zubairuddin conducted a Finite Element Method (FEM) analysis of Grade 91 steel using SYSWELD software. The author investigated welding processes such as MMA, GTA, and Laser for Grade 91 steel [1-3]. The analysis involved examining the thermal and mechanical aspects of laser welding, and the results were subsequently validated against experimental data [4-6].

Similarly, Saravana conducted a thermal and mechanical analysis of laser welding on stainless steel grades 304L and 316L. The author compared the FEM-calculated residual stresses and distortion with experimental measurements [7-9].

For this paper, the chosen material for laser welding is stainless steel AISI 316Ln, which has extensive practical applications. The FEM analysis was performed using SYSWELD software.

## III. EXPERIMENTAL WORK

The experiment utilizes AISI 316Ln as the chosen material, with dimensions of 200 x 160 x 1.5 mm. The welding parameters for Laser Welding, TruPulse 556, are provided in Table 1.

TABLE I.HEAT INPUT VALUES

| Welding Speed (mm/sec) | Power (w) | Pulse duration (ms) | Energy (J) | Average Power (w) |
|---|---|---|---|---|
| 2.3 | 5 | 10 | 28 | 240 |

## IV. FINITE ELEMENT ANALYSIS

Modelling the heat source for laser welding poses significant challenges within the finite element method. In this study, conical heat source models were chosen based on an examination of the bead cross section.

The utilization of a 3D conical model, as depicted in Fig.1, proves to be a dependable heat source model for simulating laser welding with a significant depth of penetration. The power density is mathematically represented by Equation 1.

$$Q_r = Q_0 \exp\left(\frac{-3r^2}{r_0^2}\right)$$

(1)

Where r and $r_0$ is given by

$$r = \sqrt{x^2 + y^2}$$

$$r_0 = r_e - \frac{(r_e - r_i)(z_e - z)}{(z_e - z_i)}$$

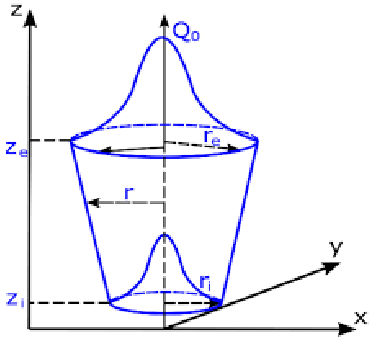


Fig. 1. 3D conical model

### A. *Meshing*

The welding plate has been discretized using 8-node hexahedron elements as shown in Fig. 2. The combined number of nodes and elements in the model amounts to 74,163 and 83,541, respectively. Due to the high heat transfer rate experienced by the Heat Affected Zone (HAZ) and Fusion Zone (FZ), they have been meshed with fine elements.

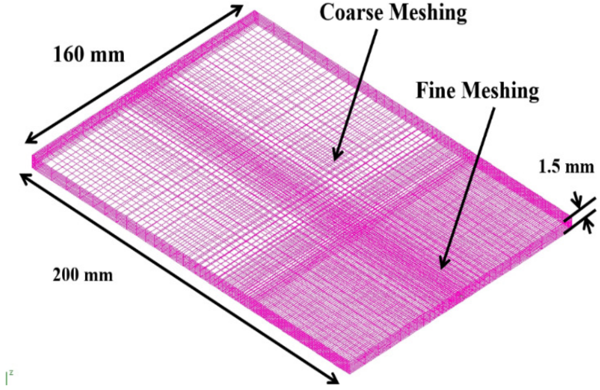
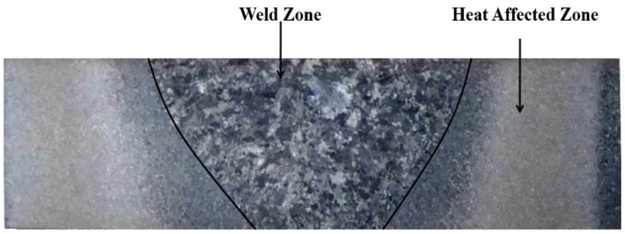


Fig. 2. Meshing of weld plate

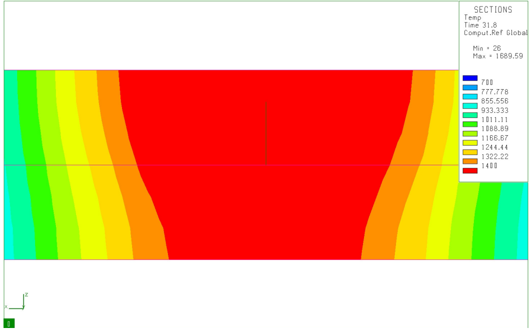
### B. *Thermal Analysis*

The weld profile of the butt joint plate was obtained by cutting through the centre of the joint, and the dimensions of the weld profile were measured using a microscope. The experimental weld profile is depicted in Fig. 3 (a). The measured depth of penetration in the weld profile is 1.5 mm, with a Fusion Zone (FZ) width of 1.42 mm and Heat Affected Zone (HAZ) width of 1.24 mm.

The conical-based model predicts the HSF of the weld profile, illustrated in Fig. 3 (b). Conical Model demonstrates the full depth of penetration, consistent with the experimental measurements of the weld specimen. Notably, the FZ width in conical model measures 1.48 mm, which closely aligns with the experimental value.



(a) Experimental weld specimen



(b) Predicted weld profile

Fig. 3. Weld profile

By employing the Finite Element Method (FEM), the temperature cycle at a distance of 10 mm from the weld line is computed and subsequently compared with recorded values. The comparison reveals a close agreement in the temperature distribution, demonstrating the accuracy of the predictions. The maximum temperature attained during welding is determined to be 512ºC. Notably, the conical model predicts a peak temperature value of 532ºC.

## V. CONCLUSIONS

1. The study focuses on the thermal analysis of laser welding for autogenous welding of 316LN stainless steel with a thickness of 1.5 mm.
2. SYSWELD software is utilized for conducting the thermal analysis through finite element analysis.
3. The simulation in SYSWELD accurately models the welding process by considering material properties, laser parameters, and boundary conditions.
4. The simulation provides insights into the temperature distribution within the workpiece during welding, enabling the evaluation of solidification behaviour, formation of the heat-affected zone (HAZ), and potential issues related to excessive thermal stress.

In conclusion, this study employs SYSWELD software to analyse the thermal behaviour of laser welding on 316LN stainless steel. The simulation provides valuable information about temperature distribution, thermal cycles, and potential issues, aiding in understanding the welding process and optimizing welding parameters for improved quality and performance.

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