

Optimization of Process Parameters in Robotic Welding of Stainless Steel to Low Carbon Steel by the Taguchi Method. Review

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ABSTRACT

Dissimilar welding of stainless steel and low-carbon steel has received considerable attention due to its potential to combine corrosion resistance, strength, and economic advantages in automotive, marine, and structural applications. However, differences in chemical composition, thermal properties, and metallurgical behaviour create significant challenges in producing reliable joints. This review summarizes recent developments in robotic MIG/GMAW welding of stainless steel–low carbon steel dissimilar joints, with emphasis on the influence of process parameters and optimization techniques. The reviewed studies indicate that welding current and heat input are the dominant factors controlling penetration, dilution, hardness, and tensile performance, while filler metal selection strongly influences microstructural evolution and joint integrity. Taguchi-based optimization, ANOVA, Grey Relational Analysis, and Response Surface Methodology have been widely employed to improve weld performance. Despite significant progress in robotic welding, challenges remain in real-time adaptive control, defect prediction, and integrated process modelling. Future research should focus on combining robotics, artificial intelligence, sensor-based monitoring, and advanced simulation approaches for developing reliable and adaptive dissimilar welding systems.

Introduction

Welding is a definitive technique for fusing two or more metals or alloys by the use of pressure and/or heat (ECHEZONA ET AL., 2021);(Inspection, 2023).

Welding serves multiple purposes for joining dissimilar metals throughout various technical and industrial sectors, such as automotive, aerospace, maritime, and construction (Habib *et al.*, 2026).

Pressure welding methods for joining dissimilar metals are extensively used in many engineering fields, e.g., in nuclear power plants, coal fired boilers, automotive industry etc.(Ghosh, Pal and Nandi, 2017).

Due to the variations in physical, mechanical, and metallurgical properties of the base materials, the process of alloying dissimilar metals is often more complex than that of alloying similar metals (Scutelnicu *et al.*, 2021).

A multitude of industrial applications has extensively utilised robotic welding, which involves the employment of an automated programmable device for welding operations (Imam, Oterkus and Oterkus, 2024).

Robotic welding is garnering significant interest in the maritime sector because of its ability to improve the quality of marine constructions and optimise the production process (Imam, Oterkus and Oterkus, 2024).



Figure 1: Robotic MIG welding experimental setup and main instrument(Yao *et al.*, 2025)

The synthesis of materials that are generally incompatible has attained increasing

relevance in the industrial sector, allowing for notable decreases in product weight and

manufacturing costs, provided that appropriate safety and structural regulations are observed (REPORTS, 2026). A range of techniques, such as robotic, explosive,

ultrasonic, diffusion, friction, electron beam, arc, and resistance spot welding, can be applied to connect dissimilar metals (Ogedengbe *et al.*, 2018).

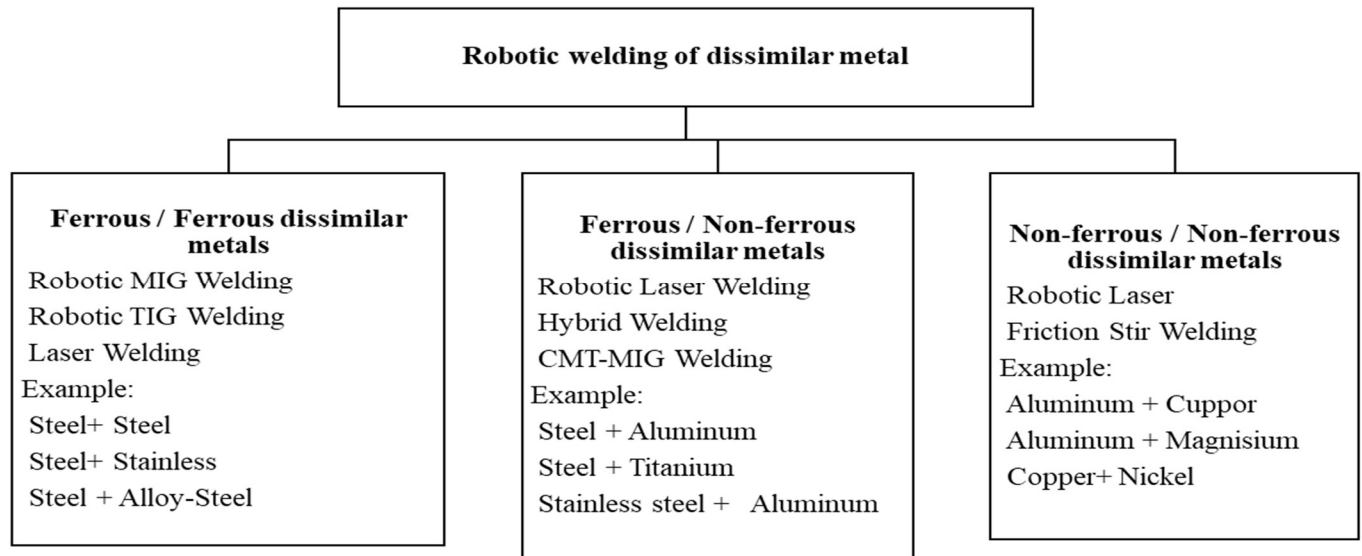


Figure 2: Various processes for dissimilar metals welding

This process often involves melting the workpieces and including a filler substance to create a weld pool that solidifies into a robust junction, occasionally employing pressure with heat, or independently, to achieve the weld (Jeet *et al.*, 2018).

(Citybabu and V, 2021) examined the fusion of dissimilar metals AISI 304 stainless steel and Mild Steel IS 2062 by the resistance spot welding technique to enhance weld integrity by fine-tuning process variables. AISI 304 stainless steel, which includes chromium, nickel, and manganese, offers superior corrosion resistance, ductility, and

formability owing to the development of a protective chromium oxide layer (Çayırhan and Karakoç, 2025). Conversely, Mild Steel IS 2062 has excellent toughness, ductility, malleability, weldability, and affordability, despite its inferior corrosion resistance (Series and Science, 2020)..

The distinct welding of stainless steel to low carbon steel is crucial in contexts that demand both corrosion resistance and mechanical durability. Nevertheless, these joints encounter difficulties because to varying thermal characteristics and metallurgical discordance (e.g., alloy

dilution, martensite development) (Kumar and Kumar, 2025).

Robots were first introduced in the 1960s within American industries, and since the 1980s, they have been employed for spot welding processes. Recently, robots are advancing rapidly in the arc welding process (YUVARAJ, 2018).

The Taguchi Method is a statistical and optimisation approach aimed at enhancing product quality and performance while reducing manufacturing expenses (Huong *et al.*, 2024). (Ogbonna *et al.*, 2023a) enhanced the dissimilar junctions of AISI 1008 mild steel and AISI 316 stainless steel with the application of the Grey-based Taguchi technique.

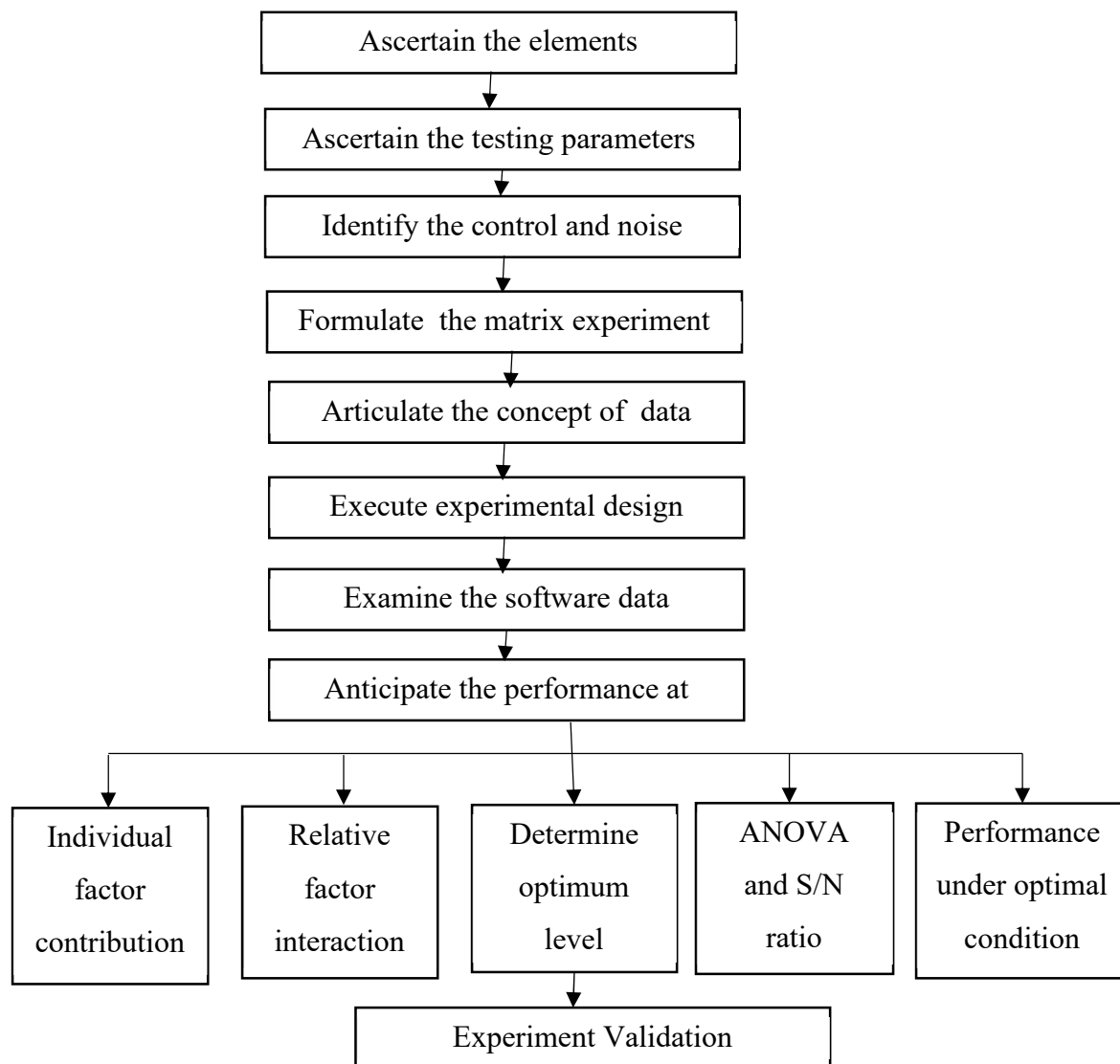


Figure 3: Taguchi's method procedure (Ali and Magdy, 2024)

This assessment consolidates an examination of the enhancement of process parameters in robotic MIG welding of dissimilar junctions between stainless steel and low carbon steel. The assessment seeks to examine the impact of essential welding parameters, such as welding current, voltage, welding speed, wire feed rate, shielding gas flow rate, and heat input, on weld quality, mechanical attributes, weld bead features, and microstructural evolution. Moreover, the assessment examines the use of the Taguchi optimisation technique, encompassing orthogonal array design, signal-to-noise ratio evaluation, and ANOVA, to determine ideal welding parameters and enhance joint efficacy. Furthermore, this analysis aims to pinpoint current research deficiencies and prospective avenues by examining the incorporation of sophisticated optimisation methods to improve the efficiency, dependability, and industrial relevance of robotic MIG welding procedures.

Materials, weldability and property mismatches

The selection of materials is a critical phase in the design of vehicles. Numerous critical elements such as weight, safety, longevity, ease of manufacturing, recyclability, ecological impact, and financial

considerations must be evaluated for appropriate material selection (Karim and Park, 2020).

The shortest path to understanding dissimilar robotic welding is to look first at property mismatch.

Stainless–carbon steel

Alloyed steel with stainless and carbon components Stainless-carbon steel remains functional; however, inadequate over-alloying of the filler at the fusion boundary may lead to the formation of hard microstructures. (Dilli *et al.*, 2023) employed Taguchi analysis to refine the spot-welding parameters of the ABB IRB6700 robot, enhancing tensile shear strength. The electrode force, welding current, and duration of welding were steel. (Ogbonna *et al.*, 2023b) refined MIG welding parameters for joints of AISI 1008 mild steel and AISI 316 stainless steel employing a Grey-based Taguchi approach.

The welding current, voltage, and gas flow rate were examined in relation to tensile strength, yield strength, elongation, and hardness.

A research study examined the impact of MIG robotic welding parameters on the mechanical characteristics of mild steel welded connections utilising a KUKA KR-10 industrial robot. The influence of welding current, voltage, welding speed, and wire

feed rate was analysed to assess their effects on joint strength and hardness. ANOVA and TOPSIS methodologies were utilised to assess the importance of process parameters (Ali *et al.*, 2022). The examination of TIG welding joints between different AISI 316L stainless steel and IS 2062 mild steel utilised filler metals ER316L, ER316, ER70S-6, ER308, and ER309. The welds were produced using a single-pass GTAW technique with a welding current of 210 A, a voltage of 24 V, and argon as the shielding gas. The filler metals were refined according to mechanical and microstructural properties assessed via tensile, impact, hardness testing, and SEM examination (Habib *et al.*, 2026).

Welding Process Parameters

In all the studies welding current and heat input were the most important parameters. Most experiments show that at higher currents of welding the penetration and heat input are greater and that this coarsens the grains of the weld metal and HAZ (Heat Affected Zone), which generally decreases tensile strength and toughness. For instance, (Swami, Jadhav and Deshpande, 2016) discovered that optimal strength for mild steel was reached at 190 A with higher current reducing the strength. (Vimal and Kavitha, 2020) also demonstrated that for the

SAE 1022 steel, the microstructure is coarser for the upper range of the current setting of the robotic GMAW. Welding voltage (arc length) was also important as too much voltage causes the bead to be wider and may help to reduce depth of fusion. The heat input is inversely proportional to travel speed/weld speed: the higher the speed, the lower the heat per unit length and the narrower the bead and the finer the grain. (Nguyen *et al.*, 2020) found that high speed travel helps to decrease the peak temperature gradient and hence the solidification cracking in Cu–SS joints. However, in the dissimilar SS–MS context, the following factors can also influence the metal dilution and mixing: e.g., a study conducted on C20+SUS201 steel indicated that control of stick-out was critical to prevent excessive mixing and dilution (Nguyen *et al.*, 2024). Some works mention interactions, in addition to main effects. (Loukas *et al.*, 2021) showed that it is possible to reduce excessive heat build up by sequence of passes and dynamic adjustment of arc time (also known as multi-pass welding). (Yue, Yin and Huang, 2022) suggested that control of the beam alignment (laser) or arc oscillation (rotating arc MIG) can adjust the dilution and mixing. In general, the relationships between the parameters and the properties are nonlinear and thus are

usually mapped using design of experiments (DoE) methodology such as Taguchi or RSM. Representative process-property trends are: Welding Current $\uparrow \rightarrow$ Penetration $\uparrow$, Bead width $\uparrow$, Heat input $\uparrow \rightarrow$ Grain size $\uparrow$, Hardness $\uparrow$ (in weld), Tensile strength $\downarrow$. As the travel speed increases: Heat input decreases, Penetration decreases, Bead width decreases $\rightarrow$ Finer grains, lower dilution. Arc Voltage $\uparrow \rightarrow$ Arc length $\uparrow$, Weld reinforcement $\uparrow$, Penetration $\downarrow$ (if speed constant). Wire Feed Rate $\uparrow \rightarrow$ (for robotic MIG) Deposition rate $\uparrow$, but may lead to too much melt and spatters if not matched with current. Gas Composition (CO_2 vs Ar mix) $\rightarrow$ CO_2 has an effect on the stability of the

arc and penetration – more CO_2 can lead to more penetration but more spatter. Finally, in dissimilar robotic GMAW, it is critical to have a measure of precise heat input (often calculated as

$$H = \frac{V \times I \times 60}{1000 \times v} \text{-----}1$$

Where,

H = Heat input (kJ/mm)

V = Welding voltage (V)

I = Welding current (A)

v = Welding travel speed (mm/min)

Good balance between high current (for fusion) and adequate travel speed (to not overheat) is stressed again and again in the literature.

Table 1: Literature Survey on Welding Process Parameters

References	Materials / Welding Process	Parameters Investigated	Key Findings
(Imam, Oterkus and Oterkus, 2024)	Robotic GMAW, WAAM, Laser welding, Hybrid welding; marine steels and alloys	Welding techniques, robot systems, automation level, material selection	GMAW was identified as the most widely used robotic welding process. Robotic systems improved productivity, quality, and safety, but process control and cost remain challenges.
(Ghosh, Pal and Nandi, 2017)	AISI 316L stainless steel; MIG welding with ER316L filler	Welding current, gas flow rate, nozzle-to-plate distance	Welding current was the most significant parameter affecting joint strength. Optimal parameters improved weld quality.

(Kumar <i>et al.</i> , 2026)	EN24T steel; robotic MIG welding using KUKA KR-10 robot	Current, voltage, welding speed, wire feed rate	Voltage and current significantly influenced weld strength and hardness. Optimized parameters improved joint performance.
(Ogbonna <i>et al.</i> , 2023a)	AISI 1008 mild steel and AISI 316 stainless steel; MIG/GMAW	Current, voltage, gas flow rate	Optimal parameters were 180 A current, 14 V voltage, and 19 L/min gas flow rate. Voltage had the highest contribution.
(Kumar <i>et al.</i> , 2026)	Aluminium 5083 alloy; robotic GMAW with ABB IRB 1520 robot	Wire feed rate, travel speed, torch angle	Torch angle strongly affected penetration, wire feed rate influenced bead width, and travel speed-controlled bead height.
(Swami, Jadhav and Deshpande, 2016)	E250 mild steel; CO ₂ MIG welding	Welding current, gas flow rate, shielding gas composition	Optimum tensile strength was achieved at 190 A current with controlled gas flow and Ar–CO ₂ mixture. Current was the dominant factor.
(Das, 2026)	IS 2062 E250A mild steel; MIG welding	Current, voltage, welding speed	Taguchi L9 design successfully optimized weld bead geometry. Current and voltage strongly affected penetration and bead characteristics.
(Nguyen <i>et al.</i> , 2024)	C20 low carbon steel and SUS201 stainless steel	Current, voltage, speed, stick-out	Welding current showed the strongest influence on tensile strength. Optimized parameters improved joint performance.
(Huang, 2022)	SUS304 stainless steel and SS400 low carbon steel; robotic GMAW	Welding current, arc voltage, welding speed	Optimized parameters improved tensile strength and corrosion resistance of dissimilar welded joints.

Mechanical Properties (Tensile, Hardness, Toughness, Residual Stress)

The mechanical properties of dissimilar MIG joints are related to alloy mixing and microstructure. Tensile strength: Most studies indicate the maximum strength is nearly equal to the weaker base material. For instance, (Ogundimu, Akinlabi and Erinosh, 2006) obtained the joint efficiency of ~95% (or 672 MPa UTS) for 304SS/AISI304 joints using TIG–MIG hybrid process. Dissimilar 1010MS–304SS SMAW joints, on the other hand, reached maximum UTS (≈ 400 –600 MPa) at various currents. Hard martensite (in carbon steel side) and brittle intermetallics (in more exotic couples) can drastically affect strength. (Baykara and Oral, 2025) report that lower current in Al GMAW actually resulted in a higher joint hardness and strength due to the lack of turbulence of the molten pool. Weld metal hardness generally increases with

increasing heat input (due to coarse grains or martensite) and decreases in over-heated HAZ, as demonstrated by (“Ozan C, oban,” 2023) for armor steel, with heat input of 1.2 kJ/mm. (Zafar *et al.*, 2026) reported that no observed change in microstructures occurred in Ti-64+MoS₂ AM welds because they had similar hardness to the as-received material.. (Olaogun and Olubambi, 2025) reported that annealing decreased the hardness but increased the ductility of 1007 steel joints. (Alam *et al.*, 2026) measured that dissimilar 304SS–1018MS welds with PWHT saw ~48% reduction in residual stress.

The Weld bead geometry is affected by the input process parameters which has to be optimized for better weld bead quality. The three principal factors that have an impact on the quality of weld beads as demonstrated in figure 4 are the width of the weld bead, reinforcement and depth of penetration.

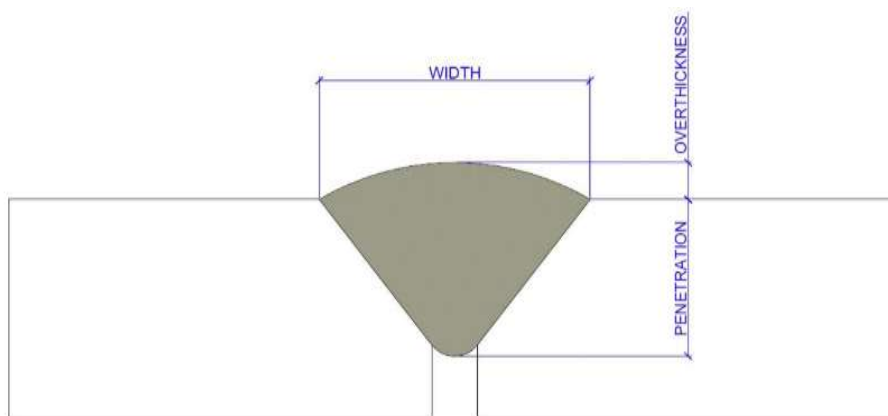


Figure 4: Weld Bead Geometry(YUVARAJ, 2018)

The weld face and root are shown. Control of weld bead width (W), penetration depth, and reinforcement height is crucial for joint performance.

Table 2: Literature Survey on Mechanical Properties (Tensile Strength, Hardness, Toughness & Residual Stress)

Authors / Year	Materials / Welding Process	Mechanical Properties Evaluated	Key Findings
(Habib <i>et al.</i> , 2026)	IS 2062 mild steel and AISI 316L stainless steel; TIG/GTAW welding with ER309L filler	Tensile strength, toughness, hardness, microstructure	ER309 filler achieved high tensile strength (656 MPa), while ER316 filler provided the best combination of strength, toughness, and hardness.
(Olaogun and Olubambi, 2025)	AISI 1007 mild steel; TIG-MIG hybrid welding	Tensile strength, hardness, impact toughness, microstructure	Heat treatment improved ductility and toughness by refining grain structure, while annealing promoted carbide formation.
(Ogbonna <i>et al.</i> , 2023b)	AISI 1008 mild steel and AISI 316 stainless steel; MIG/GMAW	Tensile strength, yield strength, elongation, hardness	Optimized parameters produced 559.25 MPa tensile strength and 250.63 HV hardness. Voltage was the dominant factor affecting weld performance.
(Janapareddy <i>et al.</i> , 2025)	AISI 304 stainless steel and AISI 1018 mild steel; multipass SMAW/GTAW	Tensile strength, impact toughness, hardness, residual stress	Post-weld heat treatment reduced residual stress by approximately 48.5% and improved impact toughness, although tensile strength slightly decreased.
(Vimal and Kavitha, 2020)	SAE 1022 low carbon steel; robotic and conventional GMAW	Tensile strength, hardness, weld	Robotic GMAW improved tensile strength (647 MPa), hardness, and weld consistency

		efficiency, microstructure	compared with conventional welding.
(Murat, Uğur and Tümer, 2026)	Armor 500 steel; robotic MAG welding with different fillers	Tensile strength, toughness, hardness	ER110 filler achieved maximum strength (1052 MPa), while ER309 provided the highest toughness.
(Gu, 2023)	DSS2205 duplex stainless steel; MIG/GMAW	Tensile strength, hardness, corrosion resistance	Nitrogen-containing shielding gas improved ferrite-austenite balance, strength, and corrosion resistance.
(Touileb <i>et al.</i> , 2022)	AISI 316L stainless steel and DSS2205; TIG/ATIG welding	Tensile strength, hardness, corrosion behaviour, microstructure	Optimized ATIG flux produced full penetration, narrower HAZ, and improved weld quality.

Optimization Methods

Design-of-experiments and statistical optimization have been applied to many studies to determine the best parameters. The Taguchi methods such as L9 and L18 array were used to carry out preliminary screening of MIG parameters (current, voltage, speed etc.) and multi-response optimization using Grey Relational Analysis. ANOVA was often used to measure factor contributions (e.g. current is often 50-70% of the factor effect on the strength).

Some studies (Jeet *et al.*, 2018) used a continuous relationship between settings and outputs, fitted with Response Surface

Methodology (RSM) and regression modelling. The hybrid and AI-based are more recent.

Loukas *et al.* (2021) used cost functions and path planning (not statistical optimization as such), to reduce welding time and filler. Lawong *et al.* (2025) tuned the multi-objective optimization of a robotic weld using RF-RT, and this led to a higher weld hardness and lower heat input. Geng *et al.* (2025) review highlights the increased use of machine learning in weld quality prediction and adaptive control. Various known methods are known such as Genetic Algorithms (GA), Particle Swarm and

combination methods such as Grey-Relational – GA (multi-response). To conclude, Taguchi + ANOVA are traditional tools that continue to be used as robust parameter optimization methods, while AI/ML techniques are emerging and could help better manage nonlinear interactions and adapt dynamically.

Signal-to-noise ratio for ‘nominal is best’

$$n = 10log \frac{1}{n} \sum_{i=1}^n \frac{\mu^2}{\sigma^2} - - - - - (2)$$

Signal-to-noise ratio for ‘smaller the better’

$$n = -10log \frac{1}{n} \sum_{i=1}^n yi^2----- (3)$$

Signal-to-noise ratio for ‘larger the better’

$$n = -log \frac{1}{n} \sum_{i=1}^n \frac{1}{yi^2} - - - - - (4)$$

Table 3:Literature Survey on Taguchi Optimization Methods

Authors / Year	Materials / Welding Process	Optimization Method & Parameters	Key Findings
(Ghosh, Kumar and Nandi, 2016)	AISI 316L stainless steel; MIG welding	L9 Taguchi array, Grey relational analysis; current, gas flow rate, nozzle distance	Taguchi optimization identified welding current as the most influential parameter affecting weld strength.
(Dilli <i>et al.</i> , 2023)	Stainless steel and mild steel sheets; ABB IRB6700 robotic spot welding	Taguchi orthogonal array, S/N ratio, ANOVA; electrode force, current, weld time	Electrode force was the dominant parameter with contributions of 58.51% for stainless steel and 70.95% for mild steel.
(Ogbonna <i>et al.</i> , 2023b)	AISI 1008 mild steel and AISI 316 stainless steel; MIG/GMAW	L9 Taguchi array, Grey relational analysis; current, voltage, gas flow rate	Optimal parameters improved tensile strength, elongation, and hardness of weld joints.

(Mishra & Chandola 2026)	AISI 304 and AISI 430 stainless steel; GMAW	Taguchi L27 design and ANOVA; current, voltage, travel speed	Optimized parameters achieved 630.7 MPa tensile strength and improved hardness.
Sharma et al. (2023)	AISI 1026 mild steel; MIG welding	Taguchi-TOPSIS; current, voltage, wire feed rate	Current was the most influential factor with 68.2% contribution; optimized parameters improved weld strength.
(Das, 2026)	IS 2062 E250A mild steel; MIG welding	Taguchi L9 orthogonal array; current, voltage, welding speed	Taguchi method effectively optimized weld bead geometry and penetration characteristics.
(Nguyen et al., 2024)	C20 low carbon steel and SUS201 stainless steel	Taguchi optimization; current, voltage, speed, stick-out	Current had the strongest influence on tensile strength; optimized conditions improved weld properties.
(Kumar et al., 2026)	Aluminium 5083 alloy; ABB robotic GMAW	Taguchi L27 array and ANOVA; wire feed rate, travel speed, torch angle	Torch angle, wire feed rate, and travel speed were identified as major factors affecting weld geometry.
(Abioye et al., 2019)	AISI 304 stainless steel and low carbon steel; GMAW	Factorial design and ANOVA optimization; wire feed rate, voltage, welding speed	Welding speed strongly affected tensile strength and bead width, while voltage influenced hardness.

Quantitative Analysis of Reviewed Literature

Overview of the search strategy

A systematic literature search was conducted to identify relevant studies related to robotic MIG/GMAW welding of stainless steel and low carbon steel with optimization of process

parameters using the Taguchi method. The search was performed using scientific databases such as Scopus, Web of Science, ScienceDirect, IEEE Xplore, and Google Scholar. The search keywords included combinations of robotic MIG welding, GMAW, dissimilar welding, stainless steel, low carbon steel, Taguchi method,

orthogonal array, and ANOVA. The identified studies were screened based on their relevance to robotic MIG welding, dissimilar stainless steel–low carbon steel joints, and optimization of welding parameters. Research articles focusing on welding current, voltage, welding speed, wire feed rate, shielding gas flow rate, and their effects on weld quality characteristics such as

tensile strength, hardness, penetration, and bead geometry were selected for detailed analysis. Taguchi-based optimization studies were further evaluated to understand parameter interactions and optimal welding conditions for achieving improved joint performance(Imam, Oterkus and Oterkus, 2024)

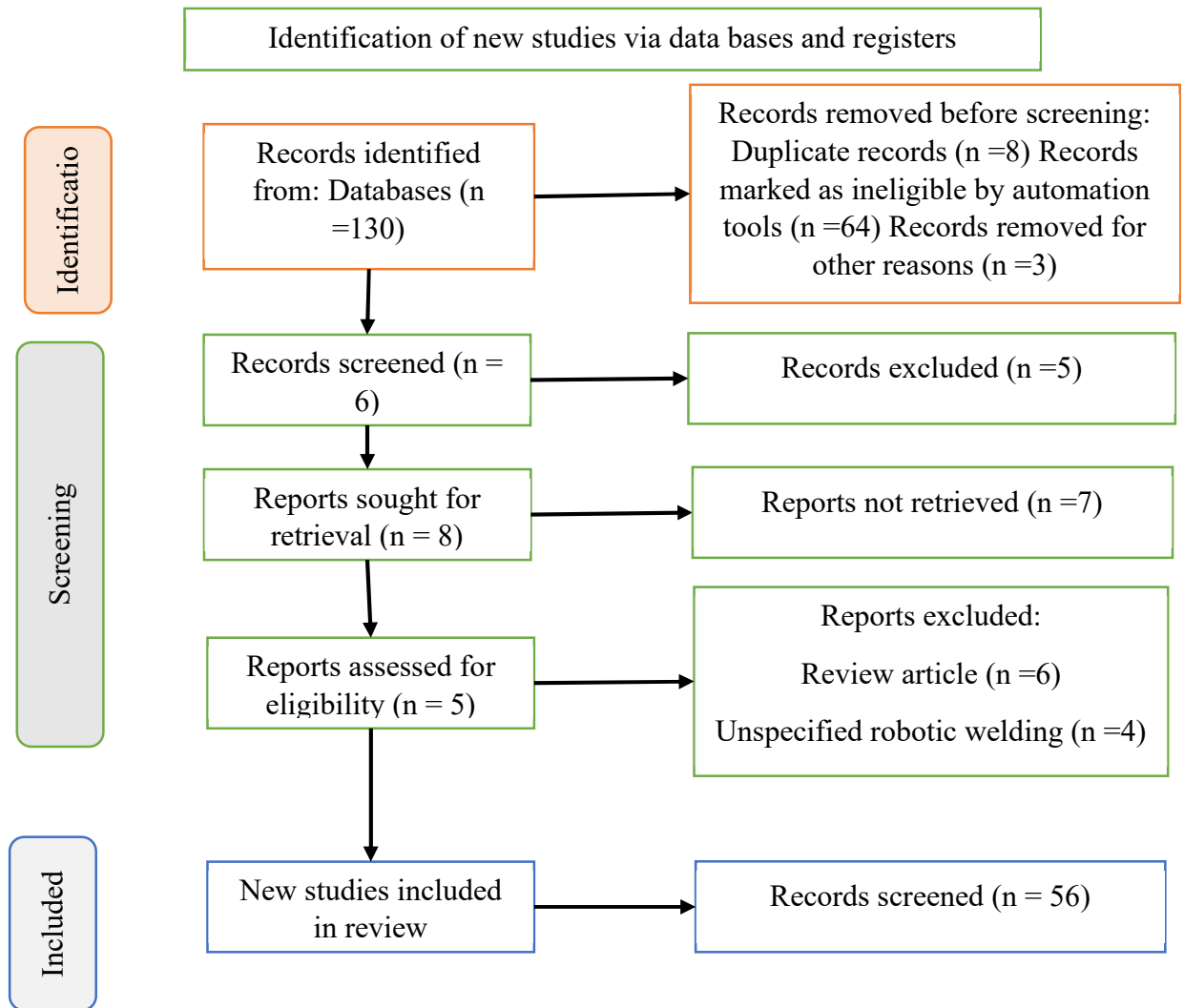


Figure 5: Process flow diagram for a systematic literature review (PRISMA flowchart)

Publisher Distribution

The references originate from various publishers. Table 3 shows counts by publisher. The majority ($\approx 31\%$) are from Elsevier journals or proceedings (Mater. Today, Additive Manufacturing, etc.).

Table 4: Publisher Distribution

Publisher	No. of Studies
Elsevier (ScienceDirect, Materials Today, JMEP, Manufacturing Processes, etc.)	20
Springer Nature (Welding in the World, IJAMT, JMEP, Scientific Reports, etc.)	10
MDPI	4
IOP Publishing	6
IEEE	1
ASM / Metallography & Microstructure	1
Emerald Publishing	2
MAT Journals / IJ-series / regional journals	7

Springer (including ASM/IEEE Robotics) accounts for $\sim 21\%$. The remaining are distributed among MDPI, IOP, IEEE, and others. A pie chart visualization is shown below.

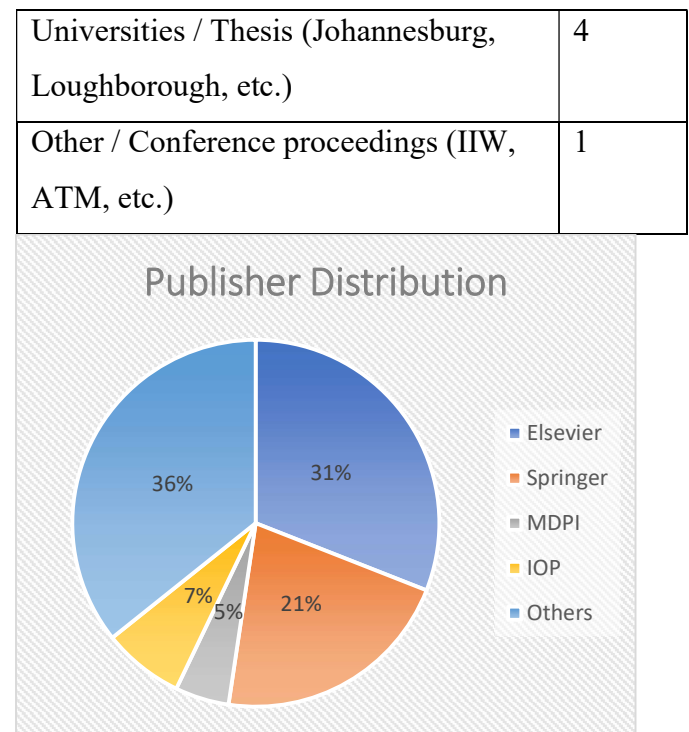


Figure 6: Publisher Distribution

Journal vs Conference Proportion

Out of the peer-reviewed items (excluding theses), journal articles dominate. Table 5 and the bar chart below summarize counts

Table 5:Journal vs Conference proportion

Type of Publication	Count
Journal Articles	40
Conference Papers	7
Review Articles	4
Theses / Dissertation	3
Technical Reports / Industry docs	2

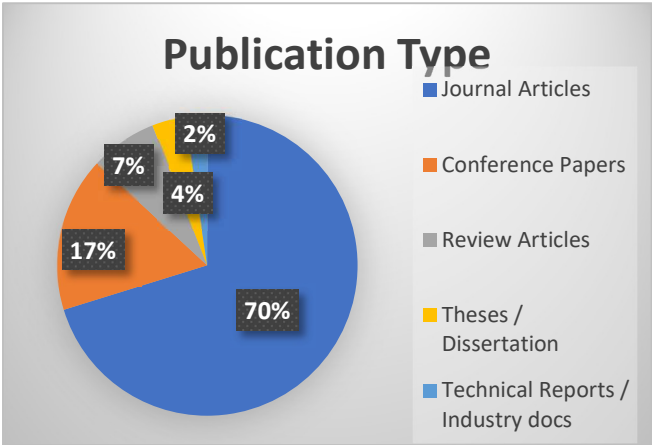


Figure 7: Journal vs Conference proportion

Publication Year Trend

A timeline of publications indicates a strong increase in the last years, reflecting growing interest in robotic welding and AI applications. No mermaid markup is needed here, but a simplified timeline is provided:

Table 6:Publication year Distribution

Year	No. of Studies	Trend Insight
2016	5	Shift toward statistical optimization
2017–2019	10	Growth in robotic welding systems
2020	4	Microstructure + hybrid welding focus
2021	4	Sensor + automation + GMAW dominance
2022	5	AI + optimization + dissimilar welding
2023	5	Experimental robotic welding surge
2024	6	Machine learning + hybrid welding rise
2025	8	Strong focus on AI + robotics integration
2026	10	Peak research activity (AI + digital welding systems)

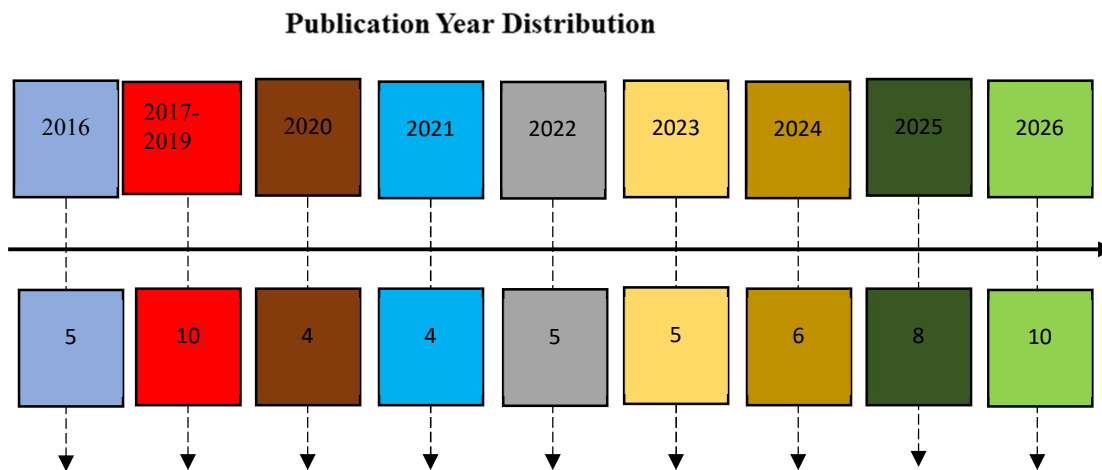


Figure 8: the number of studies published each year

Discussion: Gaps and Future Directions

Research on robotic MIG/GMAW welding of dissimilar stainless steel–mild steel joints has mainly focused on optimizing welding parameters and studying mechanical properties. However, limited attention has been given to real-time process control, AI-based defect prediction, multi-physics simulation, and multi-objective optimization. Future studies should combine robotic welding, sensor-based monitoring, machine learning, and advanced modelling techniques to improve weld quality and predict defects during fabrication. A proposed study on robotic GMAW of AISI 304L stainless steel and IS 2062 E250 carbon steel using ER309L/ER316L fillers would involve ABB robotic welding with vision-based seam tracking, parameter optimization using Taguchi and RSM, and detailed weld characterization through mechanical testing, microscopy, residual stress analysis, and non-destructive evaluation. The aim is to develop a reliable and adaptive welding approach that produces stronger, tougher, and defect-free dissimilar joints.

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Author Contributions

Professor Chalamalasetti Srinivasa Rao: Supervision, Methodology, Conceptualization. **Kahsay Gebremicheal Gebru:** Writing original draft, Visualization, Validation, Resources, Methodology, Formal analysis, Conceptualization. **Professor V.V.S. Keseva Rao :** Visualization, Supervision, Resources, Methodology, Formal analysis, Conceptualization.

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Declaration of Generative

AI and AI-assisted technologies in the writing process During the preparation of this work, the authors used ChatGPT and Grammarly to rephrase sentences and enhance language. After using these tools/services, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

Declaration of Competing Interest

The authors declare that they have no conflicts of interest with regard to the publication of this work.

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