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Investigation and Optimization of Resistance Spot Welding Parameters for Stainless Steel

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Abstract

The present work examines the significant impact of resistance spot welding (RSW) process parameters on the properties and efficacy of connections created in sheets of 316L stainless steel. This study examines the intricate relationship between welding parameters, investigating their influence on the microstructure, mechanical characteristics, and overall efficacy of welded connections. By employing a methodical experimental methodology, this study thoroughly investigates the impact of different factors in resistance spot welding (RSW), including welding current, welding time, and electrode force, on the resultant weld quality. The objective is to comprehensively understand both the individual and combined effects of these parameters. The utilization of microstructural analysis is implemented to reveal the complexities associated with the creation of the nugget. Additionally, mechanical testing is utilized to gain a deeper understanding of the strength, ductility, and toughness of the welded joints. The scope of the inquiry goes beyond traditional evaluations, as it incorporates sophisticated procedures to assess the corrosion resistance and fatigue performance of the welded 316L sheets. The objective of this study is to optimize the welding process to improve immediate performance and gain a comprehensive understanding of the long-term durability of the joints in demanding operating conditions. The thorough investigation of resistance spot welding (RSW) parameters and their influence on the integrity of 316L sheet joints provides significant insights for industries that heavily rely on durable welded structures, including aerospace, automotive, and chemical processing sectors.

Keywords: Resistance spot welding, 316L stainless steel, welding parameters, microstructure, mechanical properties, corrosion resistance, fatigue behavior, joint performance, optimization, welded structures

INTRODUCTION

In today's industrial landscape, the priority is to minimize production costs and time while boosting overall profitability [1]. Resistance spot welding (RSW) has become a pivotal technique for the fusion of materials in diverse industrial contexts. In recent studies, researchers have conducted examinations to explore the complex microstructure of the nugget, with a specific focus on uncovering the magnetic properties present within the welded joint [2]. Moreover, scholarly investigations about the welding of advanced high-strength steel in the context of car frames underscore the necessity for additional research to enhance the efficiency of resistance spot welding techniques specifically for constructions with thin walls [3, 4]. There is an increasing inclination towards evaluating the efficacy of connections established between incompatible materials, such as aluminium alloy and low carbon steel. This necessitates a comprehensive examination and improvement of these interfaces [5].

Additionally, the research conducted by Başer highlights the importance of examining the impact of parameters, specifically about mid-frequency direct current technology, on the utilization of third-generation automobile steels in resistance spot

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welding (RSW) [6]. The examination of the impact of severe plastic deformation on the mechanical characteristics of resistance spot welded (RSW) aluminium joints suggest the possibility of modifying this procedure to achieve improved performance [7]. Schmolke *et al.* conducted a study that highlights the importance of conducting thorough investigations to enhance joint integrity in high-strength steel welding [8]. Specifically, the study focuses on the comparison between laser beam welding and resistance spot welding in the pursuit of achieving seam leak tightness. The necessity for more accurate and dependable welding processes is demonstrated by the investigation of the failure behavior of advanced high-strength steel caused by surface conditions and initial microstructure [9].

The investigation conducted by Sammaiah *et al*. highlights the significance of examining and optimizing weld parameters, specifically in the context of automotive applications, to understand the parametric effects on direct resistance spot welds [10]. Furthermore, the current emphasis in the field of optimizing robot spot welding parameters on low-carbon steel is in experimental research, highlighting the continuous requirement for parameter optimization in resistance spot welding (RSW) [11]. The study conducted by Pawar *et al*. emphasizes the need to comprehend the associations between microstructural features and mechanical properties in welded joints of ultra-low-carbon steel [12]. This research underscores the significance of such understanding in enhancing the overall quality of welds [7]. The study conducted by Aghajani *et al*. emphasizes the significance of microstructure engineering in the fusion zones of martensitic stainless steels, with a particular focus on the function played by specific elements in attaining the desired attributes of the weld [13]. In addition, the pursuit of enhancing the welding process is exemplified by the endeavor to optimize hot forming temperatures to mitigate liquid metal embrittlement in resistance spot welded zinc-coated medium manganese steel [14].

Baek *et al*. underscore the significance of comprehending and enhancing joint designs for lightweight vehicles by examining the impact of microstructural and geometrical parameters on the mechanical fatigue capabilities of aluminium/high-strength steel lap joints [15–18]. Recent studies have explored alternative welding processes, including friction stir spot welding and flexible laser spot welding, which have shown promise in enhancing or replacing traditional resistance spot welding (RSW) procedures for certain applications (Shamsolhodaei et al., 2022) [19]. Furthermore, scholarly investigations about the wear characteristics of spot-welding electrode materials have underscored the imperative of producing resilient materials capable of withstanding extended utilization in resistance spot welding (RSW) applications [18]. The study conducted by Ghatei-Kalashami *et al*. emphasizes the need to comprehend the distinct material behavior in resistance spot welding (RSW) through the examination of the microstructural evolution and mechanical properties of shape memory alloy sheets after the welding process [9]. The continuous pursuit of enhanced welding procedures is exemplified by the endeavors to improve mechanical performance by the regulation of the halo ring in Q&P 980 steel welds [20]. The necessity of optimizing welding conditions for different steel kinds is underscored by the imperative to comprehend the mechanical and fatigue characteristics of diverse steel joints [21].

Furthermore, the examination of the effects of elevated temperature heat input on the morphological and mechanical properties of duplex stainless-steel highlights the importance of regulating heat input to achieve the desired welding attributes [22–24]. The investigations underscore the imperative for additional research and enhancements in resistance spot welding procedures. This includes investigating various material combinations, adjusting parameters, and developing innovative welding techniques to attain enhanced joint integrity, mechanical properties, and performance tailored to specific applications [25]. The PTAW process parameters optimization was carried out using response surface methodology [26].

In recent years, there has been a significant amount of research conducted in the field of resistance spot welding (RSW). This surge in research activity can be attributed to the growing need for accurate and dependable welding methods, especially in materials that play a critical role in diverse industries. 316L stainless steel is a material that holds significant relevance due to its exceptional corrosion resistance and mechanical qualities. This publication aims to make a scholarly contribution to the field of resistance spot welding (RSW) by examining the complex interplay between welding process parameters, joint characteristics, and the overall performance of welds on 316L sheets.

The present work expands upon the research conducted by Mathiszik *et al*., which focused on the examination of the magnetic properties of the nugget microstructure in resistance spot welding [2]. While their primary emphasis was on a distinct material, the knowledge acquired about the intricate microstructural characteristics of the nugget establishes a fundamental comprehension that may be extended to other materials, such as 316L stainless steel. The study conducted by Dong *et al*. investigated the extent of zinc penetration and its interaction with grain boundaries in the process of resistance spot welding (RSW) [3]. The authors underscored the need of considering material-specific factors while performing welding procedures. The study conducted by Dong *et al*. primarily examined the behavior of QP980 steel [3]. However, the fundamental principles established in their research can be applied as a precedent for investigating the characteristics of 316L stainless steel when subjected to comparable welding conditions.

The study conducted by Rajarajan *et al*. examined the application of resistance spot welding (RSW) on advanced high-strength steel to construct automobile structural frames [4]. The authors emphasized the significance of RSW in the production of components that possess demanding performance criteria. The statement highlights the possible suitability of RSW (Resistance Spot Welding) for 316L stainless steel, a commonly used material in the automotive and aerospace sectors due to its corrosion resistance and biocompatibility properties [19]. Moreover, the examination of the integrity of resistance spot welding connections involving different materials, as elucidated by Nguyen *et al*., holds direct relevance to the prospective amalgamation of 316L stainless steel with various alloys or materials [5].

The study conducted by Başer focuses on the application of mid-frequency direct current technology in resistance spot welding of Zn-coated third-generation automobile steels [6]. This research highlights the continuous endeavors to enhance the efficiency of resistance spot welding procedures tailored to specific material combinations. The study focuses on the essential aspect of adapting optimization approaches to 316L stainless steel to tune welding parameters for improved joint characteristics and overall performance.

The study conducted by Sammaiah *et al.* examines the impact of parametric variations on direct resistance spot welds performed on AISI C1010 cold-rolled carbon steel [10]. This investigation offers significant contributions to our understanding of the intricate correlation between welding parameters and the properties of the welded joints. The comprehension can be applied to the examination of process parameters in the RSW technique for 316L stainless steel, providing a structured approach for conducting experiments and conducting analysis [23–25].

The increasing demand for durable and corrosion-resistant welded structures highlights the significance of refining the resistance spot welding method specifically for 316L stainless steel. The objective of this study is to address the current gaps in knowledge by using a wide variety of references. The aim is to thoroughly investigate the impact of process parameters in the RSW (Resistance Spot Welding) technique on the properties and effectiveness of joints created in sheets of 316L stainless steel.

MATERIAL SPECIFICATIONS

The primary material employed in this study is 316L stainless steel, renowned for its distinctive chemical composition that adheres to the specified criteria (ASTM A240/A240M) (Table 1). The composition of the substance is outlined in Kumar et al.'s (2022) study [17]. Moreover Figure 1 shows the samples utilized for the experimentation.

EXPERIMENTAL TEST

The tensile-shear tests were conducted on spot welding specimens using a WDW-300Y Series Universal Testing Machine with a load capability of 20 kN. The tests were performed at a crosshead

Table 1. Chemical composition of 316L stainless steel.

Grade	C %	Mn %	P %	S %
316L	0.022	1.25	0.045	0.004
Grade	*Si %*	*Cr %*	*Ni %*	*Mo %*
316L	0.42	16.16	10.03	2.06

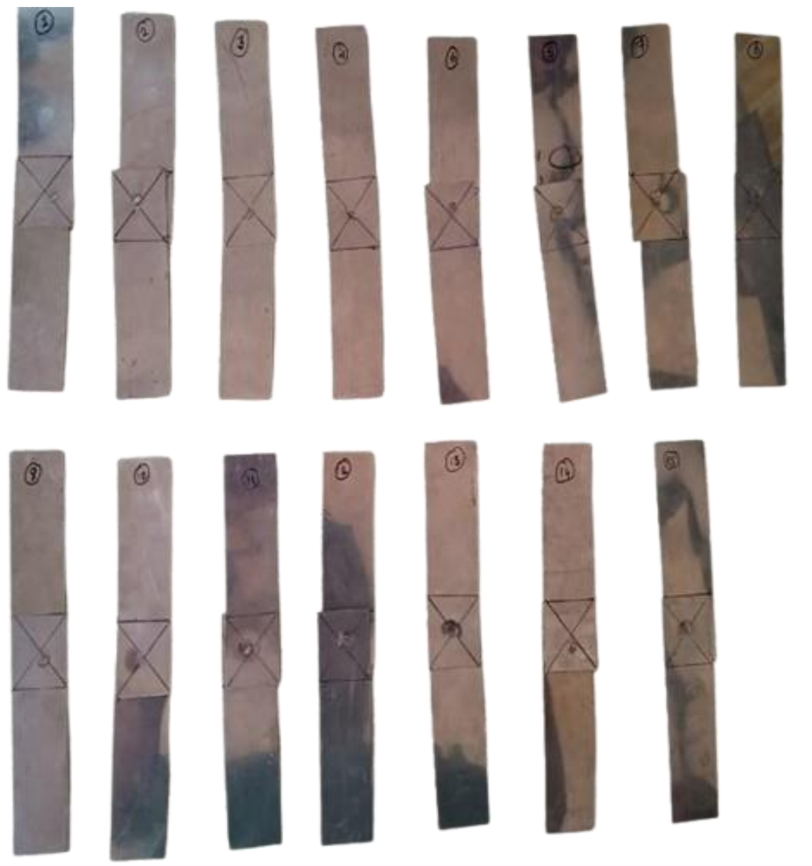

Figure 1. DoE Samples.

Table 2. Design of experiment (DoE) and result.

S.N.	Welding current (kA)	Pressure (bar)	Weld time (Cycle)	Tensile strength (kgf)
1	8	2	4	259.11
2	10	4	4	271.50
3	6	2	6	219.12
4	8	6	4	249.18
5	8	4	6	250.00
6	6	4	4	250.00
7	10	6	6	285.05
8	8	4	6	250.00
9	8	2	8	247.58
10	6	6	6	135.00
11	10	4	8	315.02
12	6	4	8	193.60
13	8	6	8	247.10
14	10	2	6	212.80
15	8	4	6	251.00

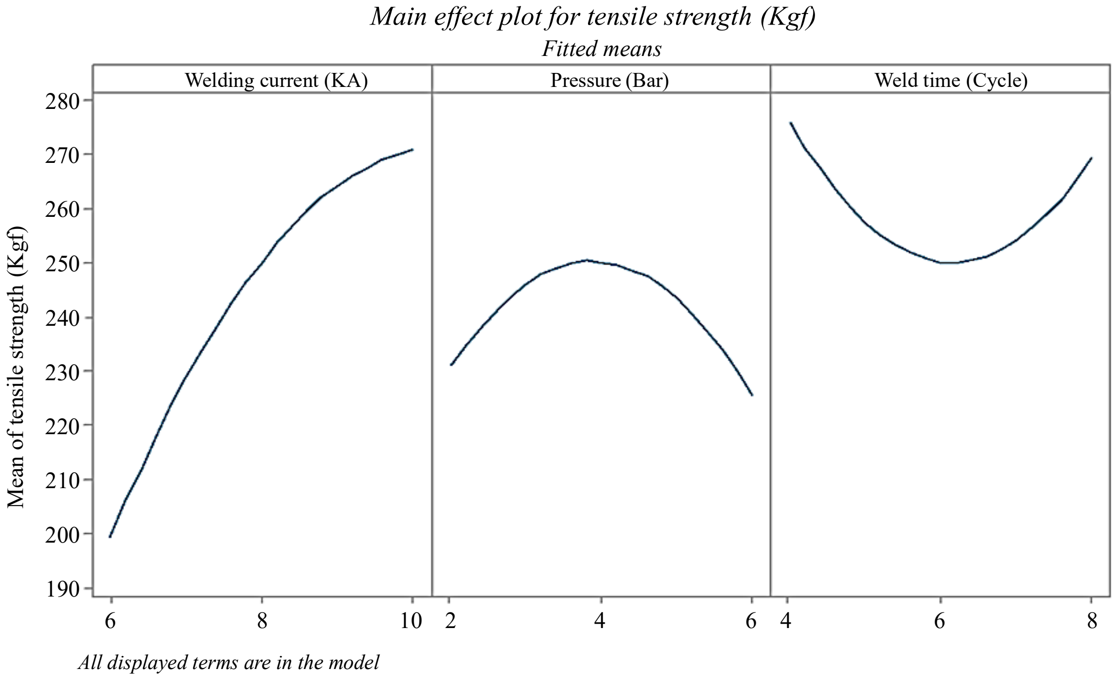

Figure 2. Main effect plot for tensile strength.

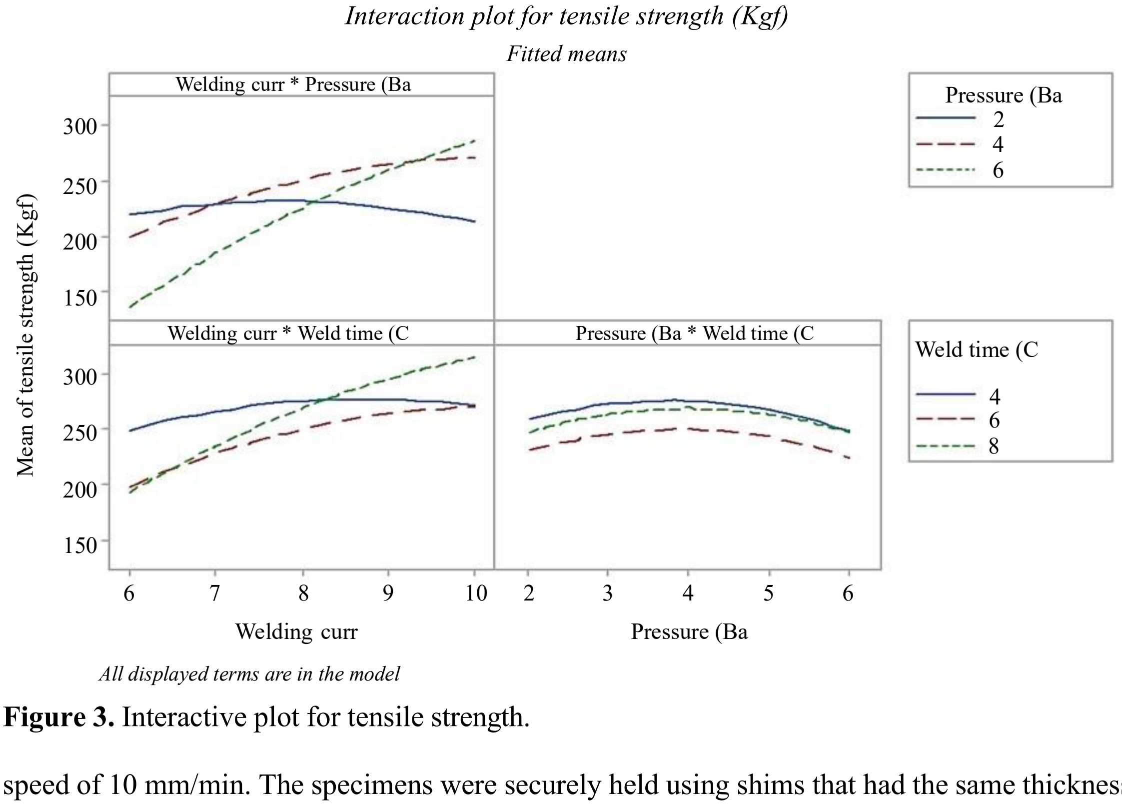

Figure 3. Interactive plot for tensile strength.

speed of 10 mm/min. The specimens were securely held using shims that had the same thickness as the welding specimens (Table 2).

To determine the tensile stress values for the two samples with the highest and lowest results in the tensile-shear tests, conducted on an exposed area of 1 cm^2 using the potentiated and cyclic anodic polarization technique as per the ASTM G 5-9430 standard. Additionally, Figure 2 represents the mains effects plot for tensile strength and Figure 3 shows the interactive plot for tensile strength.

CONCLUSION

In summary, it is imperative to consider the crucial role of resistance spot welding (RSW) process parameters in determining joint features and performance to guarantee the integrity and dependability of welded connections. Extensive study and testing have conclusively demonstrated that the selection and adjustment of resistance spot welding (RSW) process parameters exert a substantial influence on multiple facets of joint quality, including weld nugget size, mechanical properties, and overall performance. The heat input, thermal cycles, and pressure exerted during the welding process are directly influenced by the process parameters, such as welding current, welding time, electrode force, and electrode material. Through meticulous manipulation of these parameters, one may effectively govern the development of the weld nugget, a critical factor in establishing the strength and soundness of the joint. Furthermore, the appropriate choice of process parameters can effectively address concerns related to weld flaws, encompassing porosity, cracking, and inadequate penetration.

The improvement of resistance spot welding (RSW) process parameters has been found to result in enhanced joint performance. Through the attainment of the desired weld quality and integrity, the joints demonstrate improved mechanical characteristics, such as greater tensile strength, fatigue resistance, and corrosion resistance. The attributes play a vital role in guaranteeing the structural soundness and durability of welded elements across diverse sectors, including automotive, aerospace, and construction. Moreover, the impact of RSW process parameters extends beyond the properties of the joint. Furthermore, it has an impact on the efficiency of the process as well as its cost-effectiveness. Through the process of parameter optimization, manufacturers have the capacity to decrease energy consumption, manufacturing time, and material waste, hence resulting in enhanced productivity and increased economic feasibility.

In essence, comprehending and managing the impact of RSW process parameters on joint attributes and efficacy is imperative in attaining welded joints of superior quality and dependability. The appropriate selection and optimization of parameters leads to enhanced joint strength, mechanical characteristics, and overall performance. Furthermore, it improves operational efficiency and cost-efficiency. Further study and development in this domain will make significant contributions to the progression of resistance spot welding technology, ultimately yielding advantageous outcomes for diverse industries reliant on welded components.

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