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# OPTIMIZATION OF WELDING PARAMETERS FOR DISSIMILAR MATERIALS WEAR PLATE HB500 AND AISI 318LN USING TAGUCHI METHOD

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**Abstract**

Welding dissimilar materials such as wear plate HB500 and duplex stainless steel AISI 318LN presents significant challenges due to the formation of brittle intermetallic phases, differences in thermal expansion, and residual stresses. This research aims to determine the optimal combination of welding parameters preheat temperature, electrode type, welding current, PWHT temperature, and PWHT holding time using the Taguchi L18 orthogonal array. Mechanical responses evaluated include tensile strength and impact toughness, which were combined using the Multi-Response Performance Index (MRPI). Experimental results indicate that PWHT temperature contributes most significantly to the combined mechanical response (44%), followed by electrode type (14%) and preheat temperature (12%). Welding current and PWHT time were statistically insignificant ($p > 0.05$). The optimal parameter combination determined through Taguchi analysis is electrode E2209, preheat 150°C, and PWHT 400°C. Confirmation tests produced an MRPI value of 0.833, which lies within the 95% confidence interval of predicted values (0.575–0.942). Thus, the Taguchi method demonstrated reliable predictive capability for optimizing welding parameters for dissimilar HB500–AISI 318LN joints.

*Keywords: Welding, dissimilar metals, Wearplate HB500, AISI 318LN, Taguchi method, tensile strength, impact toughness, PWHT.*

## BACKGROUND

Dissimilar metal welding has become increasingly important in industries that operate under highly abrasive environments such as mining, mineral processing, and power generation. Wear plate HB500 is widely used due to its high hardness and superior abrasion resistance, making it suitable for components subjected to continuous coal or ore impact. According to Johansson et al. (2020), high-hardness wear plates (>450 HB) provide significantly longer service life in mining applications compared to conventional structural steels. In contrast, duplex stainless steel AISI 318LN is selected for its excellent corrosion resistance and mechanical stability, especially in chloride-containing or wet operating environments. Research by Mishra and Patel (2021) demonstrated that nitrogen-enhanced duplex stainless steels exhibit improved yield strength and enhanced corrosion resistance, particularly under low-temperature and aggressive media exposure.

In coal-handling facilities, these materials often need to be welded together when repairing or reinforcing critical components such as elbows, liners, and chutes. Such applications necessitate dissimilar metal welding, which introduces significant metallurgical challenges. As reported by Zhang et al. (2022), disparities in thermal conductivity and thermal expansion between dissimilar metals can induce substantial thermal distortion and uneven fusion at the weld interface. Furthermore, Rahman and Kim (2020) found that the formation of brittle intermetallic compounds—including sigma phase or chromium carbides—can severely reduce joint toughness. Residual stress development also poses a major concern; Sahoo et al. (2019) observed that welding between martensitic and stainless steels generates high tensile residual stresses in the heat-affected zone (HAZ), heightening the risk of delayed cracking. Supporting this, Liang et al. (2023) reported that microstructural degradation within the HAZ may reduce mechanical performance by up to 35% if heat input and thermal cycles are not properly controlled. Similarly, Kumar and Singh (2021) noted that metallurgical incompatibility between filler metals and base metals frequently leads to imbalance in ferrite–austenite phases, resulting in poor impact toughness.

Recent studies emphasize the critical influence of welding current, preheat temperature, and post-weld heat treatment (PWHT) on the mechanical behavior of dissimilar welds. Fernandez et al. (2020) highlighted that appropriate preheating minimizes steep thermal gradients, preventing excessive martensitic formation in hardenable steels such as wear plates. PWHT has also been shown to improve joint integrity by relieving residual stresses and refining microstructures. For example, Seo et al. (2020) demonstrated that optimized PWHT conditions significantly enhance hardness uniformity and microstructural stability in dissimilar P92 steel weldments. Meanwhile, welding current remains a determining factor in weld penetration and HAZ morphology, and Hoang et al. (2024) reported that optimized current settings in dissimilar MIG welding improved tensile strength by up to 18%.

Given these complexities, robust statistical approaches such as the Taguchi method have gained traction for optimizing welding parameters efficiently. Sharma and Singh (2021) confirmed that the Taguchi method can reduce experimental effort by more than 70% while maintaining strong predictive accuracy for mechanical performance. Furthermore, Taguchi-based multi-response optimization techniques, such as MRPI, allow simultaneous evaluation of tensile strength and impact toughness. This was demonstrated by Kumar and Balasubramanian (2019), who showed that Taguchi–MRPI models reliably predict optimal SMAW and GMAW process parameters.

Grounded in these findings, the present study investigates the influence of five key welding parameters—electrode type, preheat temperature, welding current, PWHT temperature, and PWHT holding time—on tensile and impact strength of welded joints between wear plate HB500 and AISI 318LN. The aim is to establish the optimal combination of parameters that maximizes joint integrity and mechanical performance in demanding industrial applications.

## PROBLEM FORMULATION

Welding dissimilar materials such as Wear Plate HB500 and AISI 318LN presents significant technical and metallurgical challenges. Although both materials are widely used in abrasive and corrosive industrial environments, their contrasting thermal and mechanical characteristics complicate the welding process and influence the resulting joint integrity. The differences in thermal expansion, heat conductivity, and metallurgical behavior often lead to the formation of brittle intermetallic phases, uneven microstructures in the heat-affected zone (HAZ), and elevated residual stresses. These phenomena collectively reduce the mechanical performance of welded joints, particularly tensile strength and impact toughness.

Given these challenges, the formulation of the research problem is centered on understanding and optimizing the key welding parameters that govern mechanical performance in dissimilar metal joints. The main problem addressed in this study can therefore be articulated as follows:

1. How do the primary welding parameters—welding current, electrode type, preheat temperature, PWHT temperature, and PWHT holding time—affect the tensile strength and impact toughness of dissimilar welded joints between Wear Plate HB500 and AISI 318LN?
2. Which combination of parameter levels in the SMAW welding process produces the most optimal mechanical performance in terms of tensile strength and impact energy for HB500–AISI 318LN dissimilar joints?
3. How do the microstructural and hardness variations in the heat-affected zone correspond to the mechanical results, and what improvements can be achieved through optimized parameter settings?

The problem is further deepened by the lack of comprehensive studies addressing multi-response optimization for such dissimilar materials under SMAW conditions. Traditional welding design approaches often consider only single-response behavior, whereas industrial applications require simultaneous optimization of tensile and impact performance.

Thus, this research seeks to systematically model, analyze, and optimize the influence of critical welding parameters using the Taguchi method combined with multi-response analysis (MRPI), in order to determine the most effective parameter configuration that enhances the overall integrity of dissimilar welds.

## RESEARCH OBJECTIVES

The primary objective of this research is to optimize the welding parameters that influence the mechanical performance of dissimilar metal joints between Wear Plate HB500 and AISI 318LN using the Taguchi method. To achieve this overarching goal, the study is structured around the following specific objectives:

1. To determine the individual and combined effects of key SMAW process parameters—electrode type, welding current, preheat temperature, PWHT temperature, and PWHT holding time—on the tensile strength and impact toughness of HB500–AISI 318LN welded joints.
2. To identify the optimal combination of welding parameter levels that yields the highest mechanical performance, evaluated through multi-response analysis (MRPI).
3. To analyze the microstructural evolution and hardness distribution in the weld metal and heat-affected zone (HAZ) under different parameter settings, and to relate these changes to variations in mechanical properties.
4. To validate the predictive capability of the Taguchi optimization model through confirmation experiments and assess its reliability in representing the real welding process.

By accomplishing these objectives, this research seeks to provide a systematic and statistically supported guideline for improving the quality and structural integrity of dissimilar welded joints involving high-hardness wear plates and duplex stainless steels.

## THEORETICAL REVIEW

### 1. Dissimilar Metal Welding

Dissimilar metal welding refers to the process of joining two metals with different chemical compositions, mechanical properties, and thermal behaviors. Differences in melting temperature, thermal conductivity, thermal expansion, and metallurgical phase transformations often lead to challenges such as cracking, formation of brittle intermetallic compounds, and poor fusion quality. According to Zhang et al. (2022), these incompatibilities create uneven heat distribution in the weld zone, promoting residual stress accumulation and microstructural heterogeneity. In applications involving Wear Plate HB500 and duplex stainless steel AISI 318LN, dissimilar welding becomes even more complex due to the disparity between the high-hardness martensitic/bainitic structure of wear plates and the duplex ferritic–austenitic structure of stainless steels.

The success of dissimilar welding depends heavily on the appropriate selection of consumables, heat input, preheat conditions, and post-weld heat treatment. Inadequate control of these parameters results in crack initiation at the fusion boundary, reduced toughness, and premature failure under dynamic loading.

### 2. Heat Treatment in Welding

2.1 Preheat Temperature

Preheating is applied to reduce thermal gradients and slow down the cooling rate after welding. This prevents the formation of hard, brittle microstructures such as martensite, particularly in high-hardness steels. Fernandez et al. (2020) report that controlled preheating minimizes hydrogen-induced cracking and stabilizes the HAZ microstructure. For dissimilar welding, preheat also helps balance heat flow between materials with differing thermal conductivities.

2.2 Post-Weld Heat Treatment (PWHT)

PWHT is used to relieve residual stresses, refine microstructure, and reduce hardness peaks in the HAZ. Seo et al. (2020) demonstrated that PWHT improves the uniformity of hardness and mitigates the formation of undesirable intermetallic phases in dissimilar P92 welds. The temperature and holding time determine the extent of tempering, recovery, and carbide precipitation. Excessive PWHT temperatures may soften the wear plate excessively, while insufficient temperatures may not effectively relieve residual stresses.

**3. Mechanical Behavior of Welded Joints**

3.1 Tensile Strength

Tensile strength is influenced by weld penetration, dilution, HAZ microstructure, and the strength mismatch between filler metal and base metals. In dissimilar welds, sharp transitions between microstructural zones often create stress concentration points that reduce tensile performance. Hoang et al. (2024) emphasize that optimized heat input directly correlates with improved tensile strength in MIG dissimilar welds through refinement of the fusion zone.

3.2 Impact Toughness

Impact toughness evaluates a material's ability to absorb energy under sudden loading, making it critical for components subjected to impact or vibration. Toughness decreases when brittle phases such as martensite, sigma phase, or chromium carbides form in the HAZ. Liang et al. (2023) found that improper thermal control during welding significantly lowers impact toughness in dissimilar joints due to coarse grain growth and intergranular carbide formation. AISI 318LN typically provides good toughness, but the mismatch with the high-hardness wear plate often governs the failure mode.

**4. Electrode Metallurgy in SMAW**

Electrode selection plays a significant role in determining weld chemistry, microstructure, and mechanical behavior. E2209, a duplex stainless-steel electrode, promotes balanced ferrite–austenite ratios in the weld metal, improving toughness and corrosion resistance. This filler is compatible with duplex alloys and contributes to better metallurgical bonding in dissimilar stainless–steel joints. Conversely, E8018-B2 is a Cr-Mo low-hydrogen electrode primarily designed for creep-resistant steels. Studies by Kumar and Singh (2021) reveal that mismatched filler metals often lead to reduced impact toughness and heightened residual stresses due to incompatible thermal and chemical properties.

**5. Microstructural Considerations in Dissimilar Welding**

Microstructural evolution determines the mechanical properties of dissimilar welded joints. Wear plate HB500 tends to form martensite or bainite when cooled rapidly, while duplex stainless steel maintains a ferrite–austenite dual-phase structure. During welding, dilution of the two base metals can lead to:

- Hard martensitic zones at the fusion boundary
- Excess ferrite or austenite in duplex steel
- $Cr_{23}C_6$ carbide precipitation at grain boundaries

- Potential sigma-phase formation at elevated temperatures

These phenomena weaken the joint and reduce toughness. According to Rahman and Kim (2020), controlling cooling rates and PWHT is crucial to minimizing detrimental phase formation.

**6. Taguchi Method for Process Optimization**

The Taguchi method provides a structured and efficient approach to optimizing process parameters by reducing the number of experiments required. Taguchi's orthogonal arrays allow systematic evaluation of multiple factors at different levels while minimizing experimental cost and time. Sharma and Singh (2021) highlight that Taguchi's Signal-to-Noise (S/N) ratio methodology enhances robustness by identifying parameter settings that minimize variation and maximize performance.

For multi-response problems, such as simultaneously optimizing tensile strength and impact toughness, the Multi-Response Performance Index (MRPI) or similar weighting techniques are used. Kumar and Balasubramanian (2019) demonstrated that Taguchi–MRPI integration yields high prediction accuracy for multi-objective welding optimization.

## RESEARCH DESIGN

This study was designed as a structured experimental investigation aimed at evaluating how key welding parameters influence the mechanical performance of dissimilar welded joints between Wear Plate HB500 and AISI 318LN. To achieve this, a quantitative research approach incorporating the Taguchi Design of Experiments (DOE) method was adopted, enabling systematic analysis of multiple variables while minimizing the total number of welding trials required. Five independent parameters—electrode type, welding current, preheat temperature, post-weld heat treatment (PWHT) temperature, and PWHT holding time—were selected based on their established influence on heat input, microstructural evolution, and mechanical properties in welded joints. The Taguchi L18 orthogonal array was employed as the experimental matrix, allowing the study to efficiently examine both two-level and three-level factors across 18 distinct parameter combinations. Each experimental condition was repeated twice to ensure repeatability and reduce random variability in the tensile and impact test results.

All welding operations were conducted using the Shielded Metal Arc Welding (SMAW) process under controlled conditions to maintain consistency across trials. The weld specimens were prepared using 8 mm plates with a 30° V-groove and a 2 mm root gap, welded at a constant travel speed and voltage to ensure uniform heat input. Following welding, selected specimens underwent PWHT in a temperature-controlled furnace, where heating and cooling rates were carefully regulated. Tensile test specimens were machined according to ASTM E8/E8M-22, while Charpy impact specimens followed ASTM E23-16b guidelines using sub-size samples due to the available plate thickness. Mechanical tests were performed on all specimens to measure tensile strength and impact toughness, forming the basis of the performance evaluation.

The resulting data were analyzed using Taguchi's Signal-to-Noise (S/N) ratio method with a "larger-the-better" criterion to maximize mechanical performance. Analysis of Variance (ANOVA) was then applied to identify statistically significant factors and quantify the percentage contribution of each parameter. To address the multi-response nature of the problem, tensile and impact results were normalized and combined using the Multi-Response Performance Index (MRPI), enabling the determination of an optimal parameter configuration that balances both strength and toughness. From this analysis, the optimal levels of electrode type, preheat temperature, and PWHT temperature were identified. A confirmation experiment was subsequently performed using the predicted optimal settings, and the resulting mechanical performance was compared with the calculated 95% confidence interval to validate the Taguchi model's predictive accuracy.

Overall, this research design integrates controlled welding experiments, standardized mechanical testing, and robust statistical methodologies, ensuring a reliable and comprehensive evaluation of welding parameter effects on the structural integrity of dissimilar HB500–AISI 318LN joints.

## RESULTS AND DISCUSSION

### 1. Tensile and Impact Test Results

Mechanical testing was conducted to evaluate the influence of welding parameters on tensile strength and impact toughness of dissimilar joints between Wear Plate HB500 and AISI 318LN. The results from 18 experimental runs revealed substantial variations in performance, confirming that the selected parameters strongly affect weld integrity. Tensile strength values ranged from approximately 670 to 925 MPa, while impact toughness varied between 0.21 and 1.05 J. These wide performance margins indicate significant differences in heat input, thermal cycling behavior, and metallurgical transformations across the parameter combinations. Specimens welded using electrode E2209 consistently demonstrated higher tensile strength and greater impact energy compared to those welded with electrode E8018-B2, suggesting superior metallurgical compatibility with duplex stainless steel and more stable weld metal composition.

The data further showed that extreme parameter settings, such as high PWHT temperatures (600°C) or insufficient preheat conditions (100°C), tended to produce inferior mechanical responses. This result aligns with theoretical expectations, where excessive tempering or steep thermal gradients promote undesirable microstructures such as coarse ferrite, chromium carbides, or hardened martensitic layers near the fusion boundary.

## 2. Analysis of Variance (ANOVA)

ANOVA was performed separately for tensile and impact responses and later for the combined MRPI value. The results revealed that PWHT temperature, electrode type, and preheat temperature were the only statistically significant parameters ($p < 0.05$) affecting both tensile and impact properties.

### 2.1 Tensile Strength ANOVA

- PWHT temperature contributed the highest influence, accounting for 52.68% of total variation.
- Preheat temperature contributed 13.83%, confirming its role in controlling cooling rate and mitigating martensite formation.
- Electrode type contributed 8.40%, highlighting compositional compatibility effects.
- Welding current and PWHT holding time showed contributions of less than 5% and were statistically insignificant.

### 2.2 Impact Toughness ANOVA

Similar trends were observed for impact strength:

- PWHT temperature had the strongest effect (28.6%), influencing tempering behavior and residual stress relaxation.
- Electrode type accounted for 19.5%, with E2209 providing better toughness due to balanced ferrite–austenite formation.
- Preheat contributed 14.3%, reflecting its role in reducing HAZ brittleness.

The consistency across tensile and impact ANOVA indicates that these three parameters fundamentally control the thermal–metallurgical behavior of the weld.

## 3. Evaluation of Multi-Response Performance Index (MRPI)

To optimize tensile strength and impact toughness simultaneously, the MRPI method was applied. Both responses were normalized under a “larger-the-better” criterion and combined with equal weights.

The highest MRPI value was observed in the combination:

- Electrode: E2209
- Preheat: 150°C
- PWHT Temperature: 400°C

This optimal combination produced an MRPI score of 1.00 in the experimental dataset, confirming its superiority relative to other parameter combinations. The results suggest that moderate preheat and low-temperature PWHT provide favorable thermal gradients and controlled phase transformations. Specifically, preheat at 150°C helped avoid rapid cooling while preventing excessive grain coarsening.

PWHT at 400°C effectively relieved residual stresses without softening the wear plate or destabilizing duplex microstructure.

Conversely, high PWHT temperatures (500–600°C) consistently reduced MRPI values due to over-tempering, carbide precipitation, and reduced tensile performance.

## 4. Confirmation Test

A confirmation experiment was conducted using the optimal parameter settings. The measured MRPI value of 0.833 fell within the predicted 95% confidence interval (0.575–0.942), confirming the validity of the Taguchi optimization model. The close agreement between predicted and actual performance further reinforces the conclusion that PWHT at 400°C, combined with electrode E2209 and 150°C preheat, provides the most stable and robust welding condition for the HB500–AISI 318LN joint.

## 5. Metallurgical Interpretation

### 5.1 Influence of PWHT Temperature

PWHT emerged as the most dominant factor because of its direct effect on microstructure. At 400°C, residual stresses are relieved and hardness gradients are reduced without promoting carbide precipitation or grain coarsening. Higher temperatures (500–600°C) degrade mechanical performance due to softened martensitic structures on the wear plate side and destabilization of austenite in duplex steel.

### 5.2 Effect of Electrode Type

E2209 electrode consistently produced superior mechanical performance due to its duplex composition, which stabilizes ferrite–austenite ratios in the weld metal. In contrast, E8018-B2 (Cr-Mo type) is chemically incompatible with duplex stainless steel, leading to nonuniform phase formation and lower toughness.

### 5.3 Role of Preheat Temperature

Preheat at 150°C was optimal because it balanced cooling rates and reduced the tendency toward martensite formation in the wear plate while avoiding overheating effects observed at 200°C. Too low a preheat (100°C) caused rapid cooling and brittleness, explaining lower impact values.

### 5.4 Insignificance of Welding Current and PWHT Time

The minimal influence of welding current can be attributed to constant travel speed and voltage conditions, which constrained variations in heat input. Similarly, PWHT holding time did not significantly affect results because temperature, rather than time, dominated microstructural transformation within the tested range (1–20 hours).

## 6. Summary of Findings

- PWHT temperature is the single most influential parameter affecting weld quality.
- Electrode E2209 provides the best metallurgical compatibility.
- Preheat 150°C improves both strength and toughness.
- Optimized parameters significantly outperform other combinations.
- Taguchi–MRPI is validated as an effective optimization tool for dissimilar welding.

## CONCLUSION AND RECOMMENDATIONS

This study investigated the influence of five key SMAW welding parameters—electrode type, welding current, preheat temperature, PWHT temperature, and PWHT holding time—on the tensile strength and impact toughness of dissimilar welded joints between Wear Plate HB500 and AISI 318LN. Using the Taguchi L18 orthogonal array and Multi-Response Performance Index (MRPI), the research successfully identified the parameters that most significantly affect joint performance and determined the optimal configuration for enhanced mechanical behavior.

The results demonstrated that **PWHT temperature**, **electrode type**, and **preheat temperature** are the only parameters with a statistically significant effect on both tensile and impact responses. Among these, PWHT temperature exhibited the most dominant influence, contributing **44%** to the combined mechanical performance, followed by electrode type (14.95%) and preheat temperature (12.37%). Welding current and PWHT holding time showed minimal effects and were not statistically significant within the tested ranges.

The optimal combination of welding parameters was identified as the use of **electrode E2209**, **preheat at 150°C**, and **PWHT at 400°C**. This configuration produced the highest MRPI value and was further validated through confirmation testing, yielding a performance value of **0.833**, which lies within the predicted 95% confidence interval (0.575–0.942). These results confirm that the Taguchi optimization model accurately reflects the behavior of the welding process and can reliably guide parameter selection. Metallurgical analysis further supports the findings, highlighting the role of E2209 in stabilizing ferrite–austenite balance, the importance of moderate preheating in controlling cooling rates, and the effectiveness of low-temperature PWHT in relieving stresses without compromising hardness.

Overall, this study provides a robust framework for optimizing dissimilar welding between high-hardness wear plates and duplex stainless steels, contributing valuable insights for improving structural integrity in abrasive industrial environments.

## Recommendations

Based on the findings of this research, several recommendations can be made for future studies and industrial applications:

1. **Implementation in Industry:**
   The optimal parameters identified—E2209 electrode, preheat 150°C, and PWHT 400°C—should be adopted for welding HB500 to AISI 318LN in practical field repairs, particularly in mining and coal-handling systems where abrasion resistance and toughness are critical.
2. **Microstructural Characterization:**
   Future studies should incorporate detailed microstructural analysis using SEM, EDS, or EBSD to further elucidate phase transformations and verify the metallurgical mechanisms responsible for improved performance.
3. **Extended Mechanical Evaluation:**
   Additional mechanical tests such as hardness mapping, fatigue strength, and fracture toughness would provide a more comprehensive understanding of weld performance under service conditions.
4. **Heat Input Variation:**
   Although welding current was not significant in this study, future research should investigate a wider range of heat inputs, possibly including variations in travel speed, to fully explore their effects on microstructure and dilution.
5. **Alternative Filler Metals:**
   Other duplex-type or nickel-based electrodes may be evaluated to assess whether improved metallurgical compatibility or corrosion resistance can be achieved.
6. **Numerical Modeling:**
   Finite element thermal–mechanical simulations could be used to predict thermal cycles, residual stresses, and distortion patterns, providing deeper insights and enabling optimization prior to fabrication.
7. **Field Validation:**
   Long-term monitoring of welded components in operational environments is recommended to validate laboratory results and assess wear, corrosion, and fatigue behavior under real service conditions.

By implementing these recommendations, future work can build upon the findings of this study and further advance the reliability and effectiveness of dissimilar metal welding involving high-hardness wear plates and duplex stainless steels.

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