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The Effect of weld groove variations on the impact toughness and hardness of AISI 1050 steel

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Abstract

Shielded Metal Arc Welding (SMAW) is a metal joining process that utilizes heat energy to melt both the base metal and the electrode. This study aims to evaluate the effect of weld groove variations on the impact toughness and hardness of AISI 1050 steel. Three types of groove configurations were examined: V Groove, Bevel Groove, and Double V Groove. Tests were conducted in the regions of the Weld Metal, Weld Root, Heat-Affected Zone (HAZ), and Base Metal using a welding current of 100 Amperes. The test results show that the Bevel Groove produced the highest impact toughness at the Weld Root (1.78 Joule/mm²), the V Groove at the Weld Metal (1.65 Joule/mm²), and the Double V Groove at the HAZ (1.48 Joule/mm²). In terms of hardness, the V Groove and Double V Groove showed the highest values in the HAZ (86.5 HRC), while the Bevel Groove exhibited the highest hardness in the Base Metal (81 HRC). The lowest hardness value was found in the Weld Root of the Bevel Groove (56.67 HRC). Overall, the hardness values in the Weld Metal area for all three groove types were the same, measuring 76.5 HRC.

1. Introduction

Indonesia is a developing country with significant potential to drive economic growth, particularly in the construction and manufacturing sectors. These two sectors play a vital role in national development, as they contribute substantially to economic activity and serve as key components in infrastructure development. A robust infrastructure functions as the physical foundation for achieving sustainable development and improving the quality of life for society.

The application of welding technology in the construction sector is extensive, encompassing shipbuilding, bridge construction, steel frameworks, pressure vessels, transportation facilities, railway tracks, and piping networks [1]. Welded joints are a method of joining two or more metals by heating them—either with or without filler metal—until they reach a molten state and subsequently solidify to form a unified metallic bond. In steel construction, welded joints are widely used due to their ability to produce strong, efficient, and versatile connections for various applications [2].

In welding practice, various types of joints and groove designs are employed depending on technical requirements and structural load demands [3]. These joints are designed to efficiently transfer loads or stresses, thereby ensuring the strength and reliability of the structure. The quality of welded joints is influenced by several factors, one of which is the welding procedure [4], [5]. This procedure includes technical planning for welding implementation—from construction method selection, material specification, equipment use, execution sequence, to welding preparation, including the selection of welding machines, welders, electrodes, and appropriate groove types [6], [7], [8], [9].

One critical factor affecting the mechanical performance of welded joints is the groove configuration [10], [11], [12]. Groove variations influence heat distribution, weld area, the size of the heat-affected zone (HAZ), and residual stress distribution, all of which ultimately affect the joint's toughness, particularly in absorbing impact loads.

Although several previous studies have examined the effect of groove geometry on tensile and bending strength in various materials, limited research has specifically analyzed the influence of groove variation on impact toughness and hardness distribution in medium carbon steel, such as AISI 1050 [13].

This study aims to fill that gap by evaluating three types of weld grooves—V Groove, Bevel Groove, and Double V Groove—in terms of impact energy and hardness distribution across critical regions of the weld joint, including the Weld Metal, Weld Root, HAZ, and Base Metal. The findings are expected to provide technical insights for selecting optimal groove designs in steel structure applications using AISI 1050 material.

2. Research Methods

2.1 Materials and Test Specimen Specifications

This study utilized medium carbon steel of type AISI 1050 with plate dimensions of 100 mm × 40 mm × 13 mm as the base material for testing. The welding electrode used was type E6010 with a diameter of 2.6 mm. The groove variations applied included V Groove, Bevel Groove, and Double V Groove, as illustrated in Fig. 1. Each groove type was prepared with a root gap of 2.6 mm, a root face of 2 mm, and a groove angle of 35°. The dimensions and shape of the test specimens were prepared by the ASTM E23 standard for impact toughness testing.

2.2 Welding Process

The welding process was carried out using the Shielded Metal Arc Welding (SMAW) method in the flat position (1G) with Direct Current Electrode Positive (DCEP) polarity. The welding current was set at 100 Amperes. Welding was performed by a certified and experienced welder under the direct supervision of the author to ensure adherence to procedures and welding quality. Before welding, the specimens were cut according to specified dimensions, and the grooves were shaped using a grinding machine based on each groove type specification.

(a) V Groove

(b) Bevel Groove

(c) Double V Groove

Fig. 1. Groove Types

2.3 Preparation and Testing Procedure

2.3.1 Impact Toughness Test

After the welding process, specimens were prepared for impact toughness testing by the ASTM E23 standard, as illustrated in Fig. 1. The specimens were cut and machined to match the standard impact test dimensions. Testing was conducted using a Charpy Impact Testing Machine, to evaluate the absorbed energy values of each specimen based on the different groove configurations used, as shown in Fig. 2.

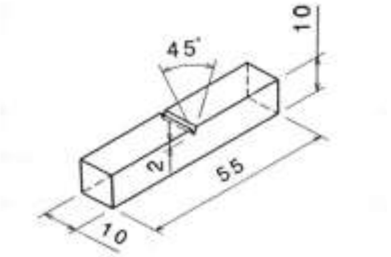
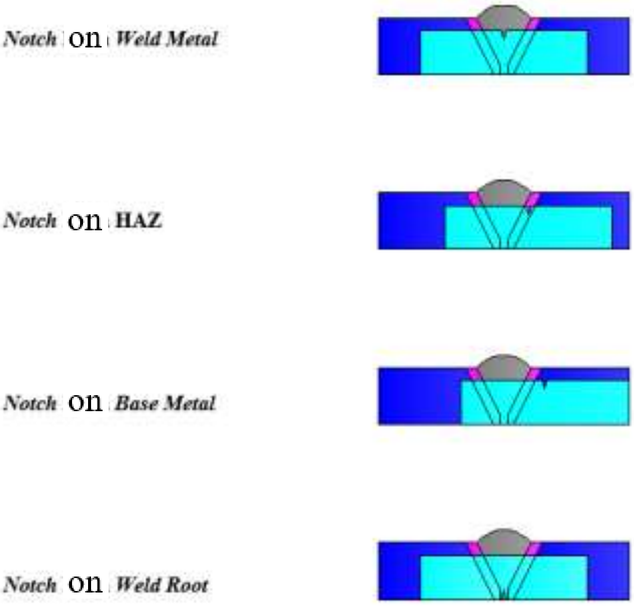
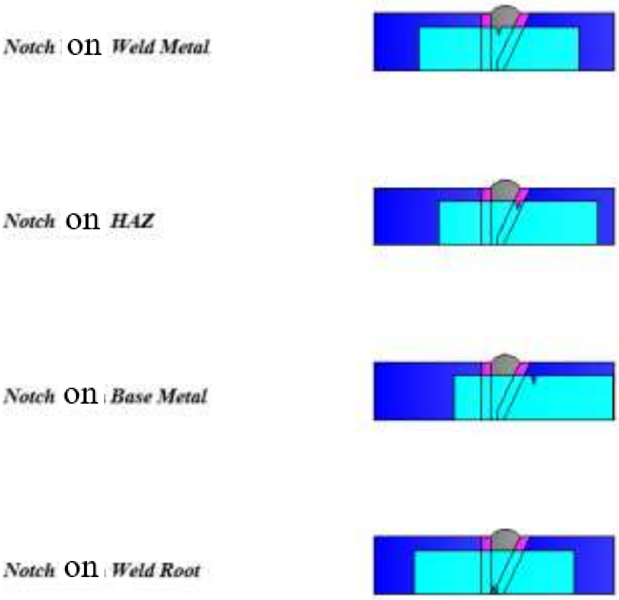


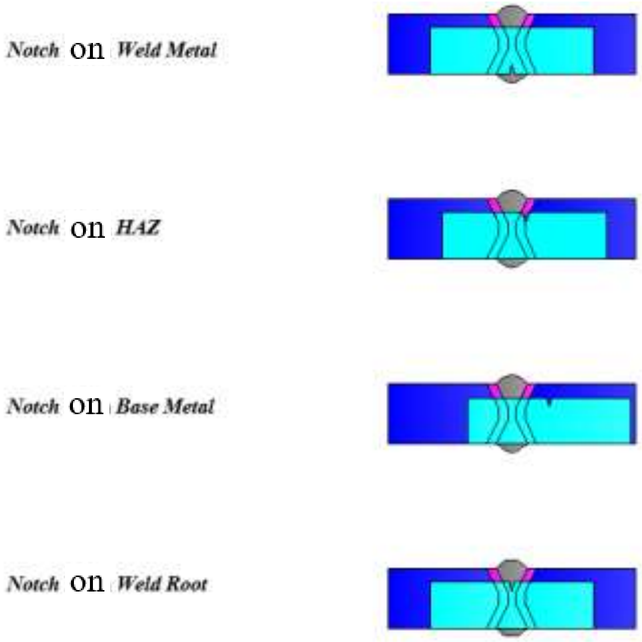
Fig. 2. Charpy Impact Test Specimen



(a) Specimen V Groove



(b) Bevel Groove Specimen



(c) Double V Groove Specimen

(d) Impact Test Specimen

Fig. 3. Groove Design Variations

🟦 ***Test Piece Impact***

⬛ ***Weld Metal***

🟪 ***HAZ***

🟦 ***Base Metal***

2.3.2 Hardness Testing

The hardness testing in this study was conducted using the Rockwell C method [14][15]. Measurements were taken in four different areas for each welded specimen, as illustrated in Fig. 4. The first area was the weld metal, measured approximately 3 mm from the centerline of the joint. The second area was the weld root, measured about 3 mm from the bottom of the weld. The third area was the Heat-Affected Zone (HAZ), taken at a distance of approximately 3 mm from the fusion boundary. The final area was the base metal, located outside the influence of the welding process. This testing was performed to determine the distribution of hardness values across each area and to map the hardness characteristics in the critical regions of the welded joint.

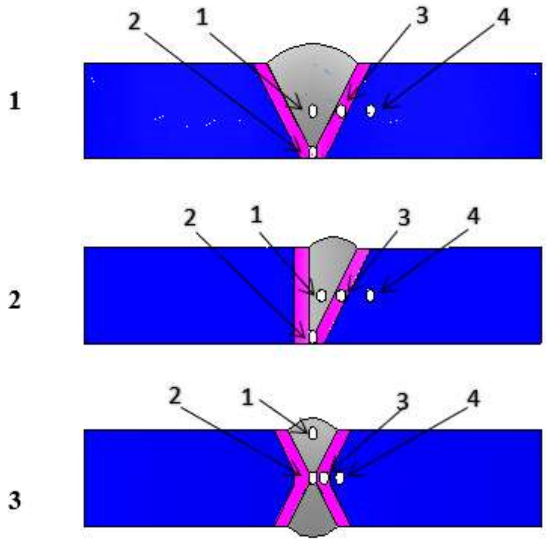
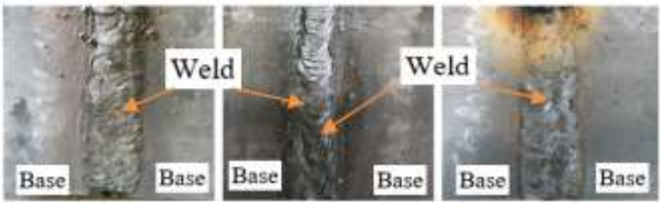


Fig. 4. Hardness Test Locations

3. Results and Discussion

This study carried out the welding process using the Shielded Metal Arc Welding (SMAW) method on medium carbon steel of type AISI 1050. Three types of weld grooves were employed: Double V Groove (X Groove), V Groove, and Bevel Groove, as shown in Fig. 5. The welding was performed using E6010 electrodes with a diameter of 2.6 mm and a welding current of 100 Amperes. Upon completion of the welding process, a series of mechanical tests were conducted to evaluate the mechanical properties of the welded joints. These included impact toughness testing and hardness testing, aimed at determining the toughness values and the hardness distribution across critical regions of the welded areas on AISI 1050 steel.



(a) (b) (c)

Fig. 5. Welding Results. (a) Double V, (b) Single V Groove, (c) Single Bevel Groove

3.1 Non-Destructive Testing (NDT) Using Liquid Penetrant Method

After the welding process was completed, a Non-Destructive Test (NDT) was conducted using the Liquid Penetrant method. This test aimed to detect surface defects such as cracks, open porosity, or other discontinuities not visible to the naked eye. The NDT process began by cleaning the surface of the welded material using a cleaner/remover solution to ensure that the inspection area was free from dirt, oil, and welding residues. Once the surface was thoroughly clean, the penetrant liquid was sprayed onto the weld area and left for approximately 15 minutes to allow the liquid to seep into any fine cracks or surface flaws that might be present on the metal..

After the dwell time was completed, the surface was cleaned again using a cleaner and a clean cloth, ensuring that only the penetrant trapped within surface defects remained. Subsequently, a developer was sprayed onto the weld surface. This developer functions to draw the penetrant out from within any cracks or voids to the surface, making defect indications clearly visible. The results of the penetrant testing are shown in Fig. 4.1, which indicates the presence or absence of surface defects in the weld. These results are crucial as an initial step before proceeding to mechanical testing, ensuring that the welded area is free of surface defects that could affect the outcomes of the impact toughness and hardness tests, as illustrated in Fig. 6.

Fig. 6. Penetrant Test Results

Based on the results of the penetrant testing conducted on all welded specimens, it was found that the weld with the V Groove joint exhibited minor surface defects. These defects appeared due to an insufficient and uneven cover pass during the final welding layer, which caused the formation of gaps or imperfections on the weld surface. After a grinding process was carried out to even the surface, a second penetrant test was conducted, and the defect indications were still visible.

To address this issue and ensure that the welds were free from surface defects before mechanical testing, a milling process was performed on all test materials. The purpose of milling was not only to remove the surface defects but also to prevent distortion during the welding process. The initial plate thickness of 13 mm was then reduced to 10 mm for all groove types to comply with the standard dimensions of Charpy impact test specimens based on ASTM E23. This process ensured that the tested specimens had a uniform surface quality and met the requirements for both impact and hardness testing..

3.2 Impact Test Results

The impact test aims to measure the material's toughness under sudden dynamic loading. In this test, the energy absorbed by the specimen is usually expressed in joules and can be directly read from the dial scale on the impact testing machine. The impact energy (HI) in the Charpy test is delivered by a swinging pendulum that strikes the test specimen.

From the results of the Charpy impact testing, the absorbed energy (E) for each groove type is presented in Fig. 7. Fig. 7 illustrates the differences in energy absorption for each groove configuration tested, providing an overview of the material toughness across various weld joint geometries. These findings offer valuable insights into the behavior of AISI 1050 steel in resisting impact loads after the welding process.

(a) (b) (c)

Fig. 7. Charpy Impact Test Specimen. (a) Single V Groove, (b) Single Bevel Groove, (c) Double V Groove

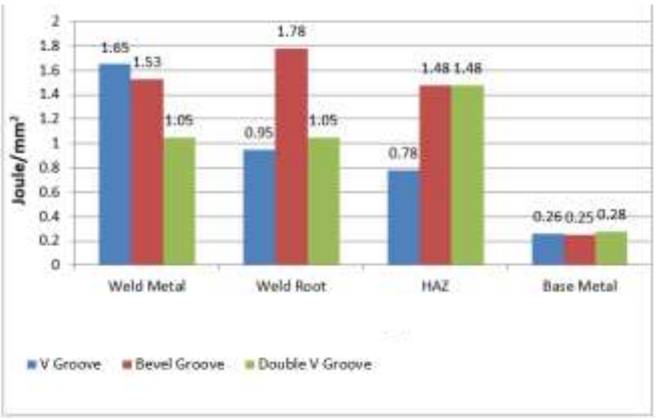


Fig. 8. Comparison Chart of Charpy Impact Values for Single V Groove, Single Bevel Groove, and Double V Groove

Fig. 8 also presents a comparison of the Charpy impact values between the V Groove, Bevel Groove, and Double V Groove joints. The V Groove showed the highest impact value in the Weld Metal area, at 1.65 J/mm², while the Bevel Groove recorded the highest value in the Weld Root, at 1.78 J/mm². The Double V Groove exhibited its highest value in the Heat-Affected Zone (HAZ), at 1.48 J/mm².

Furthermore, the Bevel Groove and Double V Groove had the same impact value in the HAZ, which was 1.78 J/mm², and the Double V Groove also showed identical values in the Weld Metal and Weld Root areas, both at 1.05 J/mm².

From the graph, it can be concluded that the choice of groove type in welding significantly influences the impact toughness across different regions—Weld Metal, Weld Root, and HAZ. Based on the results of the Charpy impact test, the Bevel Groove produced the best overall impact performance across all regions.

3.3 Hardness Test Results

The hardness test was conducted to obtain data regarding the hardness values for each weld groove variation. The testing was performed using a Model HR-150 Rockwell Hardness Tester. Measurements were taken at four different regions of the welded specimens: the Weld Metal, Heat-Affected Zone (HAZ), and Base Metal, in order to examine the distribution of hardness in each region after the welding process.

The test results revealed varying hardness values in each measured region, reflecting the influence of the different groove types—V Groove, Bevel Groove, and Double V Groove—on the hardness profile. The hardness values for each region and groove variation are presented in Fig. 8.

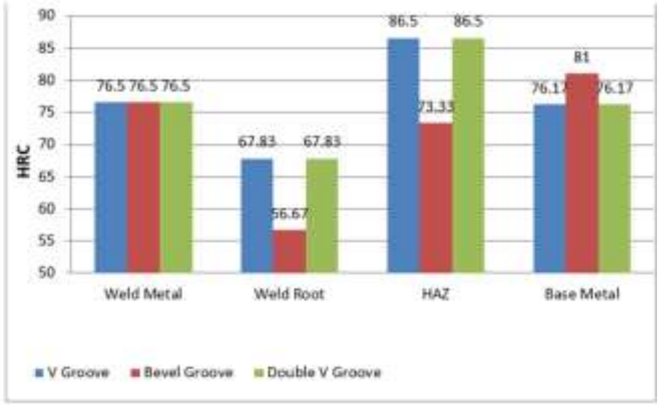


Fig. 6. Comparison Chart of Hardness Values for V, Bevel, and Double V Grooves

Fig. 6 shows a comparison of hardness values between V Groove, Bevel Groove, and Double V Groove. According to the chart, the V Groove and Double V Groove demonstrated the highest hardness values in the Heat-Affected Zone (HAZ), both at 86.5 HRC. Meanwhile, the Bevel Groove showed the highest hardness in the Base Metal area, at 81 HRC. The lowest hardness value was found in the Weld Root area of the Bevel Groove, measured at 56.67 HRC.

In general, all three groove types exhibited the same hardness value in the Weld Metal area, which was 76.5 HRC. Additionally, the V Groove and Double V Groove displayed consistent hardness across all tested regions, including Weld Metal, Weld Root, HAZ, and Base Metal.

From the chart, it can be concluded that groove design significantly affects hardness values across different regions of the weld. In particular, the V and Double V Grooves demonstrated consistent hardness distribution, indicating mechanical stability of the welded joints.

The results from both the impact and hardness tests revealed variations in values across different zones, namely the Weld Metal, Weld Root, HAZ, and Base Metal, for each groove type. These differences emphasize the importance of quality control in welding, as each weld zone possesses unique mechanical characteristics.

In the Charpy impact test, the Bevel Groove showed more uniform toughness, with impact values of 1.78 J/mm^2 (Weld Root), 1.53 J/mm^2 (Weld Metal), and 1.48 J/mm^2 (HAZ). On the other hand, the Base Metal had nearly similar impact values across all groove types, indicating that the Bevel Groove offers more consistent impact toughness across weld regions. In the hardness tests, the Weld Metal region of all groove types displayed uniform values of 76.5 HRC. The highest hardness was found in the HAZ of the V and Double V Grooves, measured at 86.5 HRC.

3.4 Comparison of Impact Values and Hardness

The test results reveal a significant comparison between impact toughness and hardness. In the Charpy test, the Base Metal recorded the lowest impact value, at 22 Joules, making it the weakest in terms of toughness among all samples. Conversely, the hardness test showed that the Base Metal had the highest average hardness value, around 77.78 HRC, although still lower than the HAZ region.

This contrast indicates an inverse relationship between impact toughness and hardness: the lower the impact value, the more brittle the material tends to be, and the higher its hardness. This insight highlights the trade-off between toughness and hardness, emphasizing how these properties influence material performance in structural applications.

4. Conclusion

This study demonstrates that weld groove variation significantly influences the mechanical properties of AISI 1050 steel, particularly toughness and hardness. The results showed that the Bevel Groove provided the most uniform impact toughness across the Weld Root, Weld Metal, and HAZ, with respective values of 1.78 J/mm^2, 1.53 J/mm^2, and 1.48 J/mm^2. Meanwhile, the highest impact value was observed in the Weld Metal area of the V Groove, reaching 132 Joules. Hardness tests revealed that the Weld Metal area exhibited consistent hardness values of 76.5 HRC across all groove variations. However, the lowest average hardness was found in the Bevel Groove, despite its superior impact values in some weld regions. In conclusion, the choice of groove type significantly affects the distribution of toughness and hardness, which has practical implications for welded structure performance.

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