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# Optimization of Spot Welding Parameters on Shear Tensile Strength of 0.9 mm SPCC Material using the Taguchi Methods

**Yudha Samodra[1], Adhi Setya Hutama[2]*, Perwita Kurniawan[2], Winastwan Sista Hayu[2], Th. Adi Nugroho[3]**
[1]Rekayasa Teknologi Manufaktur, Politeknik ATMI Surakarta,
[2] Perancangan Manufaktur, Politeknik ATMI Surakarta,
[3]Teknik Perancangan Mekanik dan Mesin, Politeknik ATMI Surakarta,
Jl. Mojo No. 01, Karangasem, Laweyan, Surakarta
* E-mail: setya.hutama@atmi.ac.id

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***Abstract***

*Resistance spot welding (RSW) is one of the most widely used joining methods for thin metal sheets in the manufacturing industry, particularly for low-carbon steel materials such as SPCC. At PT. XYZ, inconsistencies in weld quality have been observed due to the absence of optimized process parameters. This study aims to analyze the influence of spot welding parameters—welding current, welding time, and holding time—on the shear tensile strength of 0.9 mm SPCC material. The Taguchi method with an L9 orthogonal array experimental design was employed to identify the optimal parameter combination. Shear tensile testing was conducted in accordance with ISO 14273:2016, while data analysis was performed using the Signal-to-Noise (S/N) ratio with the "larger is better" criterion and Analysis of Variance (ANOVA).The results indicate that welding current is the most dominant factor, contributing 71.12% to the variation in shear tensile strength, followed by welding time at 21.11%, while holding time has a relatively minor contribution of 5.66%. The optimal condition was achieved at 34 kA (welding current), 15 cycles (welding time), and 10 cycles (holding time), yielding a maximum shear tensile strength of 572.06 kgf and an S/N ratio of 54.00 dB. This study demonstrates that the Taguchi method is effective for optimizing spot welding parameters with a minimal number of experiments, providing a reliable technical guideline to improve the quality and consistency of production processes in the manufacturing industry.*

***Keywords:*** *Resistance spot welding (RSW); SPCC steel; Taguchi method; shear tensile strength; welding parameters*

**Abstrak**

Pengelasan titik (resistance spot welding/RSW) merupakan salah satu metode penyambungan yang paling banyak digunakan untuk lembaran logam tipis dalam industri manufaktur, khususnya pada material baja karbon rendah seperti SPCC. Di PT. XYZ, terjadi ketidakkonsistenan kualitas las akibat belum diperolehnya parameter proses yang optimal. Penelitian ini bertujuan untuk menganalisis pengaruh parameter pengelasan titik—arus pengelasan (welding current), waktu pengelasan (welding time), dan waktu penahanan (holding time)—terhadap kekuatan tarik geser pada material SPCC tebal 0,9 mm. Metode Taguchi dengan desain eksperimen array ortogonal L9 digunakan untuk mengidentifikasi kombinasi parameter yang paling optimal. Pengujian tarik geser dilakukan sesuai standar ISO 14273:2016, sedangkan analisis data menggunakan rasio Sinyal-ke-Bisingan (Signal-to-Noise/SN) dengan kriteria "lebih besar lebih baik" (larger is better) dan Analisis Variansi (ANOVA). Hasil penelitian menunjukkan bahwa arus pengelasan merupakan faktor dominan dengan kontribusi sebesar 71,12% terhadap variasi kekuatan tarik geser, diikuti oleh waktu pengelasan sebesar 21,11%, sementara waktu penahanan hanya memberikan kontribusi sekitar 5,66%. Kondisi optimal dicapai pada parameter 34 kA (arus pengelasan), 15 siklus (waktu pengelasan), dan 10 siklus (waktu penahanan), yang menghasilkan kekuatan tarik geser maksimum sebesar 572,06 kgf dengan nilai S/N ratio sebesar 54,00 dB. Penelitian ini membuktikan bahwa metode Taguchi efektif digunakan untuk mengoptimalkan parameter pengelasan titik dengan jumlah percobaan yang minimal, serta dapat memberikan panduan teknis yang andal untuk meningkatkan kualitas dan konsistensi proses produksi di industri manufaktur.

**Kata kunci:** RSW; SPCC steel; Taguchi method; shear tensile strength; welding parameters

## 1. Introduction

Resistance spot welding (RSW) is one of the most widely used joining methods in the manufacturing industry, particularly for thin sheet materials such as low-carbon steel [1]. This process is extensively applied in the automotive, electronics, and household appliances industries due to its efficiency, speed, and ability to produce structurally strong joints [2]. RSW operates by passing an electric current through two electrodes that apply pressure on two or more metal sheets, generating heat at the interface due to electrical resistance. This heat induces localized melting and the formation of a weld nugget, which constitutes the core of the joint strength[3].

One of the industries utilizing resistance spot welding (RSW) in its production process is PT. XYZ, particularly within its Sheet Metal Work Fabrication division. RSW is applied for joining thin structural components made of SPCC (Steel Plate Cold-Rolled Commercial). SPCC is a low-carbon steel produced through cold rolling, characterized by excellent ductility and uniform thickness, making it highly suitable for sheet metal fabrication applications [4]. In its production process, PT. XYZ employs a TECNA TE-180 spot welding machine from 1994 to perform resistance spot welding on 0.9 mm thick SPCC sheets. Based on observations conducted on the production floor, several issues were identified in the production process using the aforementioned machine, particularly concerning the weld joint quality of 0.9 mm SPCC material at PT. XYZ. This inconsistency poses a potential risk to the structural reliability of the final product. One of the suspected factors contributing to this instability is the absence of optimized welding parameters. In light of these findings, an optimization of welding parameters is required to maximize and stabilize the shear tensile strength of the spot welds.

Several relevant studies on welding parameter optimization to achieve improved tensile strength quality have been previously conducted. For instance, one study evaluated the weld quality of titanium alloy TC2 using a hybrid approach based on regression analysis & artificial neural networks, revealing that welding current and welding time are the dominant parameters most influencing nugget formation & joint strength [5]. Another study demonstrated that increasing welding current enhances the shear tensile strength in AISI 409M stainless steel; however, excessive current may lead to expulsion & internal defects, highlighting the necessity for an optimal combination of welding parameters [6].

An experimental study on welding parameter optimization for AISI 304 stainless steel employed an L9 orthogonal array and signal-to-noise (S/N) ratio analysis. The results indicated that welding current is the most dominant factor affecting shear tensile strength, contributing over 70% according to ANOVA—findings consistent with those reported in this study [7]. Through only nine experimental trials (L9 array), the study achieved an 18% improvement in joint strength compared to standard conditions, while simultaneously reducing test result variability. This approach demonstrates that the Taguchi method is highly efficient for industrial applications, particularly when time and cost constraints are critical considerations [8]

Based on the aforementioned explanations, optimization of resistance spot welding (RSW) parameters is necessary to maximize the shear tensile strength of 0.9 mm SPCC material. The novelty of this study lies in the application of the Taguchi method for optimizing RSW parameters on 0.9 mm SPCC material within a manufacturing industrial setting—a subject that has not been extensively reported in prior research.

This study has purpose to analyze the influence of spot welding parameters—namely welding current, welding time, and holding time—on the shear tensile strength of 0.9 mm SPCC material. The Taguchi method with an L9 orthogonal array experimental design is employed to identify the optimal parameter combination for maximizing joint strength. The results are expected to provide a reliable technical guideline for improving the quality and consistency of the production process in the manufacturing industry.

## 2. Material and Method

### 2.1. Material

The material used in this study is SPCC (Steel Plate Cold-Rolled Commercial) with a thickness of 0.9 mm and length-width dimensions conforming to ISO 14273 (Figure 1). This material is one of the production materials employed at PT. XYZ. SPCC is a cold-rolled steel product characterized by excellent ductility, smooth surface finish, and uniform

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thickness, making it widely used in sheet metal fabrication applications such as structural components and body panels [4]. The chemical composition of SPCC consists of a maximum of 0.15% carbon (C), up to 0.60% manganese (Mn), a maximum of 0.10% phosphorus (P), and 0.05% sulfur (S), with the remainder being iron (Fe). Its mechanical properties exhibit a maximum tensile strength of approximately 270 MPa and a minimum elongation of 36%, indicating high plastic deformability [4].

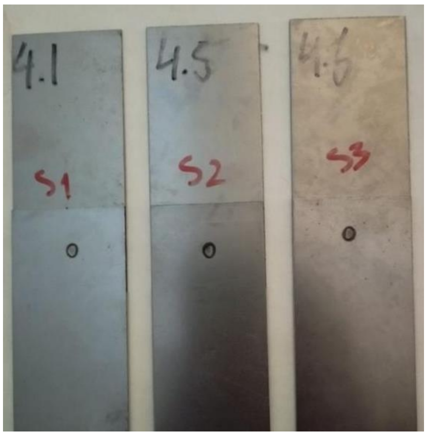



**Figure 1.** Speciment for This Research

There are Several instruments and machines were used in this study, including a spot welding machine, a tensile testing machine, and auxiliary measuring devices. The detailed specifications of these equipment are presented in **Table 1.**

**Table 1.** Tools for This Research

| Tools | Function |
|---|---|
| Universal Testing Machine GD-1100-100B  | Tensile Tester Machine |
| Spot Welding TECNA TE-180  | Spot Welding Machine |

2.2. Methods

The Taguchi method is a part of Design of Experiments (DOE) that is widely used for process optimization with a minimal number of experimental trials [3], [5]. A key advantage of this method is its ability to simplify complex experimental designs into a relatively small number of tests without compromising the quality of the analysis.

Furthermore, the Taguchi method incorporates Signal-to-Noise Ratio (S/N) analysis, which facilitates the identification of dominant factors and the most robust parameter combinations against process variations [6]. The method has also been applied in various studies, such as optimizing parameters to reduce burn defects [7] and analyzing the influence of hardening parameters on distortion in CT58 specimens [8].

The independent variables analyzed include welding current (kA), welding time (cycles), and holding time (cycles), each set at three levels as shown in **Table 2**. The selection of these three parameters is based on their critical role in determining the quality of resistance spot welding (RSW) joints. Welding current was selected as it is the most dominant factor influencing nugget size and joint tensile strength [9], [10]. Welding time controls the amount of heat input during the welding process; insufficient time may result in inadequate nugget formation, while excessive time increases the risk of expulsion or internal defects [11]. Holding time is included because it affects nugget cooling and joint solidification, thereby influencing the stability and consistency of tensile test results [12]. Therefore, these three variables are considered key parameters in spot welding and are highly relevant for analysis within the context of process optimization.

**Table 2**. Independent Variable and Level

| No. | Variabel Bebas | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| **1** | Welding Current (kA) | 18 | 26 | 34 |
| **2** | Welding Time (cycle) | 5 | 10 | 15 |
| **3** | Holding Time (cycle) | 5 | 10 | 15 |

In this study, an L9 orthogonal array was employed, enabling the analysis of the effects of three parameters at three levels with only nine experimental runs. The selection of the L9 array was based on efficiency considerations, as a full factorial design for three factors at three levels would require 27 experiments. By using the L9 array (**Table 3**), the number of trials is reduced by two-thirds, while still providing sufficient information to evaluate the influence of each factor [13]. This approach aims to identify the optimal parameter combination that is not only effective in maximizing joint strength but also robust against process variations.

**Table 3.** Orthogonal Array L9

| Run | Welding Current (kA) | Welding Time (cycle) | Holding Time (cycle) |
|---|---|---|---|
| **1** | 18 | 5 | 5 |
| **2** | 18 | 10 | 10 |
| **3** | 18 | 15 | 15 |
| **4** | 26 | 5 | 10 |
| **5** | 26 | 10 | 15 |
| **6** | 26 | 15 | 5 |
| **7** | 34 | 5 | 15 |
| **8** | 34 | 10 | 5 |
| **9** | 34 | 15 | 10 |

In the analysis phase, the Signal-to-Noise (S/N) ratio is used to evaluate the performance of each parameter combination. The general formula for the S/N ratio with the "Larger is Better" criterion is given in Equation (1):

$$\frac{S}{N} = -10\log_{10}\frac{1}{n}\sum_{i=0}^{n}\frac{1}{y\frac{1}{y_i^2}} \quad (1)$$

where yi represents the individual shear tensile strength measurement from the i -th trial, and n is the number of repetitions per experiment. This S/N ratio formulation is applied to maximize the response (shear tensile strength), emphasizing both higher mean values and reduced variability, thus enabling the identification of robust parameter settings where n is the number of experimental replications and yi is the response value (tensile shear force) from the i -th trial [14] [15]. This "Larger is Better" criterion was selected based on the fact that higher tensile shear force values indicate superior structural joint quality.

Subsequently, the S/N ratio analysis results are used to determine the optimal level for each factor. To identify the relative contribution of each independent variable to the response variation, Analysis of Variance (ANOVA) is performed. ANOVA enables the calculation of the percentage contribution of each factor, F-test values, and significance levels (p-values), thereby allowing the identification of the most dominant factors influencing tensile shear force [9], [10]

## 3. Results and Discussion

The tensile shear force tests were conducted by combining the levels of the independent variables, with three replications performed for each parameter combination. The results of the tensile shear tests on 0.9 mm SPCC material for the nine experimental runs based on the L9 orthogonal array are presented in **Table 4**. The response values, expressed in terms of tensile shear force (kgf), were obtained through tensile testing in accordance with ISO 14273:2016.

These data were subsequently used to calculate the Signal-to-Noise (S/N) ratio using the "larger is better" criterion and further analyzed via Analysis of Variance (ANOVA). This approach enables the identification of the optimal parameter combination as well as the determination of the most dominant factor influencing joint strength.

**Table 4.** Result L9 Experiment

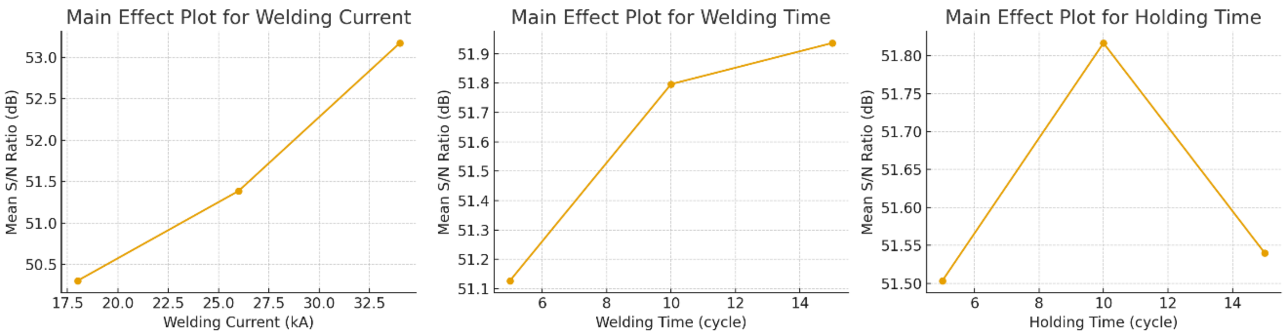
| **Run** | **Welding Current (kA)** | **Welding Time (cycle)** | **Holding Time (cycle)** | **Tensile Shear Force (kgf)** | | | **S/N Ratio (dB)** |
|---|---|---|---|---|---|---|---|
| | | | | I | II | III | |
| **1** | 18 | 5 | 5 | 317,13 | 315,60 | 316,11 | 50,01 |
| **2** | 18 | 10 | 10 | 342,63 | 312,03 | 323,76 | 50,25 |
| **3** | 18 | 15 | 15 | 360,98 | 320,19 | 344,67 | 50,65 |
| **4** | 26 | 5 | 10 | 385,45 | 368,12 | 339,57 | 51,20 |
| **5** | 26 | 10 | 15 | 381,38 | 403,30 | 385,96 | 51,80 |
| **6** | 26 | 15 | 5 | 373,73 | 355,37 | 355,88 | 51,16 |
| **7** | 34 | 5 | 15 | 391,06 | 418,09 | 409,93 | 52,17 |
| **8** | 34 | 10 | 5 | 463,46 | 480,29 | 450,72 | 53,34 |
| **9** | 34 | 15 | 10 | 572,06 | 550,14 | 548,10 | 54,00 |

After obtaining the tensile shear test results and calculating the Signal-to-Noise (S/N) ratio using the "larger is better" criterion, the next step involves constructing main effects plots for each factor. These plots are used to examine the influence of each parameter—welding current, welding time, and holding time—on the mean S/N ratio. Details of these plots are presented in **Figure 2.**

At a welding current of 18 kA, the average shear tensile strength ranges between 317–361 kgf. This increases to 374–403 kgf at 26 kA, and reaches its highest value of up to 572 kgf at 34 kA. This trend clearly indicates that welding current is the most influential factor on joint quality, as it directly determines the amount of heat generated at the weld zone.

Variations in welding time and holding time also affect the tensile shear strength, although their contributions are less significant compared to welding current. Increasing the welding time from 5 to 15 cycles generally improves joint strength due to more adequate heat input; however, fluctuations are observed in certain combinations, likely caused by excessive melting or inconsistent cooling rates. Meanwhile, holding time exhibits a relatively minor effect on shear tensile strength, as evidenced by the small and non-significant differences in response values across its levels.

The S/N ratio values for each experimental run show a consistent trend with the measured tensile shear force: higher tensile strength corresponds to higher S/N ratio. The optimal condition is achieved in Run 9, with parameters set at 34 kA (welding current), 15 cycles (welding time), and 10 cycles (holding time), yielding a tensile shear force of 572.06 kgf and an S/N ratio of 54.00 dB. This combination represents the most robust and high-performing setting within the tested parameter range.




**Figur 2**. SNR Graphics

After obtaining the main effects plots, which illustrate the trend of each factor's influence on the S/N ratio values, the next step is to perform a quantitative analysis using Analysis of Variance (ANOVA). This analysis is essential for calculating the relative contribution of each factor to the response variation, thereby enabling the identification of the most dominant parameter affecting the shear tensile strength of the weld joint. **Table 5** presents the results of the ANOVA calculation conducted using SPSS software.

**Table 5**. ANOVA Table

| Faktor | SS | DOF | MS | F | Kontribusi (%) |
|---|---|---|---|---|---|
| **Welding Current** | 9.67 | 2 | 4.835 | 37.53 | 71.12 |
| **Welding Time** | 2.87 | 2 | 1.435 | 11.13 | 21.11 |
| **Holding Time** | 0.77 | 2 | 0.385 | 2.98 | 5.66 |
| **Error** | 0.26 | 2 | 0.130 | – | 2.11 |
| **Total** | 13.57 | 8 | – | – | 100 |

Based on the table, welding current contributes the most significantly—approximately 71.12%—with an F-value substantially higher than that of the other factors. This confirms that welding current is the most influential parameter in nugget formation and in determining the shear tensile strength of the weld joint. Welding time ranks as the second most significant factor, contributing 21.11%, indicating that welding duration also plays a crucial role in ensuring the formation of a strong and consistent weld. In contrast, holding time contributes only about 5.66%, reflecting its relatively minor influence on response variation. Therefore, it can be concluded that the most influential factor affecting joint quality in resistance spot welding of 0.9 mm SPCC material is welding current, followed by welding time, while holding time has the least impact.

## 4. Conclusion

This study aimed to analyze the influence of spot welding parameters—namely welding current, welding time, and holding time—on the shear tensile strength of 0.9 mm SPCC material using the Taguchi method with an L9 orthogonal array experimental design. The results indicate that this objective has been successfully achieved. The Signal-to-Noise (S/N) ratio analysis and ANOVA results confirm that welding current is the dominant factor, contributing the largest proportion—approximately 71.12%—to the variation in shear tensile strength, followed by welding time with a contribution of 21.11%. In comparison, holding time has a relatively minor influence, accounting for only 5.66% of the variation. The optimal parameter combination was achieved at 34 kA (welding current), 15 cycles (welding time), and 10 cycles (holding time), yielding the highest shear tensile strength of 572.06 kgf and an S/N ratio of 54.00 dB. Thus, this study successfully identifies the most optimal parameter set for maximizing joint quality in resistance spot welding of thin-gauge SPCC sheets. These findings can serve as a reliable technical guideline for manufacturing industries, particularly in enhancing the quality and consistency of production processes involving resistance spot welding.

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