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The Effect of V and X Groove Configurations in SMAW Welding on the Hardness of Low-Carbon Steel

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Abstract. This study compared the distribution of Rockwell A hardness in SMAW joints with V- and X-grooves made from 10 mm low-carbon steel plates. Welding used 3.2 mm AWS E7016/LB 52U electrodes. Three specimens were prepared for each groove, and hardness was measured at three points in the base metal, heat-affected zone (HAZ), and weld metal. The data were analyzed descriptively using specimen means and combined means for each region. The X-groove produced higher combined means than the V-groove in the base metal (80.92 versus 77.52 HRA), HAZ (81.85 versus 79.77 HRA), and weld metal (83.92 versus 81.98 HRA). The highest regional mean was approximately 84.16 HRA in the weld metal of specimen X3, whereas the highest value for the V-groove was 83.06 HRA in the weld metal of specimen V3. Both groove types showed an increase in hardness from the base metal toward the weld metal. Under the conditions of this study, the X-groove was associated with a higher hardness profile; however, this finding cannot be generalized as superior joint strength because only hardness was measured.

Keywords: *Groove Weld, Hardness, Low-Carbon Steel, Rockwell A, SMAW.*

A. INTRODUCTION

The development of the manufacturing, construction, shipbuilding, automotive, and heavy-equipment fabrication industries has increased the need for reliable steel joints. Low-carbon steel is widely used because of its combination of strength, ductility, ease of fabrication, and relatively low cost. Plates with a thickness of 10 mm are used, among others, in frame structures, tanks, bridges, and machine components that carry loads during operation (Rahman et al., 2023; Syamsuddin et al., 2025).

Shielded Metal Arc Welding (SMAW) is one of the widely used joining processes for these materials. The electric arc heat melts the electrode and part of the base metal to form a permanent joint. The heating and cooling cycles during welding can alter the microstructure of the weld metal, heat-affected zone (HAZ), and base metal. These changes affect mechanical properties, including hardness, tensile strength, toughness, and ductility (Effendi, 2019; Purbonugroho et al., 2023).

Previous studies have shown that welding results are influenced by current, process, material, and groove configuration. Awali et al. (2021) reported a tendency for hardness to decrease as current increased in SMAW–FCAW with a double-V groove. Desmon et al. (2021) found that the weld metal was generally harder than the HAZ and base metal in JIS SS400 steel. Pamungkas et al. (2023) showed that a groove with higher hardness does not necessarily produce higher tensile strength. Tambing et al. (2024) also examined the effects of current and electrode type on the strength and hardness of low-carbon steel produced by SMAW.

Although these studies provide an important basis, a direct comparison of V- and X-grooves in SMAW of 10 mm low-carbon steel plates using a fixed electrode diameter still needs to be clarified. This study aimed to determine the Rockwell A hardness distribution in the base metal, HAZ, and weld metal and compare the hardness values of SMAW joints with V- and X-grooves.

B. LITERATURE REVIEW

1. SMAW Welding

SMAW is a manual arc-welding process that uses flux-coated electrodes (Tambing et al., 2024; Afzal et al., 2025). An arc is formed when a potential difference exists between the electrode and workpiece and is maintained at a certain distance. The arc heat melts the electrode tip and part of the base metal to form a weld pool that subsequently solidifies into a joint.

The electrode flux produces shielding gas and a slag layer. The shielding gas limits the contact of molten metal with oxygen, nitrogen, and hydrogen from the air, while the slag protects the weld surface during cooling. After solidification, the slag is removed so that the joint surface can be inspected. The simplicity of the equipment and flexibility in welding positions make SMAW widely used in workshops and field applications.

2. V- and X-Grooves

A V-groove is used for butt joints by shaping both plate edges to form a V shape. The groove provides space for the filler metal to reach the joint root and increases the likelihood of achieving adequate penetration. The groove angle, root gap, plate thickness, and welding technique determine the volume of filler metal and the cross-sectional shape of the joint.

An X-groove or double-V groove is prepared on both sides of the plate and welded from two directions. This configuration can reduce the filler metal volume compared with a single V-groove for thick plates and help balance thermal shrinkage. However, joint quality remains influenced by penetration, pass sequence, heat input, distortion, and operator skill (Awali et al., 2021; Pamungkas et al., 2023).

3. Rockwell Hardness Testing

Rockwell testing determines a material's resistance to indentation based on the difference in indentation depth before and after the application of the major load. The minor load stabilizes the contact between the indenter and surface, after which the major load is applied according to the selected scale. The hardness value is read directly from the machine indicator. Rockwell hardness testing of metallic materials is generally governed by ASTM E18 (ASTM International, 2022).

The results are affected by specimen condition and thickness, surface flatness and cleanliness, scale selection, indenter condition, machine calibration, indentation spacing, and specimen stability. In general, the Rockwell hardness number can be expressed as:

$$HR = E - e$$

In this equation, HR is the Rockwell hardness number, E is the scale constant, and e is the permanent indentation depth resulting from the major load, expressed in multiples of 0.002 mm

C. METHOD

The study was conducted over five months, from March to July 2026, at Manado State Polytechnic. The experimental design was comparative, comparing the hardness of SMAW welds with V- and X-grooves. The material used was 10 mm-thick low-carbon steel plate. The electrode used was a 3.2 mm AWS E7016/LB 52U. The main equipment included a Miller Bluthunder 340 welding machine, Bosch grinder, Mitutoyo caliper, and Zwick/Roell hardness tester.

The plates were cut as required, and the joint edges were then prepared into V- and X-grooves. After welding, the specimen surfaces were leveled and sanded sufficiently for indentation testing. Three specimens were prepared for each groove type and coded V1–V3 and X1–X3. Testing was conducted on the base metal, HAZ, and weld metal.

The specimens were positioned perpendicular to the indenter on the machine anvil. The total load recorded in the procedure was 60 kgf. Each region was tested at three points, resulting in nine readings for each specimen and 27 readings for each groove type. The source manuscript states the use of the Rockwell A scale together with a steel-ball indenter. Because the A scale conventionally uses a diamond indenter, the indenter configuration needs to be verified against laboratory records before the article is submitted for publication. This article retains the HRA designation in accordance with the source data.

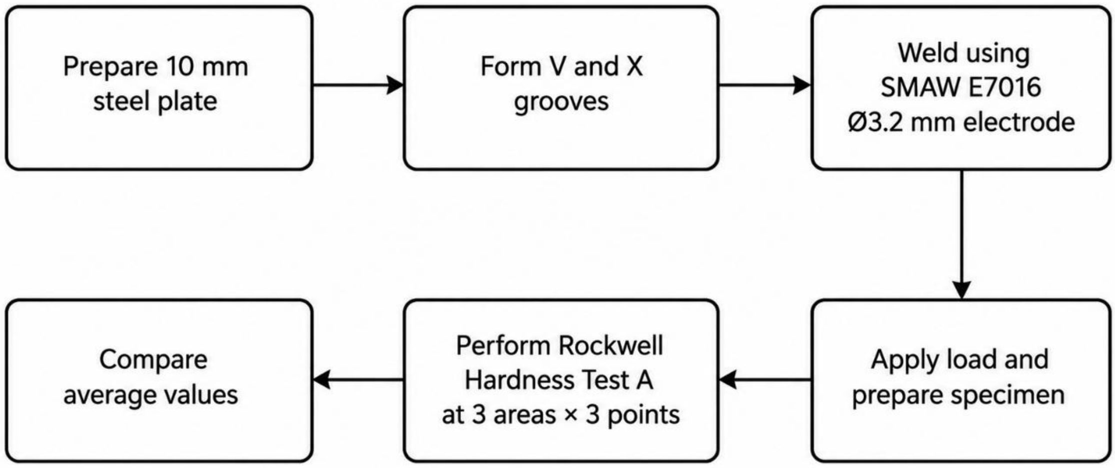

Figure 1. Research Implementation Flowchart

The data were analyzed descriptively. The mean for each specimen and region combination was calculated from three test points, while the combined mean for each groove and region was calculated from nine readings. The comparison was expressed as the difference between the mean values of the X-groove and V-groove. Hypothesis testing was not applied because the status of the three points as independent replicates or subsamples was not adequately defined in the initial design.

D. RESULT AND DISCUSSION

1. Hardness of Unwelded Metal

Three readings on the unwelded metal produced a mean hardness of 77.10 HRA. This value provides an initial indication of the material hardness before comparison with the regions of the welded specimens.

Table 1. Rockwell A Hardness Test Results for Unwelded Metal

No.	Hardness (HRA)
1	78,70
2	75,70
3	76,90
Mean	**77,10**

2. Comparison of V- and X-Grooves

The combined means showed an increase in hardness from the base metal toward the weld metal for both groove types. For the V-groove, the mean hardness increased from 77.52 HRA in the base metal to 79.77 HRA in the HAZ and 81.98 HRA in the weld metal. For the X-groove, the values increased from 80.92 HRA to 81.85 HRA and 83.92 HRA in the same regions. The highest regional mean was recorded in the weld metal of specimen X3 at approximately 84.16 HRA, while the V-groove reached approximately 83.06 HRA in the weld metal of specimen V3.

Table 2. Mean Hardness by Groove Type and Test Region

Test Region	V-Groove (HRA)	X-Groove (HRA)	Difference X−V (HRA)
Base metal	77,52	80,92	3,40
HAZ	79,77	81,85	2,08
Weld metal	81,98	83,92	1,94

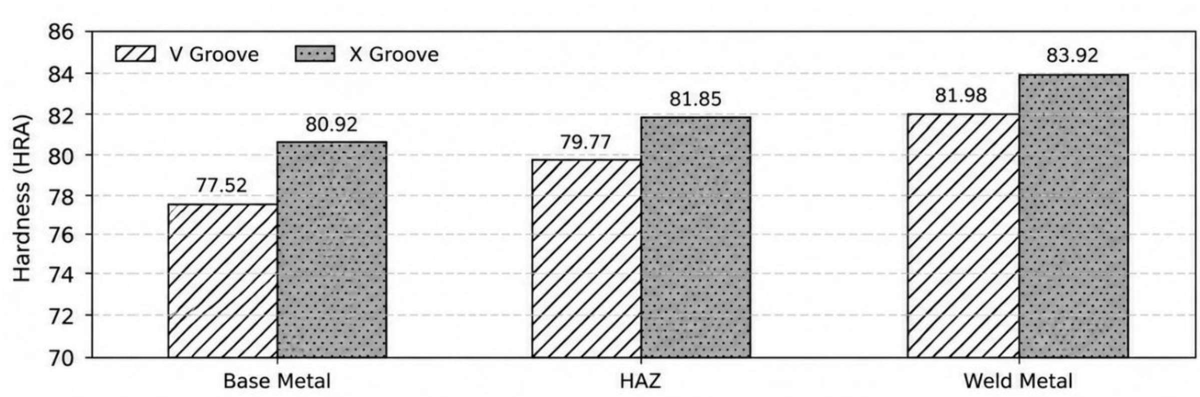

Figure 2. Comparison of Mean Hardness between V- and X-Grooves

The difference between the X- and V-grooves was 3.40 HRA in the base metal, 2.08 HRA in the HAZ, and 1.94 HRA in the weld metal. The difference already observed in the base metal indicates that not all differences can be directly attributed to the groove configuration alone. Initial material variation, measurement-point location, or differences in thermal exposure at the locations identified as base metal may also have contributed (Rosyid et al., 2022; Swasono & Azriadi, 2018).

These results should be interpreted as a comparison of hardness rather than a comprehensive comparison of joint strength. Hardness represents resistance to localized indentation and is not equivalent to tensile strength, toughness, ductility, or fatigue life. Groove selection should therefore also consider penetration, weld defects, distortion, filler-metal consumption, welding position, and design requirements.

Methodological traceability also limits the generalization of the results. The indenter type needs to be confirmed because the use of a ball indenter is inconsistent with the Rockwell A scale. The current, voltage, welding speed, groove angle, root gap, number of passes, polarity, and interpass temperature were not fully recorded. Future studies should include microstructural characterization, tensile or impact testing, and statistical analysis with clearly defined experimental units.

E. CONCLUSION

SMAW welding of 10 mm-thick low-carbon steel plates using 3.2 mm AWS E7016/LB 52U electrodes produced a hardness pattern that increased from the base metal toward the weld metal. The combined means for the V- and X-grooves were 77.52 and 80.92 HRA in the base metal, 79.77 and 81.85 HRA in the HAZ, and 81.98 and 83.92 HRA in the weld metal, respectively. The highest regional mean was approximately 84.16 HRA in the weld metal of specimen X3, while the V-groove reached approximately 83.06 HRA in the weld metal of specimen V3. Thus, the X-groove specimens showed higher hardness values than the V-groove specimens in all tested regions. This conclusion is limited to hardness and cannot be directly interpreted as indicating higher tensile strength, toughness, or structural suitability. Verification of the indenter type, more complete recording of welding parameters, microstructural examination, and additional mechanical testing are required before the results can be generalized.

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