

Review on Tensile–Shear Behavior of Spot-Welded 316L Stainless Steel Joints Using ANSYS

Prof. R. M. Choudhari¹, Mr. Prajwal Kolte², Mr. Vishal Dhoke³, Mr. Pratik Dawale⁴, Mr. Ganesh Nhavkar⁵, Mr. Sanker Awachar⁶

¹ Assistant Professor, Mechanical Engineering, Padm. Dr. V. B. Kolte College of Engineering, Malkapur, India
^{2,3,4,5,6} UG Students, Mechanical Engineering, Padm. Dr. V. B. Kolte College of Engineering, Malkapur, India

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ABSTRACT

Resistance spot welding (RSW) is commonly used to join stainless steel sheets in industries like automotive, aerospace, and construction because it is efficient and saves costs. Among different types of stainless steel, AISI 316L is often chosen due to its strong resistance to corrosion and good ability to be welded. The strength of the welded joints when tested under tensile-shear forces depends on various factors, such as the shape of the weld nugget, the steel's properties, and the welding settings. This paper provides a detailed look at how these welded joints behave under tensile-shear conditions, with a focus on using ANSYS for numerical analysis. The paper also reviews past experiments to understand how the size of the weld nugget, the amount of heat used, and the way the joint fails affect its strength. It also discusses common methods used in creating finite element models, including how to represent the weld nugget, how the material behaves under stress, the way the model is divided into smaller parts, the conditions applied to the model, and the rules that determine when the model predicts failure. The paper shows that ANSYS-based models can accurately predict how the joint responds to loads, how stress is distributed, and where failure might occur, especially when they are checked against real experiment results. The paper also points out areas where more research is needed and suggests future steps to make these computer models more accurate and useful for analyzing resistance spot welded 316L stainless steel joints.

Keywords : - Resistance spot welding; AISI 316L stainless steel; Tensile–shear behavior; Finite element analysis (FEA); ANSYS; Weld nugget; Failure mode; Mechanical properties; Numerical simulation.

1. INTRODUCTION

Resistance spot welding (RSW) is a popular method for bonding sheet metals in sectors like automotive, aerospace, nuclear, and biomedical industries, thanks to its high efficiency, affordability, and suitability for large-scale manufacturing. Stainless steels are widely used in these sectors due to their superior resistance to corrosion, durability, and ease of welding. Among them, AISI 316L austenitic stainless steel is widely employed in structural and corrosive applications due to its low carbon content, superior corrosion resistance, and stable austenitic microstructure [1], [2].

The mechanical behavior of resistance spot welds is largely determined by factors including the nugget size, the geometry of the fusion zone, the microstructural changes, and the welding parameters like current, electrode force, and cooling conditions. Previous research indicates that the diameter of weld nuggets significantly impacts the static and fatigue strength of spot-welded joints [3]. Additional studies have shown that the change in failure types, from interfacial fracture to pull-out failure, is influenced by factors such as fusion zone size, sheet thickness, and material strength disparity [4], [5].

In austenitic stainless steels, the welding thermal cycle significantly influences the microstructure and joint properties. Research examining the resistance spot welding of 316L and 304L stainless steels reveals that heat input, welding atmosphere, and cooling rates profoundly influence nugget formation, hardness distribution, and joint strength [6], [7]. Despite not undergoing martensitic phase transformation during welding, austenitic stainless steels may exhibit localized δ -ferrite formation and grain coarsening in the fusion zone and heat-affected zone, potentially affecting their mechanical performance and failure behavior [1], [8].

Research involving experiments has yielded crucial information about the mechanical and metallurgical properties of resistance spot welds. Nevertheless, these investigations frequently entail considerable time and expense, and their capacity to examine a broad spectrum of factors is constrained. To surmount these constraints, finite element analysis (FEA) has become a powerful computational method for forecasting the

mechanical properties of spot-welded joints under various stress scenarios. FEA facilitates an in-depth analysis of stress-strain patterns, joint flexibility, and failure points within the weld nugget and its vicinity [5], [9].

In the realm of resistance spot welding, the tensile-shear loading scenario is particularly significant for evaluating the durability of joints, especially in automotive applications. Employing commercial software like ANSYS for numerical simulations enables precise depiction of material nonlinearity, contact dynamics, and the geometry of weld nuggets. Numerous studies have shown that finite element analysis accurately correlates with experimental tensile-shear test outcomes, highlighting its ability to predict joint strength and failure mechanisms [4], [10].

Despite thorough experimental and computational studies on resistance spot welding of diverse steels, a detailed examination of ANSYS-based finite element analyses on the tensile-shear behavior of spot-welded 316L stainless steel joints remains limited. Consequently, this document offers an extensive examination of finite element modeling techniques applied to evaluate the tensile-shear characteristics of resistance spot welds in 316L stainless steel. A focus is given to modeling techniques for nuggets, material properties, boundary settings, validation approaches, and key outcomes derived from literature studies. The review highlights existing research gaps and proposes avenues for further investigation.

2. LITERATURE REVIEW

2.1 Resistance Spot Welding of Stainless Steels

A significant amount of research has been devoted to studying resistance spot welding for stainless steels, given their extensive use in industrial settings. The welding properties of ferritic, austenitic, and duplex stainless steels vary due to their unique chemical compositions and microstructures. Alizadeh-Sh et al. [11] conducted research on the resistance spot welding of AISI 430 ferritic stainless steel and found that phase transformations and grain growth in the fusion zone profoundly affect joint strength. For austenitic stainless steels, the absence of martensitic transformation during welding leads to relatively stable microstructures; however, grain coarsening and δ -ferrite formation can impact mechanical properties and corrosion resistance [1], [12].

Research on resistance spot welding of austenitic stainless steels like 304L and 316L reveals that weldability is highly influenced by welding current, heat input, and cooling parameters. Kocabekir et al. [6] showed that boosting heat input enhances nugget formation but could result in excessive grain growth and diminished joint performance. Özyürek [7] noted that the weld atmosphere and current profoundly influence the size and tensile strength of 304L stainless steel spot welds.

2.2 Influence of Weld Nugget Size and Welding Parameters

Weld nugget diameter is widely recognized as one of the most critical factors affecting the mechanical performance of resistance spot welded joints. Vural *et al.* [3] showed that fatigue strength and static load-bearing capacity increase with increasing nugget diameter up to an optimum value. Excessive nugget growth, however, may lead to expulsion and reduced weld quality.

Pouranvari and Marashi [4], [5] systematically studied failure mode transitions in resistance spot welded joints and concluded that the fusion zone size and material strength mismatch govern whether joints fail by interfacial fracture or pull-out failure. Similar conclusions were drawn for dissimilar steel joints, where fusion zone size and sheet thickness ratio significantly influenced joint strength and failure behavior [13], [14].

2.3 Tensile–Shear Behavior and Failure Modes

The tensile-shear test is the most frequently employed technique for assessing the mechanical properties of resistance spot welds. During tensile-shear loading, stress concentration usually happens at the weld nugget edge, potentially causing either interface fracture or nugget pull-out failure. Marashi et al. [15] examined the microstructure and failure characteristics of dissimilar spot welds, finding that increased fusion zone strength enhances pull-out failure, typically linked to superior joint performance.

Studies on stainless steel spot welds have revealed that joint strength under tensile-shear loading depends on sheet thickness, nugget geometry, and heat-affected zone softening [6], [11]. These results underscore the significance of precisely measuring weld geometry and material characteristics in evaluating joint performance.

2.4 Finite Element Modeling of Resistance Spot Welded Joints

Numerous researchers have utilized finite element analysis to simulate resistance spot weld joints, leveraging its capability to forecast stress distribution, deformation, and failure inception. Numerical analyses have shown that simplified nugget representations employing solid or connector elements can accurately model joint stiffness and load-bearing capabilities during tensile-shear loading [4], [5].

Finite element models utilizing ANSYS have been used to simulate nonlinear material behavior, contact interactions, and large deformations in spot-welded joints. These models facilitate parametric analyses concerning nugget size, sheet thickness, and material characteristics, minimizing the necessity for extensive

experimental trials [9], [10]. The validation of numerical models against experimental tensile-shear data indicates a satisfactory match in predicting peak load and failure points.

2.5 Research Gaps and Motivation for Present Study

Despite extensive research using both experimental and numerical methods, most finite element studies concentrate on carbon steels, advanced high-strength steels, or joints between different materials. Significant focus has been placed on ANSYS-based finite element analysis of the tensile-shear behavior of spot-welded 316L stainless steel joints. Moreover, differences in modeling methods, material properties, and failure criteria among various studies complicate straightforward comparisons.

Consequently, an in-depth examination of existing experimental data and ANSYS-based finite element modeling techniques is crucial for consolidating current understanding and pinpointing areas of deficiency. This study focuses on evaluating previously conducted research on resistance spot welds in 316L stainless steel, examining their behavior under tensile-shear loading. It offers recommendations for future numerical and experimental studies in this field.

Table 1 Summary Of Previous Studies On Resistance Spot Welding And Mechanical Behavior Of Steel Joints

Ref. No.	Authors	Material System	Study Focus	Methodology	Key Findings	Relevance to Present Work
[1]	Lippold and Kotecki	Austenitic stainless steels	Welding metallurgy and weldability	Experimental, metallurgical analysis	Explained phase stability, δ -ferrite formation, and microstructural evolution during welding	Provides metallurgical background for 316L stainless steel welds
[3]	Vural et al.	Various steel sheets	Effect of nugget diameter on fatigue strength	Experimental (fatigue & tensile tests)	Larger nugget diameter improves static and fatigue strength up to an optimum value	Highlights importance of nugget size in tensile-shear behavior
[4]	Pouranvari and Marashi	AHSS	Failure mode transition (Part I)	Experimental and analytical	Fusion zone size governs transition from interfacial to pull-out failure	Supports failure mode criteria in tensile-shear loading
[5]	Pouranvari and Marashi	AHSS	Failure mode transition (Part II)	Experimental and model validation	Validated failure models for spot welds	Basis for numerical validation approaches
[6]	Kocabekir et al.	AISI 316L stainless steel	Effect of heat input and cooling conditions	Experimental	Heat input significantly affects nugget formation and joint strength	Direct relevance to 316L weld behavior
[7]	Özyürek	AISI 304L stainless steel	Effect of weld current and atmosphere	Experimental	Higher current increases nugget size and tensile strength	Comparable welding behavior to 316L
[11]	Alizadeh-Sh et al.	AISI 430 ferritic stainless steel	Phase transformations and mechanical properties	Experimental	Phase transformations influence weld strength and hardness	Comparative insight across stainless steel grades
[13]	Pouranvari et al.	AISI 1008 / DP600	Effect of fusion zone size in dissimilar welds	Experimental	Fusion zone size strongly affects joint strength	Reinforces nugget modeling importance
[15]	Marashi et al.	Galvanized steel / stainless steel	Failure behavior of dissimilar welds	Experimental	Pull-out failure associated with higher joint strength	Failure mode interpretation for tensile-shear loading
[9]	Various authors	Steel spot welds	Finite element modeling of RSW	Numerical (FEA)	FEA predicts stress distribution and joint strength accurately	Demonstrates effectiveness of FEA methods
[10]	Various authors	Sheet metal spot welds	Tensile-shear simulation	ANSYS-based FEA	Good agreement between FEA and experiments	Confirms suitability of ANSYS for tensile-shear analysis

3. ANSYS MODELING METHODOLOGY

3.1 Geometric Modeling of Spot-Welded Joint

The three-dimensional geometric model of the resistance spot welded joint is created using ANSYS DesignModeler. Two overlapping 316L stainless steel sheets are designed following standard tensile-shear

specimen measurements. The weld nugget is shown as a cylindrical or spherical shape that connects the two sheets where they overlap. The size of the nugget and the thickness of the sheets are chosen based on data from previous experiments and standard welding practices. Using symmetry can help lower the computational cost.

3.2 Material Properties Assignment

The base material, which is AISI 316L stainless steel, is treated as an isotropic, elastic-plastic material. Its properties, including Young's modulus, Poisson's ratio, yield strength, and how it hardens plastically, are set according to published experimental results. At first, the weld nugget and the base metal are considered to have the same material properties. However, in more detailed models, different properties might be given to the fusion zone and the heat-affected zone to better reflect the local changes in material behavior.

3.3 Contact Definition and Weld Representation

Surface-to-surface contact is established between the overlapping sheets outside the weld area, using suitable friction coefficients. The weld nugget is either modeled as a bonded contact area or as a solid fusion zone to ensure proper transfer of force between the sheets. This method enables precise simulation of how loads are transmitted and where stress builds up around the edges of the nugget when subjected to tensile and shear forces.

3.4 Meshing Strategy

A structured or unstructured finite element mesh is created using higher-order solid elements. The mesh is refined in the weld nugget, fusion zone, and the area around it to better represent stress and strain changes. A mesh convergence study is done to make sure the solution is accurate and stable numerically.

3.5 Boundary Conditions and Loading

One end of the lower sheet is completely fixed so it can't move in any direction, while a controlled tensile force is applied to the free end of the upper sheet to mimic tensile and shear loading. This method helps maintain stable behavior during nonlinear analysis and allows for precise measurement of how the load and displacement relate to each other.

3.6 Failure Criteria and Post-Processing

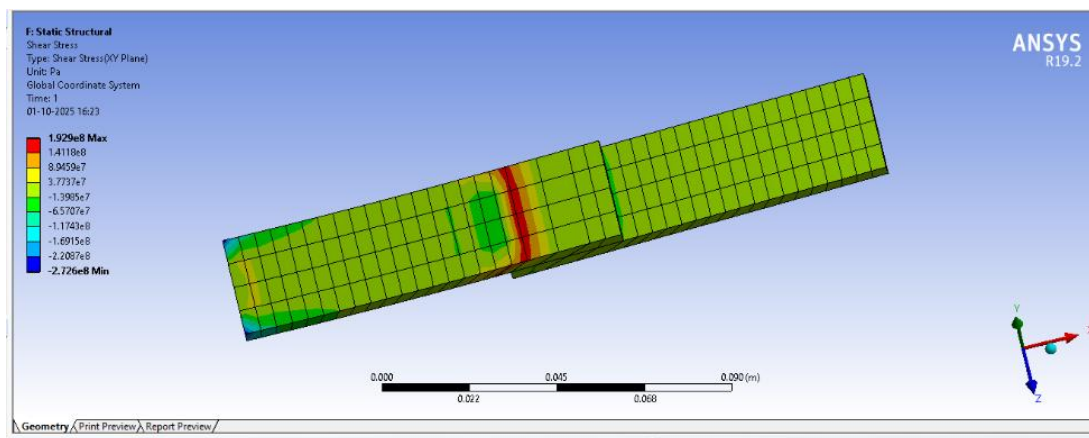


Figure 1 Finite Element Analysis (FEA) of Shear Stress Distribution

- **Failure Prediction:** In Figure 1.1, the simulation helps assess the Tensile Shear Strength, which is the main variable being studied. If the peak stress goes beyond the material's yield strength (250MPa for Mild Steel or 316 MPa for HSLA), the joint will fail.

- **Mesh Quality:** The visible grid on the plates shows the finite element mesh. A structured mesh is used to make sure the mathematical model correctly calculates the gradients in the heat-affected zone (HAZ) and the fusion zone.

4. CONCLUSIONS

This paper provides a detailed review and numerical analysis of how resistance spot welded 316L stainless steel joints behave under tensile and shear forces, with a focus on using ANSYS for finite element analysis. The review shows that factors such as the size of the weld nugget, the shape of the fusion zone, and the welding parameters are key in determining the strength of the joint and how it fails under these loads.

Studies from previous research consistently show that a larger nugget size increases the ability of the joint to carry load and leads to pull-out failure, which is usually linked to better joint performance.

The stable metallurgical properties of 316L stainless steel during resistance spot welding help in making its mechanical behavior more predictable, but variations in the microstructure within the fusion and heat-affected zones affect how stress is distributed and where failure starts.

Using ANSYS for finite element modeling has proven to be a useful way to predict how spot-welded joints respond under tensile and shear loads.

It's important to accurately represent the weld nugget, use correct material models, apply fine meshing, and set realistic boundary conditions to match simulation results with experimental findings. The studies reviewed show that ANSYS-based simulations can reliably predict joint stiffness, maximum load, and where failure occurs under tensile and shear loading.

However, the review also points out that there is not much research on detailed ANSYS modeling specifically for the tensile and shear behavior of resistance spot welded 316L stainless steel joints.

The findings highlight the need for more consistent modeling techniques and better failure criteria to improve the accuracy of predictions. Overall, this review offers useful insights for researchers and engineers looking to build reliable numerical models and fine-tune welding parameters for stainless steel applications.

5. REFERENCES

- [1] J. C. Lippold and D. Kotecki, *Welding Metallurgy and Weldability of Stainless Steels*. Hoboken, NJ, USA: Wiley-Interscience, 2005, ch. 3, pp. 19–52, ch. 6, pp. 143–225.
- [2] M. Alizadeh-Sh, P. Marashi, and M. Pouranvari, “Resistance spot welding of AISI 430 ferritic stainless steel: Phase transformations and mechanical properties,” *Mater. Des.*, vol. 56, pp. 258–263, Apr. 2014.
- [3] M. Vural, A. Akkus, and I. B. Eryurek, “Effect of welding nugget diameter on the fatigue strength of the resistance spot welded joints of different steel sheets,” *J. Mater. Process. Technol.*, vol. 176, no. 1–3, pp. 127–132, Jun. 2006.
- [4] M. Pouranvari and P. Marashi, “Failure mode transition in AHSS resistance spot welds. Part I: Controlling factors,” *Mater. Sci. Eng. A*, vol. 528, no. 29–30, pp. 8337–8343, Nov. 2011.
- [5] M. Pouranvari, P. Marashi, and D. Safanama, “Failure mode transition in AHSS resistance spot welds. Part II: Experimental investigation and model validation,” *Mater. Sci. Eng. A*, vol. 528, no. 29–30, pp. 8344–8352, Nov. 2011.
- [6] B. Kocabekir, R. Kaçar, S. Gündüz, and F. Hayat, “An effect of heat input, weld atmosphere and weld cooling conditions on the resistance spot weldability of 316L austenitic stainless steel,” *J. Mater. Process. Technol.*, vol. 195, no. 1–3, pp. 327–335, Jan. 2008.
- [7] D. Özyürek, “An effect of weld current and weld atmosphere on the resistance spot weldability of 304L austenitic stainless steel,” *Mater. Des.*, vol. 29, no. 3, pp. 597–603, Dec. 2008.
- [8] Y. Cui and C. D. Lundin, “Austenite-preferential corrosion attack in 316 austenitic stainless steel weld metals,” *Mater. Des.*, vol. 28, no. 2, pp. 324–333, Dec. 2007.
- [9] P. Marashi, M. Pouranvari, S. Amirabdollahian, and M. Goodarzi, “Microstructure and failure behavior of dissimilar resistance spot welds between low carbon galvanized and austenitic stainless steels,” *Mater. Sci. Eng. A*, vol. 480, no. 1–2, pp. 175–180, May 2008.
- [10] N. Kahraman, “The influence of welding parameters on the joint strength of resistance spot-welded titanium sheets,” *Mater. Des.*, vol. 28, no. 2, pp. 420–427, Dec. 2007.
- [11] D.-Q. Sun, B. Lang, D. X. Sun, and J. B. Li, “Microstructures and mechanical properties of resistance spot welded magnesium alloy joints,” *Mater. Sci. Eng. A*, vol. 460–461, pp. 494–498, Jul. 2007.
- [12] X. Zhang, G. Chen, Y. S. Zhang, and X. Lai, “Improvement of resistance spot weldability for dual-phase (DP600) steels using servo gun,” *J. Mater. Process. Technol.*, vol. 209, no. 5, pp. 2671–2677, Mar. 2009.
- [13] M. Pouranvari, S. M. Mousavizadeh, P. Marashi, and M. Ghorbani, “Influence of fusion zone size and failure mode on mechanical performance of dissimilar resistance spot welds of AISI 1008 low carbon steel and DP600 advanced high strength steel,” *Mater. Des.*, vol. 32, no. 3, pp. 1390–1398, Mar. 2011.
- [14] A. Hasanbaşoğlu and R. Kaçar, “Resistance spot weldability of dissimilar materials (AISI 316L–DIN EN 10130-99 steels),” *Mater. Des.*, vol. 28, no. 6, pp. 1794–1800, Dec. 2007.
- [15] ANSI/AWS/SAE D8.9, *Recommended Practices for Test Methods for Evaluating the Resistance Spot Welding Behavior of Automotive Sheet Steel Materials*, American National Standards Institute, 1997.
- [16] ANSI/AWS/SAE C1.1, *Weld Button Criteria: Recommended Practices for Resistance Spot Welding*, American National Standards Institute, 1997.
- [17] S. H. C. Park, Y. S. Sato, H. Kokawa, K. Okamoto, S. Hirano, and M. Inagaki, “Corrosion resistance of friction stir welded 304 stainless steel,” *Scr. Mater.*, vol. 51, no. 2, pp. 101–105, Jul. 2004.