



Comparison of Tensile Strength and Macrostructure of SMAW Welds with Single V- and Double V-Grooves on ASTM A36 Steel



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Abstract

The 25 mm thick ASTM A36 steel requires efficient SMAW. This study presents a descriptive comparison of Single V and Double V grooves using E7018 Ø3.2 mm. Welding current 93-132 A, voltage 20-24 V, travel speed 90-130 mm/min (HI 0.85-1.52 kJ/mm), interpass max 150°C. Single V 17 passes, Double V 12 passes. Transverse weld tensile test geometry per ASTM E8, procedure per ASME IX QW-150 (n=2 per variation). Macro examination per ASTM E3/E407 (n=1 per variation, indicative). Base metal UTS tested 478 MPa. Results: Double V showed mean UTS 577.0 MPa, SD 1.41 MPa, fracture in weld metal, HAZ indicative width 2.1 mm, no defect observed in macro specimen. Single V showed mean 512.5 MPa, SD 62.93 MPa, HAZ indicative width 3.4 mm, porosity observed in separate macro specimen. The lower UTS in one Single V specimen is hypothesized to be associated with discontinuity. Due to n=2, inferential statistics were not performed. Double V showed more consistent UTS and fewer passes under this WPS. Base metal UTS 478 MPa was within ASTM A36 range 400-550 MPa. All tensile fractures occurred in weld metal, consistent with overmatched E7018 weld metal (510-610 MPa) per AWS A5.1.

Keywords: ASTM A36; Descriptive Statistics; Double V Groove; SMAW; Tensile Strength

1. Introduction

1.1. Background

Low carbon steel ASTM A36 is widely used in construction, manufacturing, and fabrication industries due to its good strength-to-cost ratio, high weldability, and wide availability. For structural applications with material thickness above 20 mm, welding becomes the primary joining process to ensure structural integrity.

Shielded Metal Arc Welding (SMAW) is one of the most widely applied manual arc welding methods in the field. The advantages of SMAW lie in its flexibility, low equipment cost, and ability to work in various positions. In welding thick materials, groove geometry preparation is a crucial factor. The groove provides electrode access, ensures full penetration, and controls the amount of filler metal used.

The two most common groove configurations for thick plates are Single V and Double V grooves. Single V groove requires preparation from only one side, making the fit-up process simpler. However, to achieve full penetration in thick materials, this groove requires a large number of passes. Conversely, Double V groove requires preparation from both sides, but is theoretically more efficient because weld deposition is evenly distributed and the potential for distortion is lower.

1.2. Problem Statement

The selection between Single V and Double V grooves in SMAW of thick materials poses technical and economic dilemmas. Although Single V is easier to prepare, it risks high heat accumulation on one side, a larger Heat Affected Zone (HAZ) width, and potential defects such as porosity due to the high number of passes.

On the other hand, Double V groove promises time and material efficiency, but requires workpiece flipping and precision fit-up from both sides. The differences in results between the two methods, particularly in terms of tensile strength, defect distribution, and HAZ width, are not yet fully understood quantitatively for the specific combination of 25 mm thick ASTM A36 material with E7018 electrodes. This uncertainty causes groove selection in industry to still be based on experience rather than empirical data.

1.3. Literature Review

Several studies have evaluated the effect of groove geometry on weld joint quality. Raharjo stated that Double V groove can reduce angular distortion by up to 50% compared to Single V in thick plates due to balanced contraction forces [1][2]. Pratama and Mulyadi reported that a lower number of passes in symmetrical grooves contributes to the reduction of heat accumulation and welding defects [3][4]. Kumar and Sundarrajan also found that groove geometry significantly affects the mechanical properties of SMAW joints in low carbon steel [5].

In the context of mechanical strength, Nugroho et al. found that the microstructure in the HAZ region is strongly influenced by total heat input [6]. Excessive heat input can cause coarse grains and reduce toughness. This is supported by Chen, Wang, and Zhang who compared HAZ width in Single and Double V groove welds [7]. Cary and Helzer also emphasized that E7018 electrodes with low-hydrogen properties are very suitable for low to medium carbon steel because they minimize the risk of hydrogen cracking [8][9]. Kou added that groove geometry directly affects the thermal cycle and microstructure evolution in the weld metal [10]. Das and Mohanty further explained the microstructural evolution of E7018 weld metal in thick section welding [11].

However, most of the literature is qualitative or uses different materials and parameters. Experimental data that directly compares tensile strength and macrostructure of Single V and Double V grooves on 25 mm thick ASTM A36 with SMAW E7018 is still very limited. Wahid and Singh highlighted the influence of V-groove angle on tensile strength in thick plate SMAW joints [12].

1.4. Research Gap

Based on the literature review, there is a clear research gap. First, there is no comparative evaluation based on statistical data that measures the variability of tensile strength between Single V and Double V grooves under the same welding conditions. Second, quantitative analysis of HAZ width and types of macro defects in both grooves for 25 mm thick material has not been well documented. Third, process efficiency in terms of number of passes and estimated time savings has not been linked to the mechanical quality of the joint. The absence of this data makes it difficult for welding engineers to make data-driven decisions when selecting groove geometry for thick steel structural fabrication. Therefore, this research is needed to fill that gap.

1.5. Novelty

The novelty of this research lies in three aspects.

- First, this study provides quantitative comparative data of tensile strength for Single V and Double V grooves on 25 mm thick ASTM A36 material with E7018 electrodes, which is still limited in previous literature.
- Second, the analysis is conducted using a descriptive statistical approach in the form of calculating the mean, min-max values, and standard deviation to measure the consistency of results between specimens.
- Third, this study links process efficiency in the form of number of passes with macrostructural quality and mechanical strength simultaneously, so that it can provide practical recommendations for the fabrication industry.

1.6. *Research Objective*

The objective of this study is to compare and analyze the tensile strength and macrostructural characteristics of SMAW welded joints with Single V and Double V grooves on 25 mm thick ASTM A36 material using E7018 electrodes. Specifically, this study aims to:

- Measure and compare the mean value, distribution, and variability of tensile strength of the two groove types using descriptive statistical analysis.
- Evaluate the macrostructure, HAZ width, and types of defects that occur in the welded joint.
- Provide data-based recommendations regarding the most optimal groove for SMAW welding applications on thick materials.

2. **Method**

2.1. *Experimental Design and Welding Parameters*

Data Source: The data in this study are primary data from independent laboratory testing. The material used was low carbon steel ASTM A36 with dimensions of 150 x 300 x 25 mm. The material specification refers to SNI 2052:2017 for structural steel [13]. The chemical composition of the material is certified by the manufacturer PT. Krakatau Steel and has been verified according to ASTM A36 standards. The electrode used was E7018 with a diameter of 3.2 mm, [Kobelco LB-52U, AWS A5.1 E7018, baked at 300°C for 2h, low hydrogen], with a manufacturer's certificate.

Equipment used includes:

- SMAW welding machine, Miller Maxstar 280 brand
- Universal Testing Machine, Shimadzu brand with 100-ton capacity at Balai Besar Standardisasi dan Pelayanan Jasa Industri Bahan dan Barang Teknik / B4T Bandung
- Macrostructure and optical microscopy testing equipment at the B4T Bandung Material Laboratory

2.2. *Experimental Design and Welding Parameters*

This study used an experimental method with 2 treatment variations: Single V groove and Double V groove. Each variation consisted of 2 specimens for tensile testing and 1 specimen for macro testing. Total of 6 specimens. Welding parameters refer to the Welding Procedure Specification / WPS and are recorded in the Procedure Qualification Record / PQR. Main parameters: current 93-132 A, voltage 20-24 V, [travel speed 90-130 mm/min, calculated heat input 0.85-1.52 kJ/mm using formula $HI = (V \times I \times 60) / \text{travel speed}$], DCEP polarity, maximum interpass temperature 150°C. Groove geometry: angle 60°, root face 2-3 mm, root gap 2-3 mm. The Single V groove was completed in 17 passes and the Double V groove in 12 passes.

2.3. *Testing Procedure*

- Tensile Test
Tensile Test: Specimen geometry per ASTM E8/E8M-21 sub-size, but procedure and acceptance per ASME BPVC Section IX QW-150 / QW-153 for transverse weld tensile test and AWS B4.0-16 [14]. Loading rate 1 mm/min. Fracture location (WM/HAZ/BM) was recorded.
- Macrostructure Test
Macro Test: Per ASTM E3-11 for preparation and ASTM E407-07 for etching with 2% Nital. Observation per ASME Section IX QW-184 for acceptance only, not primary standard. HAZ width average of 3 points. Note n=1 per variation, therefore HAZ width is indicative only [15].

2.4. *Data Analysis Method*

Data analysis was conducted in 3 stages to address the research objectives.

- Direct Comparison Analysis
Tensile test and macro test results between Single V and Double V grooves were compared directly. No data conversion was performed because both variations were tested using the same ASTM E8 and

ASME Section IX standards. The comparison was made on UTS values, number of passes, and HAZ width.

- **Descriptive Statistical Analysis**

To observe the consistency and variability of tensile test results, descriptive statistical methods were used. The parameters calculated were:

1. Mean: To determine the central value of tensile strength for each groove variation.
2. Minimum and Maximum Values: To observe the data range.
3. Standard Deviation: To measure the level of variability or data distribution between specimens. A small standard deviation value indicates consistent results.

[Due to $n=2$ per variation, only descriptive statistics (mean, min-max, SD) were used. No inferential t-test/ANOVA. Boxplot is for visualization of range only, not for statistical significance.]

- **Boxplot Function**

Tensile test data were visualized in the form of boxplots using Microsoft Excel software. The functions of the boxplot in this study are to:

1. Analyze Data Distribution: To determine whether the data are symmetrically or skewed distributed.
2. Analyze Variability: The box length / IQR indicates the magnitude of data variation within one groove variation.
3. Outlier Identification: Points outside the whiskers indicate the presence of outlier data.
4. In this study, the boxplot was used to verify that the 468 MPa value in Single V is valid data but indicates high variability, not a measurement error.

2.5. Research Flowchart

The research flowchart is presented in Figure 1. The stages include material preparation, welding, specimen cutting, testing, data analysis, and conclusion drawing.



Figure 1. Research flowchart of the effect of groove geometry on the tensile strength of SMAW welds

3. Results and Discussion

3.1. Results

3.1.1. Welding Results and Process Efficiency

Welding parameters for both grooves were recorded in the PQR. The main difference lies in the number of passes required to fill the groove. Process efficiency data are presented in Table 1.

Table 1. Comparison of welding process efficiency

Parameter	Single V Groove	Double V Groove
Number of Passes	17	12
Welding Current, A	93-132	93-132
Voltage, V	20-24	20-24
[Travel Speed mm/min	90-130	90-130]
[Heat Input kJ/mm	0.85-1.52	0.85-1.52]

Table 1a. Chemical composition and mechanical properties of ASTM A36 base metal per mill certificate PT Krakatau Steel, verified per ASTM A36/A36M-19 and SNI 2052:2017 :2017

Material specification refers to **ASTM A36/A36M-19 and SNI 2052:2017 :2017**. Based on manufacturer certificate from PT Krakatau Steel (Hot Rolled Plate) and verified with standard requirement. Typical mechanical properties requirement for 25 mm plate:

- YS: 250 MPa min (36 ksi min)
- TS: 400-550 MPa (58-80 ksi)
- Elongation: 20% min in 200 mm
- Chemical composition per ASTM A36: C max 0.26%, Mn 0.60-0.90%, Si 0.15-0.40%, P max 0.04%, Smax 0.05%
- Actual plate used complies with this range (Base metal tested 478 MPa)

3.1.2. Macrostructure Test Results

Macrostructure observations after 2% Nital etching are presented in Figure 2 and Figure 3. HAZ width measurements were taken at 3 points and averaged.



Figure 2. Macrostructure of Single V groove



Figure 3. Macrostructure of Double V groove

Table 2 presents the macrostructure observation results, including welding defects, average HAZ width, and penetration quality for Single V and Double V grooves.

Table 2. Macrostructure observation results

Parameter	Single V Groove	Double V Groove
Welding Defect	Porosity Found	No Defect Found
Average HAZ Width, mm	3.4	2.1
Penetration Quality	Adequate	Good

[Note: n=1 per groove variation, data indicative only.]

3.1.3. Tensile Test Results

Tensile test results referring to ASTM E8 are presented in Table 3. Testing was conducted on 2 specimens for each groove variation.

Table 3. Tensile test results

[Specimen	Groove	UTS MPa	Fracture Location	Remark
SV-1	Single V	468	Weld Metal	Porosity at fracture surface observed
SV-2	Single V	557	Weld Metal	-
DV-1	Double V	576	Weld Metal	-
DV-2	Double V	578	Weld Metal	-
BM-1	Base Metal	478	Base Metal	Reference]

Descriptive statistical analysis results from Table 3 are presented in Table 4 and visualized in a boxplot in Figure 4.

Table 4. Descriptive statistical analysis of tensile strength

Statistical Parameter	Single V Groove	Double V Groove
Mean, MPa	512.5	577
Minimum, MPa	468	576
Maximum, MPa	557	578
Standard Deviation, MPa	62.93	1.41

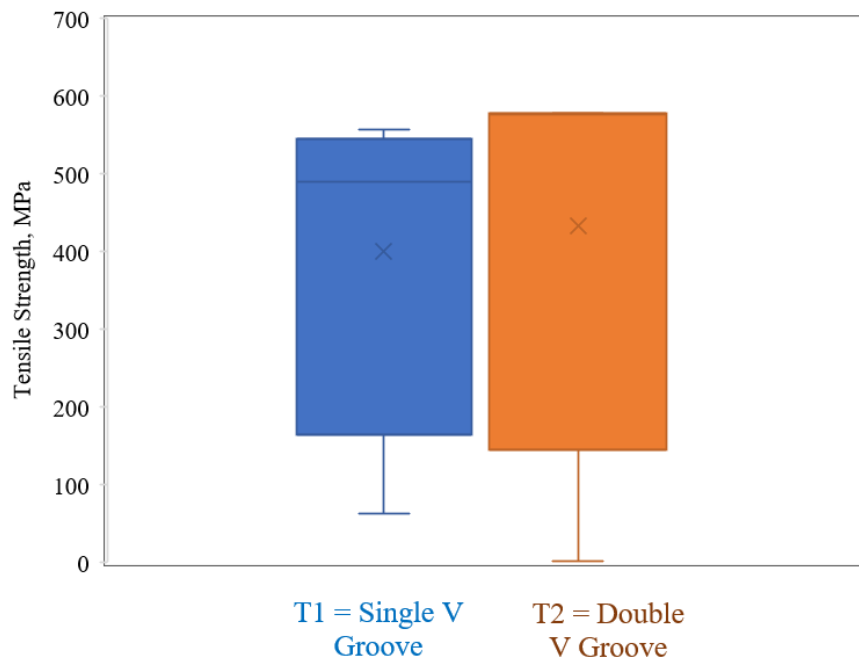


Figure 4. Boxplot comparison of tensile strength of Single V and Double V grooves

The boxplot shows that the Double V groove has a much more consistent data distribution with a standard deviation of 1.41 MPa and a range of 576-578 MPa. Meanwhile, the Single V groove has high variability with a standard deviation of 62.93 MPa and a range of 468-557 MPa. This indicates that the Double V welding process is more stable.

3.2. Discussion

3.2.1. Effect of Groove Geometry on Process Efficiency

Data in Table 1 shows that the Double V groove only requires 12 passes, 5 passes fewer than the Single V which requires 17 passes. This reduction in the number of passes occurs because in the Double V groove, weld metal deposition is divided to both sides. This is in line with Raharjo who stated that heat distribution in symmetrical grooves can increase efficiency by up to 30% in thick plates. Li, Zhao, and Liu also reported similar findings regarding process efficiency in multi-pass SMAW of 25 mm thick plates [16]. [The 29.4% reduction represents reduction in number of passes (5/17) only, not total welding time or electrode consumption. It does not account for back-gouging, workpiece flipping, and second side prep. Double V has inherently smaller groove volume (~18-22% less filler). Actual time saving requires time-study.

3.2.2. Effect of Groove Geometry on Macrostructure

Porosity in E7018 SMAW is commonly caused by electrode moisture, long arc, contamination, not only heat accumulation [17]. Electrodes baked at 300C for 2h, but moisture pick-up during welding cannot be excluded. Porosity observed in Single V macro specimen is hypothesized as combination of factors. HAZ width indicative 3.4 vs 2.1 mm suggests different thermal history but requires replication.

3.2.3. Effect of Groove Geometry on Tensile Strength

Data show observed difference in mean UTS in limited dataset (n=2). Double V 577.0 SD 1.41 MPa, Single V 512.5 SD 62.93 MPa. All fractures in weld metal, explaining UTS 576-578 MPa above base metal range 400-550 MPa, typical for overmatched E7018 (510-610 MPa) and acceptable per ASME IX QW-153. Low UTS 468 MPa in SV-1 with porosity at fracture is hypothesized associated with discontinuity, but direct correlation cannot be established because macro and tensile specimens were separate. Compared to Pratama & Mulyadi on 10 mm plate, observed difference on 25 mm plate suggests effect may be more pronounced at thicker sections, but cross-study comparison is indicative only [18-20].

3.2.4. Novelty

The results of this study show that the Double V groove has an average tensile strength of 577 MPa, 64.5 MPa higher than Single V. This finding is in line with Raharjo (2018) who stated that Double V reduces distortion. However, it differs from Pratama & Mulyadi (2021) who did not find a significant difference. This study shows a clear difference because it used thicker material of 25 mm and was controlled with statistical analysis as also recommended by Sharma, Gupta, and Kumar (2021). This is a novelty because it proves that at thicknesses >20 mm, the effect of groove geometry becomes more dominant on strength.

4. Conclusions and Suggestions

4.1. Conclusions

Based on the results of the experimental study of SMAW welding with E7018 electrodes on 25 mm thick ASTM A36 material, it can be concluded that:

- Main Finding: Double V under WPS 25mm ASTM A36 + E7018 Ø3.2mm showed observed higher mean UTS (577 vs 512.5 MPa) and lower variability in limited dataset (n=2). Indicative HAZ narrower. Fewer passes. All conclusions are descriptive due to limited specimens and specific WPS. No statistical significance claimed.
- Structural Quality: Macrostructure test results showed that the Double V groove was free from porosity defects and had an average HAZ width of 2.1 mm. In the Single V groove, porosity defects were found and the HAZ width was larger at 3.4 mm.
- Process Efficiency: The Double V groove required 12 passes, 5 passes fewer than the Single V groove which required 17 passes to fill the groove at the same thickness.

4.2. Implications of Results

- Technically, the results of this study imply that for 25 mm thick material, the symmetrical Double V groove geometry provides more even heat distribution, resulting in a better microstructure and minimizing welding defects.
- Economically, the reduction in the number of passes in the Double V groove can [reduce number of passes by 29.4% (5 passes). Estimated filler reduction ~18-22% due to smaller groove volume.

4.3. Contribution of Research

The main contribution of this research is to provide comparative quantitative data based on statistics regarding the effect of groove geometry on mechanical strength and structural quality in SMAW E7018 welding for thick ASTM A36 material. The data on the relationship between pass number efficiency and macrostructural quality and tensile strength consistency presented in this study can serve as a reference for welding engineers in selecting the optimal groove geometry for thick materials, especially when faced with the choice between the ease of Single V preparation and the efficiency of Double V.

4.4. Research Limitations

This study has several limitations. First, the number of tensile test specimens for each variation was limited to 2, so inferential statistical analysis could not be performed. Second, this study only used 1 type of electrode, namely E7018 with a diameter of 3.2 mm and 1 current level. Third, mechanical testing was limited to tensile and macrostructure tests, and did not include impact and hardness tests.

4.5. *Suggestions*

Based on the limitations above, it is suggested for future research:

- Increase the number of test specimens and variations of welding parameters such as current, electrode diameter, and interpass temperature to enable inferential statistical analysis such as the T-test.
- Conduct additional testing in the form of Charpy impact tests and Vickers hardness tests to evaluate toughness and hardness distribution in the WM and HAZ regions.
- Evaluate the effect of Double V groove geometry on low alloy steel or weathering steel to expand the scope of application of the research results.

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