TURBO Vol. 15 No. 1. 2026
Jurnal Program Studi Teknik Mesin UM Metro
p-ISSN: 2301-6663, e-ISSN: 2477-250X
URL: http://ojs.ummetro.ac.id/index.php/turbo

Evaluation of Geometric Parameter Variations in GMAW Weld Joints on SPA-H Steel: A Statistical and Practical Perspective

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Abstract

Gas Metal Arc Welding (GMAW) is widely used in manufacturing due to its efficiency in producing high-quality weld joints. However, the influence of combined geometric parameters, particularly root gap and bevel angle, on the mechanical performance of welded joints in low-carbon corrosion-resistant SPA-H steel remains insufficiently explored. This study aims to evaluate the combined effect of root gap and bevel angle on the tensile and bending performance of GMAW welded joints. A full factorial experimental design was applied using three levels of root gap (4 mm, 6 mm, and 8 mm) and bevel angle (40°, 47.5°, and 55°). Tensile, bending, and macrostructure tests were conducted, and the data were analyzed using Analysis of Variance (ANOVA) and Design of Experiments (DOE). The statistical results indicate that neither root gap nor bevel angle, including their interaction, has a significant effect on tensile strength at the 95% confidence level. However, practical trends observed in the experimental data show that the 8 mm root gap combined with a 55° bevel angle provides the best performance, achieving a tensile strength of 571.82 MPa and no visible cracks during bending. Macrostructure analysis further confirms uniform fusion and stable weld integrity under this configuration. These findings suggest that, although statistically insignificant, the selection of appropriate geometric parameters remains important for achieving reliable mechanical performance in GMAW welding of SPA-H steel.

Keywords: *bevel angle, GMAW welding, root gap, SPA-H steel, tensile strength*

1. Introduction

Welding is a crucial material joining method widely used in manufacturing and construction industries due to its ability to produce permanent and high-strength joints. Among various welding techniques, Gas Metal Arc Welding (GMAW) is widely applied because it offers high productivity, stable arc characteristics, and relatively short processing times while maintaining consistent weld quality. These advantages make GMAW particularly suitable for industrial applications that require efficient fabrication and reliable structural performance.

The mechanical performance of welded joints is influenced by several factors, including welding parameters, material properties, and joint geometry. Among these factors, the geometric configuration of the weld joint plays an important role in controlling weld penetration, fusion quality, and heat distribution within the weld area. Two geometric parameters that strongly influence weld quality are the root gap and bevel angle. The root gap determines the spacing between the plates to be joined and affects the penetration of molten metal into the root region, while the bevel angle influences the accessibility of the welding arc and the volume of filler metal required

DOI: http://dx.doi.org/10.24127/trb.v15i1.4196
Received 28 May 2025; Received in revised form 26 April 2025; Accepted 10 June 2026

during the welding process. Improper configuration of these parameters may result in welding defects such as lack of fusion, incomplete penetration, and excessive heat input, which ultimately reduce the mechanical strength and reliability of welded structures.

Several previous studies have reported that welding parameters and joint configuration significantly influence the mechanical properties of welded joints. The selection of filler wire type in GMAW welding has been shown to improve tensile strength up to 650 MPa, exceeding the base metal strength of 600 MPa while also increasing elongation from 18% to 22% [1]. In addition, variations in groove design were found to affect joint efficiency and tensile strength, where a bevel angle of 50° produced higher tensile strength compared with larger groove angles such as 70° [2]. These findings demonstrate that weld joint geometry plays a crucial role in determining the mechanical behavior of welded structures.

Recent developments in welding technology have also focused on improving welding quality through monitoring and process optimization. The application of deep learning models such as ResNet50 has demonstrated the capability to classify root gap variations between 4 mm and 8 mm with high accuracy, highlighting the growing importance of precise joint preparation and quality monitoring in welding processes [3]. Other investigations comparing welding methods have shown that MIG welding applied to Aluminum 5083 produced higher tensile strength compared with TIG welding under similar conditions, emphasizing the influence of welding parameters and process configuration on mechanical performance [4].

From a metallurgical perspective, material composition and welding conditions can significantly affect the microstructural characteristics of welded joints. Increasing chromium content in X80 pipeline steel has been reported to reduce the softening ratio in the heat-affected zone (HAZ), thereby improving structural strength [5]. Furthermore, alternative welding techniques such as Hybrid Laser Arc Welding (HLAW) have demonstrated higher fracture toughness compared to conventional GMAW in hydrogen environments, indicating that welding configuration and process parameters strongly affect the structural reliability of welded joints [6].

Research focusing on weld geometry and thermal effects has also demonstrated the significant influence of heat input on weld penetration and bead formation. Variations in heat input ranging from 0.269 kJ/mm to 0.449 kJ/mm were reported to produce penetration differences of up to 2.98 mm and bead width variations of up to 2.14 mm, indicating the strong relationship between thermal energy distribution and weld morphology [7]. In addition, microstructural observations have revealed substantial hardness differences between the heat-affected zone and the weld metal, which may lead to stress concentration and potential structural weakness within the transition region [8]. Studies investigating root gap configurations also indicate that increasing root gap can significantly improve joint strength by enhancing weld penetration and bonding stability [9].

Despite these findings, most previous studies have examined welding parameters, joint geometry, or metallurgical factors separately. Comprehensive investigations that specifically analyze the combined influence of root gap and bevel angle on the mechanical performance of GMAW welded joints remain limited, particularly for corrosion-resistant structural steels such as SPA-H steel (JIS G3125). Understanding the interaction between these geometric parameters is important to optimize weld penetration, improve mechanical strength, and ensure structural reliability in welded components.

In addition, previous studies rarely integrate mechanical testing results with statistical evaluation to determine the most effective weld geometry configuration. Therefore, investigating the interaction between root gap and bevel angle using an experimental and statistical approach provides a more comprehensive understanding of weld joint behavior and contributes to the optimization of welding parameters for corrosion-resistant structural steels.

Therefore, this study aims to experimentally evaluate the influence of root gap and bevel angle variations on the mechanical performance of GMAW welded joints on SPA-H steel. The investigation was conducted through tensile testing, bending testing, and macrostructural examination to assess weld quality and mechanical behavior. Furthermore, statistical analysis using Design of Experiments (DOE) and Analysis of Variance (ANOVA) was applied to evaluate the significance of each parameter and identify the most favorable welding configuration.

2. Literature review

Welding and GMAW Process

Welding is a metal joining process that produces a permanent metallurgical bond by melting and fusing the base metals with or without the addition of filler metal. This process is widely used in various industrial sectors, including construction, shipbuilding, and manufacturing, due to its ability to create strong and durable structural connections. Among the various welding techniques, Gas Metal Arc Welding (GMAW) has become one of the most commonly applied methods in modern fabrication industries.

According to Jumadin et al. (2023), the GMAW process utilizes a continuously fed consumable wire electrode combined with shielding gas to protect the molten weld pool from atmospheric contamination [10]. The shielding gas plays an essential role in stabilizing the welding arc and preventing oxidation during the welding process, which directly affects weld quality and mechanical performance. In addition, the semi-automatic nature of the GMAW process allows higher productivity compared with several conventional welding techniques.

Phillips (2016) explains that GMAW offers several advantages, including high deposition rates, stable arc characteristics, and the ability to be integrated with automated welding systems [11]. These advantages make GMAW particularly suitable for large-scale industrial applications requiring consistent weld quality and efficient production processes. However, achieving optimal weld performance requires careful control of several parameters, including welding current, heat input, shielding gas composition, and joint geometry.

Weld joint design

Weld joint design plays an important role in determining the quality and structural performance of welded connections. The geometry of the joint affects the distribution of heat input, the penetration of molten metal, and the overall fusion between the base materials. Proper joint preparation is therefore essential to ensure that the weld metal adequately fills the joint and forms a strong metallurgical bond.

Among various joint geometry parameters, root gap and bevel angle are two critical factors that significantly influence weld penetration and filler metal distribution. The root gap refers to the spacing between the edges of the base plates prior to welding. According to welding design principles, an appropriate root gap allows sufficient penetration of molten metal into the root region, which helps achieve complete fusion and improves joint strength [12].

Meanwhile, the bevel angle determines the accessibility of the welding arc to the joint area and influences the amount of filler metal required to fill the groove. A properly selected bevel angle facilitates better arc access and weld penetration while maintaining efficient filler metal usage. Studies indicate that bevel angles typically range between 40° and 50° in many welding applications to achieve a balance between weld accessibility and deposition efficiency [13]. Excessively large bevel angles may increase filler metal consumption and heat input, whereas smaller angles may restrict arc accessibility and reduce weld penetration.

In addition, appropriate joint geometry also helps reduce welding defects such as incomplete fusion, excessive reinforcement, and distortion. Therefore, the selection of root gap and bevel angle must be carefully considered to ensure optimal weld quality and structural reliability [14].

Mechanical Properties of Welded Joints

The mechanical performance of welded joints is commonly evaluated using mechanical testing methods such as tensile testing, bending testing, and hardness measurements. These tests provide important information about the strength, ductility, and structural integrity of the welded region.

Tensile testing is widely used to determine the maximum load-bearing capacity of welded joints and to evaluate the influence of welding parameters on joint strength. The tensile strength obtained from welded specimens reflects the ability of the joint to withstand applied forces without failure. According to welding research studies, variations in welding parameters and joint configurations can significantly influence the tensile properties of welded materials [15].

In addition to tensile testing, bending tests are frequently used to assess the ductility and soundness of welded joints. During bending tests, the welded specimen undergoes plastic deformation to determine whether cracks or surface defects appear in the weld metal or heat-affected zone. The presence or absence of cracks during bending provides valuable information about weld quality and fusion characteristics [16].

Previous Studies on Root Gap and Bevel Angle

Several studies have investigated the influence of weld joint geometry on the mechanical performance of welded structures. In particular, the root gap configuration has been reported to significantly affect weld penetration, fusion quality, and joint strength. Proper root gap settings allow better molten metal flow into the root region, improving the bonding stability between the base materials.

Previous investigations have shown that increasing the root gap within an optimal range can improve the mechanical performance of welded joints by enhancing penetration and reducing the likelihood of incomplete fusion. However, excessive root gap may also lead to welding defects such as excessive melt-through or increased filler metal consumption. Therefore, determining the optimal combination of root gap and bevel angle is essential to achieve balanced weld penetration and mechanical strength [17].

Table 1. Summary of relevant studies

Ref	Material	Parameter	Main Result
[1]	Structural steel	Filler wire type	Tensile strength increased to 650 MPa
[2]	Steel plate	Bevel angle	50° bevel produced higher joint efficiency
[3]	Welding inspection	Root gap detection	ResNet50 classified root gaps accurately
[4]	Aluminum 5083	Welding current	MIG produced higher tensile strength
[5]	X80 steel	Chromium content	Cr reduced HAZ softening
[6]	Structural steel	Welding method	HLAW produced higher fracture toughness
[7]	Steel weld joint	Heat input	Heat input affected penetration
[8]	Double-V weld	Microstructure	Large hardness difference in HAZ
[9]	Ultrasonic weld	Root gap	Root gap increased joint strength

3. Research Methodology

Type of Research

This study uses a quantitative experimental approach to analyze the effect of root gap and bevel angle variations on tensile strength.

Research Variables

Independent variables:

- Root Gap: Three levels (4 mm, 6 mm, and 8 mm)
- Bevel Angle: Three levels (40°, 47.5°, and 55°)

Dependent variable**:**

- Tensile strength (measured in Megapascals)

Tools and Materials

- OTC XD 500 welding machine for GMAW process
- Shielding gas: 82% Argon and 18% CO_2
- Low-carbon SPA-H steel material (JIS G3125) with 12 mm thickness
- AWS ER 70S-6 filler metal, 1.2 mm diameter

Research Procedure

1. Specimen Cutting
   Specimens were cut using a Tekma laser cutting machine to dimensions of 150 mm × 100 mm × 12 mm.

Figure 1. Initial Specimen

2. Bevel Angle Preparation
   Bevel angles were prepared using a CNC horizontal boring machine (BT-1) to achieve geometric accuracy for 40°, 47.5°, and 55°.

Figure 2. Bevel Angle Formation

3. Root Gap Preparation
   Root gaps of 4 mm, 6 mm, and 8 mm were created. Welding was

performed using the Gas Metal Arc Welding (GMAW) method.

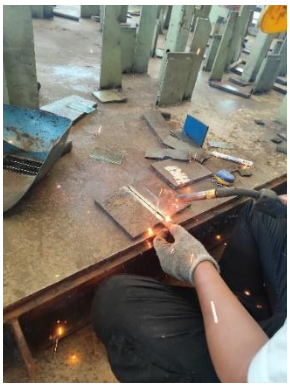

Figure 3. Root Gap Setup

4. Welding Process
   Welding was performed in the 1G position with ceramic backing to prevent melt-through at the root.

Figure 4. Welding Result

5. Mechanical Testing
   Tensile tests were conducted per BSI 709:1983 and bending tests followed ASTM E290-22. Each root gap and bevel angle combination was tested with 3 specimens, totaling 27 tensile and 9 bending test samples.

Figure 5. Specimen Tensile Test

Figure 6. Bending Testing Process

6. Macrostructure Examination
   After mechanical testing, macrostructure analysis was performed following ISO 17639 using 2% HNO_3 in alcohol for etching.

Figure 7. Metallographic Test Specimen

7. Data Analysis
   Test results were analyzed using Minitab 19 software with a full factorial Design of Experiments (DOE), including ANOVA and parameter optimization.

Research Flowchart

The research flow is illustrated in Figure 8, which depicts the sequence from specimen collection to analysis.

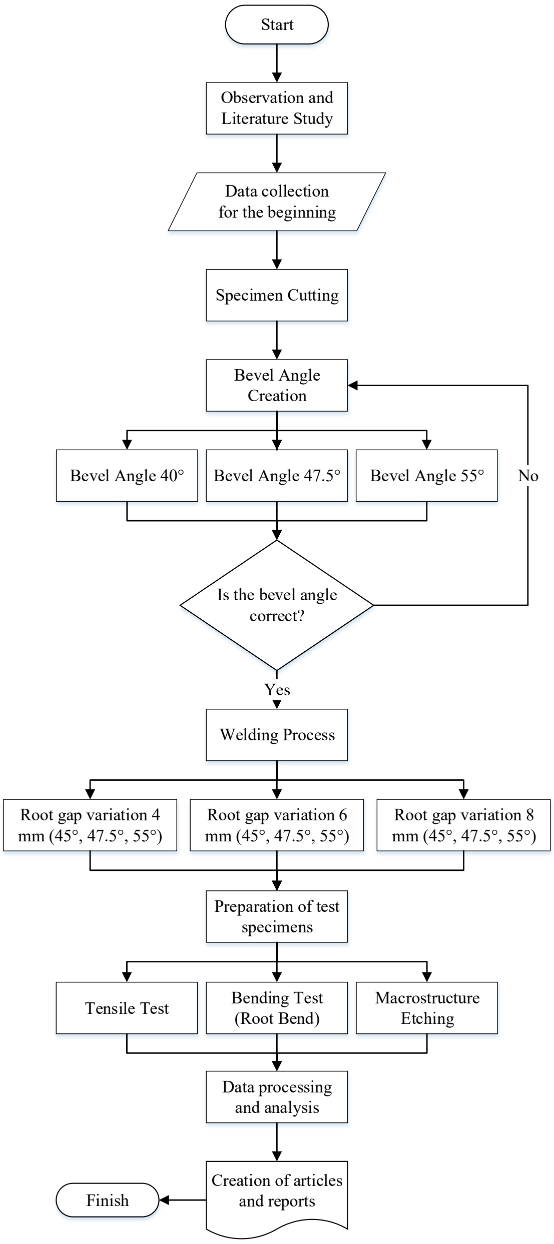

Figure 8. Flowchart

4. Results and Discussion

The results of tensile and bending tests were analyzed to evaluate the influence of root gap and bevel angle variations on the mechanical performance of GMAW welded joints. A total of nine parameter combinations were tested using three specimens for each configuration. Statistical analysis using Design of Experiments (DOE) and Analysis of Variance (ANOVA) was applied to determine the significance of each parameter and their interaction on tensile strength.

The tensile test results obtained from all parameter combinations are presented in Table 2. Each configuration of root gap and bevel angle was tested using three specimens to ensure data consistency and reliability. The results show that tensile strength values range from approximately 470 MPa to 598 MPa, indicating variations in joint performance depending on the welding geometry parameters.

Table 2. Tensile Test Results

Root Gap and Bevel Angle	**Tensile Strength (N/mm^2)**
4 mm and 40°	562.34 N/mm^2
	513.61 N/mm^2
	549.11 N/mm^2
4 mm and 47.5°	553.84 N/mm^2
	562.56 N/mm^2
	533.89 N/mm^2
4 mm and 55°	584.36 N/mm^2
	549.10 N/mm^2
	597.87 N/mm^2
6 mm and 40°	571.05 N/mm^2
	544.55 N/mm^2
	540.48 N/mm^2
6 mm and 47.5°	544.62 N/mm^2
	573.16 N/mm^2
	587.24 N/mm^2
6 mm and 55°	550.75 N/mm^2
	470.89 N/mm^2
	553.96 N/mm^2
8 mm and 40°	556.16 N/mm^2
	542.90 N/mm^2
	553.13 N/mm^2
8 mm and 47.5°	557.24 N/mm^2
	553.03 N/mm^2
	560.18 N/mm^2
8 mm and 55°	564.32 N/mm^2
	573.04 N/mm^2
	568.14 N/mm^2

Based on the data in Table 2, the highest tensile strength value was recorded in the 4 mm root gap with a 55° bevel angle, reaching 597.87 MPa. Meanwhile, the lowest value occurred in the 6 mm root gap and 55° bevel angle combination at 470.89

MPa. These variations indicate that welding geometry parameters influence the distribution of heat input and penetration behavior during the GMAW process, which subsequently affects the mechanical strength of the welded joint.

The bending test results are presented in Table 3. This test was conducted to evaluate the ductility and surface integrity of the welded joints, particularly to detect cracks that may appear in the weld metal or heat-affected zone during plastic deformation.

Table 3. Bending Test Results

Root Gap and Bevel Angle	**Crack Length (Visual)**
4 mm and 40°	Crack 20 mm
4 mm and 47.5°	No Crack
4 mm and 55°	Crack 7 mm
6 mm and 40°	No Crack
6 mm and 47.5°	No Crack
6 mm and 55°	Crack 20 mm
8 mm and 40°	No Crack
8 mm and 47.5°	No Crack
8 mm and 55°	No Crack

Based on the bending test results shown in Table 3, several parameter combinations exhibited good ductility without visible surface cracks, such as the 4 mm–47.5°, 6 mm–40°, 6 mm–47.5°, and all configurations with an 8 mm root gap. In contrast, cracks were observed in the 4 mm–40°, 4 mm–55°, and 6 mm–55° configurations. The presence of cracks indicates that certain parameter combinations may produce localized stress concentration or insufficient fusion during welding. These results suggest that both root gap and bevel angle influence the plastic deformation behavior of the welded joints.

The Influence of Root Gap and Bevel Angle

This section analyzes the influence of root gap and bevel angle on the tensile strength of GMAW welded joints using statistical evaluation methods. The analysis was conducted using Design of Experiments (DOE) and Analysis of Variance (ANOVA) to determine the significance of each parameter as well as their interaction effect on tensile strength.

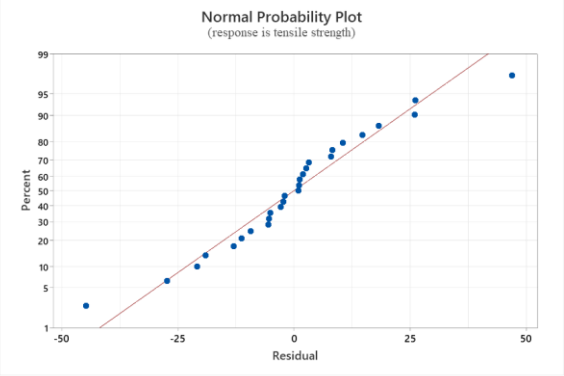

Figure 9. Normal Probability Plot

Figure 9 presents the normal probability plot of the residuals from the regression model. The residual points are distributed closely along the reference line, indicating that the residuals follow a normal distribution. This confirms that the normality assumption required for ANOVA analysis is satisfied, meaning that the statistical model used in this study is appropriate for evaluating the influence of welding parameters on tensile strength.

Table 4. *ANOVA Test*

Source	**DF**	**Adj SS**	**Adj MS**	**F-*Value***	**P-*Value***
Model	8	5635.9	704.5	1.51	0.222
Linear	4	2418.9	604.7	1.30	0.308
Root gap	2	1837.8	918.9	1.97	0.168
Bevel Angle	2	581.1	290.6	0.62	0.547
2-*Wayint erctons*	4	3217.0	804.2	1.72	0.188
Root Gap* Bevel Angle	4	3217.0	804.2	1.72	0.188
Error	18	8392.4	466.2		

The ANOVA results shown in Table 4 indicate that the overall regression model is not statistically significant at the 95% confidence level (F = 1.51; P = 0.222). Individually, the root gap factor (P = 0.168) and bevel angle factor (P = 0.547) also do not show statistically significant effects on tensile strength. In addition, the interaction between root gap and bevel angle is not statistically significant (P = 0.188).

Although the statistical significance is not observed, the Adjusted Sum of Squares (Adj SS) values reveal that the root gap parameter contributes more to the variation in tensile strength compared to the bevel angle. The root gap shows an Adj SS value of 1837.8, which is considera1qbly higher than the bevel angle contribution of 581.1. This indicates that root gap has a stronger practical influence on weld joint strength.

From a welding perspective, the root gap plays an important role in determining molten metal penetration and filler metal distribution at the weld root. An inappropriate root gap may restrict metal flow or reduce penetration efficiency, which can affect the mechanical strength of the welded joint.

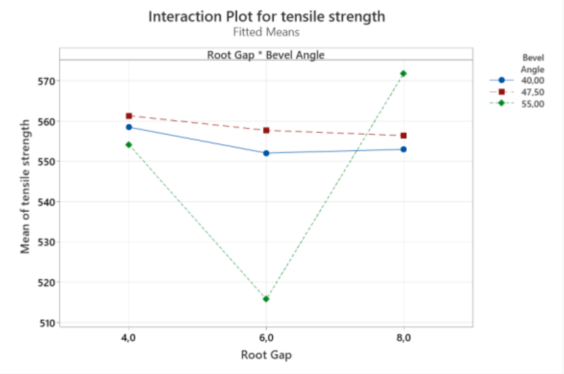

Figure 10. Interaction

Figure 10 illustrates the interaction effect between root gap and bevel angle on the mean tensile strength of the welded joints. Although the ANOVA analysis indicates that the interaction effect is not statistically significant (P = 0.188), the interaction plot reveals several observable trends in the experimental data.

At the 55° bevel angle, the tensile strength decreases noticeably at the 6 mm root gap and increases again at the 8 mm root gap. This fluctuation may be associated with changes in molten metal flow and heat distribution during welding. A moderate root gap combined with a wide bevel angle may lead to unstable molten pool behavior, which can reduce effective penetration and weaken the joint strength.

In contrast, the tensile strength values at bevel angles of 40° and 47.5° remain relatively stable across all root gap variations. This suggests that these bevel angles provide more stable welding conditions, allowing more consistent heat distribution and filler metal fusion. These observations indicate that although the statistical interaction is not significant, the parameter combination can still influence the practical performance of the welded joints.

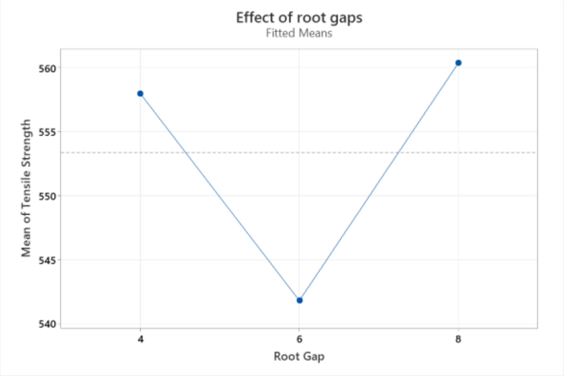

Figure 11. Effect of Root Gap

Figure 11 presents the main effect of root gap on the tensile strength of the welded joints. Although the statistical analysis indicates that the root gap factor is not significant at the 95% confidence level (P = 0.168), a practical variation in tensile strength can still be observed.

The highest average tensile strength was obtained at an 8 mm root gap (approximately 560 MPa), while the lowest average value occurred at a 6 mm root gap (approximately 542 MPa). The 4 mm root gap produced a slightly lower average tensile strength of about 558 MPa.

This non-linear trend suggests that root gap plays an important role in controlling weld penetration and filler metal distribution at the joint root. A very narrow gap may restrict molten metal flow and reduce penetration efficiency, whereas a wider gap provides better accessibility for filler metal and allows more stable weld pool formation. However, intermediate gaps may create less stable molten metal behavior, which can lead to uneven fusion and reduced tensile strength.

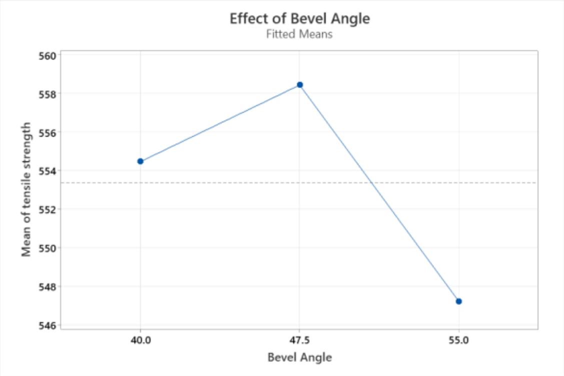

Figure 12. Effect of Bevel Angle

Figure 12 shows the main effect of bevel angle on the tensile strength of the welded joints. Although the statistical analysis indicates that bevel angle does not have a significant effect on tensile strength at the 95% confidence level (P = 0.547), a noticeable variation in the experimental results can still be observed.

The highest average tensile strength was obtained at a bevel angle of 47.5° (approximately 558.5 MPa), followed by 40° (approximately 554.5 MPa), while the lowest value occurred at 55° (approximately 547.5 MPa). This indicates that the 47.5° bevel angle provides a more favorable welding geometry for achieving stable fusion conditions.

From a welding perspective, bevel angle determines the groove shape and influences heat concentration as well as filler metal distribution within the joint. A narrower bevel angle may limit accessibility for molten metal at the root region, potentially reducing penetration quality. On the other hand, excessively wide bevel angles increase groove volume and heat dispersion, which may lead to a wider heat-affected zone and reduced joint efficiency. Therefore, a moderate bevel angle such as 47.5° can provide a balanced condition between penetration capability and thermal distribution during welding.

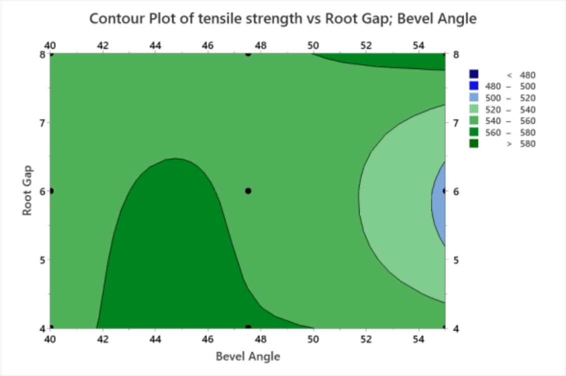

Figure 13. Contour Plot

Figure 13 presents the contour plot generated from the DOE model, illustrating the predicted tensile strength distribution across different combinations of root gap and bevel angle. The plot shows that the region corresponding to an 8 mm root gap and a 55° bevel angle falls within the highest predicted tensile strength zone, exceeding approximately 580 MPa.

The darker contour region represents parameter combinations that provide more favorable welding conditions for achieving higher tensile strength. This condition may be associated with improved weld penetration and more uniform filler metal fusion at the joint root.

The prediction from the DOE model is consistent with the experimental observations, indicating that the combination of an 8 mm root gap and a 55° bevel angle provides a favorable parameter region for achieving strong weld joints.

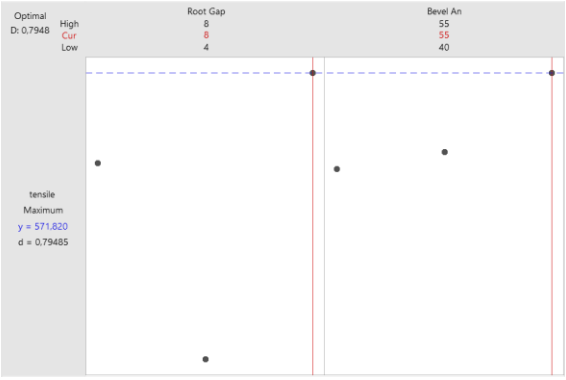

Figure 14. Tensile Strength Optimization

Figure 14 presents the optimization results obtained from the DOE model. The analysis indicates that the optimal parameter combination for maximizing tensile strength is an 8 mm root gap combined with a 55° bevel angle. Under this condition, the predicted tensile strength reaches approximately 571.82 MPa with a desirability value of 0.7948.

In the context of DOE optimization, the desirability value represents how well the selected parameter combination satisfies the optimization objective. A value closer to 1 indicates that the response is approaching the desired target. Therefore, the obtained desirability value suggests that this parameter combination provides a favorable condition for achieving high tensile strength in GMAW welded joints.

Bending Test Results

The bending test was conducted to evaluate the plastic deformation capability of the welded joints and to identify surface defects, particularly at the weld root region.

Among all parameter combinations, the 8 mm root gap combined with a 55° bevel angle exhibited no visible surface cracks, indicating good ductility and stable weld integrity during bending deformation. Other configurations such as 6 mm – 47.5° and 4 mm – 47.5° also showed no cracking, while several combinations, including 4 mm – 40° and 6 mm – 55°, exhibited surface cracks of varying lengths.

The presence of cracks suggests localized stress concentration or incomplete fusion at the weld root, which reduces the ability of the joint to withstand plastic deformation. In contrast, the absence of cracks in the 8 mm – 55° configuration is consistent with its high tensile strength performance, indicating that this parameter combination provides both strong mechanical properties and reliable structural behavior under loading.

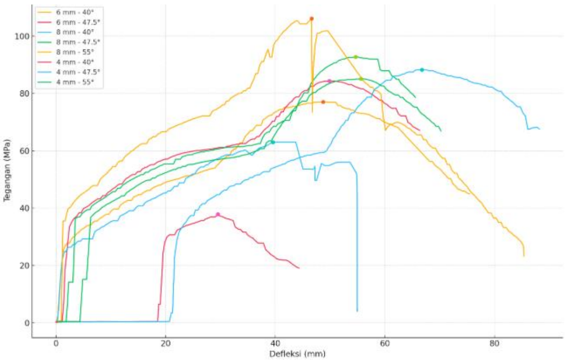

Figure 15. Bending Test Graph

Macrostructure Results

Macrostructure analysis was conducted to evaluate weld shape, fusion quality, and heat-affected zone (HAZ) distribution as a visual verification of tensile and bending test results.

Figure 16. 4 mm Root Gap

The macrostructure of the specimen with a 4 mm root gap shows relatively uniform filler metal distribution with visible penetration reaching the weld root. The heat-affected zone (HAZ) appears relatively narrow, indicating controlled heat input during the welding process.

However, variations in bevel angle influence the structural response of the joint, as evidenced by the presence of cracks in certain bending test results. This suggests that although adequate fusion is achieved, the joint performance at a 4 mm root gap remains sensitive to geometric variations. The use of ceramic backing contributes to maintaining root formation and preventing excessive melt-through, but does not fully eliminate the effect of bevel angle on mechanical behavior.

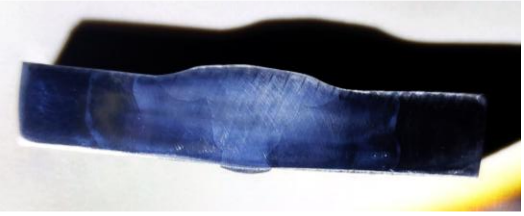

Figure 17. 6 mm Root Gap

The macrostructure of the specimen with a 6 mm root gap exhibits consistent weld metal distribution and complete penetration at the joint root. The HAZ appears slightly wider compared to the 4 mm configuration, indicating a higher heat input during welding.

Although the overall fusion appears satisfactory, the occurrence of cracks in certain specimens suggests that this configuration may produce less stable molten pool conditions under specific parameter combinations. This instability can lead to localized defects or stress concentration, which is reflected in the relatively lower tensile strength observed in this configuration. Therefore, the 6 mm root gap represents an intermediate condition that may require tighter control of welding parameters to achieve consistent mechanical performance.

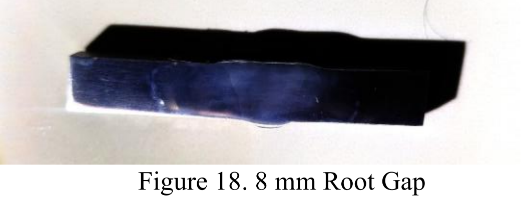

Figure 18. 8 mm Root Gap

The macrostructure of the specimen with an 8 mm root gap demonstrates uniform weld metal fusion with no visible defects such as porosity or lack of fusion. The penetration is well-developed, and the weld profile appears more open, indicating efficient molten metal flow and heat distribution.

These observations are consistent with the tensile and bending test results, where this configuration exhibited the highest average tensile strength and no visible cracks during bending. This indicates that the 8 mm root gap provides favorable conditions for achieving stable weld pool behavior, effective penetration, and strong mechanical performance. As a result, this configuration can be considered the most reliable parameter combination in terms of structural integrity and weld performance.

5. Conclusion

This study investigated the effect of root gap and bevel angle variations on the tensile and bending performance of GMAW welded joints on low-carbon SPA-H steel using a full factorial design with ANOVA and DOE analysis. The statistical results indicate that both parameters and their interaction do not have a significant effect on tensile strength at the 95% confidence level.

However, the experimental data reveal clear practical trends, where the 8 mm root gap and 55° bevel angle configuration produced the best performance, with a predicted tensile strength of 571.82 MPa and no visible cracks in the bending test. These findings are further supported by macrostructure observations, which show uniform metal fusion and a controlled heat-affected zone (HAZ), indicating stable weld integrity.

Therefore, although the statistical significance is not observed, this parameter combination provides a favorable condition for achieving reliable mechanical performance in GMAW welding of SPA-H steel. Further research is recommended to evaluate its effect on impact toughness and corrosion resistance for broader industrial applications.

Acknowledgment

The authors would like to express their sincere gratitude to the Mechanical Engineering Department of Politeknik Negeri Malang for providing laboratory facilities and technical support throughout the experimental process. Special thanks are also extended to the academic supervisors for their valuable guidance and constructive feedback during the preparation of this research. Appreciation is also given to all colleagues who contributed assistance during data collection and testing.

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