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The Effect of Current, Cr_2O_3 and MnO_2 Active Flux to The Depth of Penetration and Microstructure of A-TIG 5083 Aluminium Welding

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***Abstract*—** Materials with a thickness exceeding 5 mm require at least two layers of TIG welding; however, this challenge can be addressed through A-TIG welding. A-TIG welding utilizes an active flux to increase penetration without requiring changes to welding parameters. This research investigated the effects of current intensity and the use of Cr_2O_3 and MnO_2 active fluxes on depth of penetration, microstructure, and hardness. The study employed A-TIG welding on 5083 aluminum with current variations of 100 A, 130 A, and 160 A. Results indicated that Cr_2O_3 active flux at a current of 160 A achieved the deepest penetration of 5.7 mm, while MnO_2 at 100 A yielded the highest average hardness of 77.96 kgf/mm^2. Regarding microstructure, no significant changes were observed in the base metal across both fluxes; however, grain growth in the weld metal was more pronounced than in the Heat Affected Zone (HAZ) and base metal. Ultimately, Cr_2O_3 provided greater depth of penetration and a more dispersed distribution of Mg_2Si precipitates, whereas MnO_2 demonstrated a superior effect on hardness compared to Cr_2O_3.

Keywords— 5083 aluminium, active flux, Cr_2O_3, hardness, microstructure, MnO_2, TIG welding

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I. INTRODUCTION

As technology and tools become more sophisticated, the fields of fabrication and construction have seen a major leap forward. However, this progress must be supported by skilled professionals. Welding, in particular, has become essential due to its role in joining both ferrous and non-ferrous metals materials used everywhere from shipbuilding to pressure vessel fabrication [1][2][3].

When welding aluminum, preparing grooves is traditionally a time-consuming process. For thicknesses over 5 mm, TIG welding usually requires a V-groove design and multiple passes with filler metals [4][5][6]. To streamline this, the Activated Tungsten Inert Gas (A-TIG) technique can be used [7][8][9]. By adding a thin layer of flux to the joint surface, A-TIG achieves deep penetration without the need for grooves or gaps, which significantly cuts down on production time [10].

While A-TIG can double or even triple depth of penetration compared to conventional TIG—thanks to arc narrowing and Marangoni convection reversal—its application in aluminum welding is still relatively limited [11][12]. This study investigates A-TIG welding on 5083 aluminum by comparing two types of active flux, Cr_2O_3 and MnO_2. By varying the current strength (100 A, 130 A, and 160 A), it aims to determine how these factors influence depth of penetration, material hardness, and the resulting microstructure.

II. METHOD

For this study, it used 5083 aluminum plates with dimensions of 150 x 100 x 8 mm, testing two different active fluxes MnO_2 and Cr_2O_3. The welding was performed using the TIG (Tungsten Inert Gas) process with argon (Ar) as the shielding gas at a flow rate of 13 L/min. This study tested three different current levels, 100 A, 130 A, and 160 A, using a square butt joint configuration.

The process began by applying a thin layer of either MnO_2 or Cr_2O_3 active flux directly to the joint surfaces. Figure 1 illustrates how this active flux was applied to the specimens before the welding began. Once the welds were complete, the next step measured the depth of penetration and conducted hardness testing across both the weld metal and the Heat Affected Zone (HAZ).

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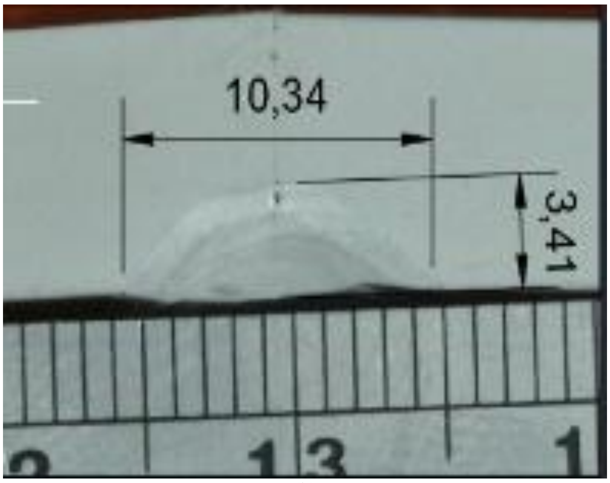
Finally, this study performed micro-testing to analyze the resulting microstructure of the joints.

Figure 1. The active flux was deposited onto the specimen surface prior to the welding process

III. Results and Discussion

Macro examination showed that the specimens using Cr_2O_3 active flux at 160 A achieved the deepest penetration at 5.7 mm, with a width of bead at 12.78 mm. In contrast, the lowest penetration occurred with MnO_2 active flux at 100 A, resulting in a depth of penetration only 3.38 mm and a width of bead at 10.84 mm. Generally, depth of penetration increased alongside the heat input of the A-TIG welding process, another key factor was the Marangoni Effect [13]. This effect involves a shift in the surface tension gradient of the weld pool from negative to positive. As the flux evaporates during welding, it constricts the arc of plasma, concentrating the heat toward the center of the weld [14][15]. This focused that heat is what drives the deeper penetration. In the tests, Cr_2O_3 active flux consistently produced deeper penetration and wider width of bead than MnO_2. These findings align with previous research [16], which also found that Cr_2O_3 outperformed MnO_2 active flux in terms of depth. The relationship between the different fluxes and depth of penetration is illustrated in Figure 2 [17][18].

(a)



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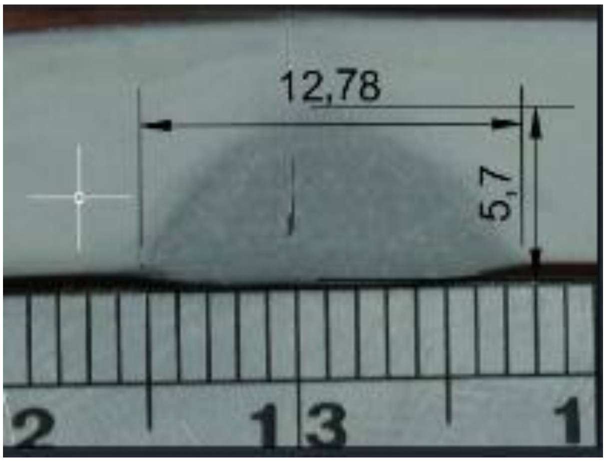

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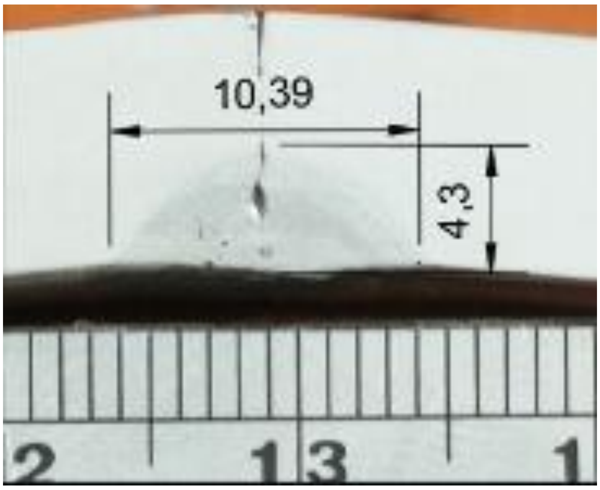
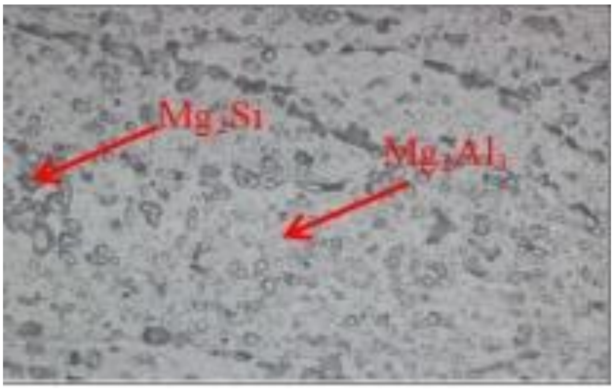


(f)

Figure 2. Cross-sectional macrostructures of A-TIG welded Al-5083 joints demonstrating the evolution of depth of penetration. Specimens (a–c) utilize Cr_2O_3 active flux at welding currents of 100 A, 130 A, and 160 A, respectively. Specimens (d–f) utilize MnO_2 active flux at 100 A, 130 A, and 160 A, respectively

This study conducted microstructural examinations to observe the changes following the welding process. After polishing and etching the specimens, it focused the observations on the base metal, Heat Affected Zone (HAZ), and weld metal at 500x magnification. In the base metal, it identified Mg_2Si precipitates, which appeared as small black dots, while the Al_6Mn compounds were lighter in color [19]. These Mg_2Si precipitates form when magnesium reacts with silicon; the results showed that these black dots were widely dispersed throughout the microphotographic region, likely due to silicon acting as an impurity. This study also observed elongated grains, a characteristic of the strain-hardening (or cold-working) process used to create 5083 aluminum. This process stretches the microstructure in the direction of formation. Generally, finer grains lead to a higher density of grain boundaries, which in turn increases the material's hardness [19].

In the Heat Affected Zone (HAZ), it observed that the Mg_2Si grains in the 5083 aluminum began to grow due to the intense heat from the welding process [20][19]. This grain growth is a common cause of strength loss in the HAZ. Within the weld metal, the microstructure was defined by the enlargement of these Mg_2Si precipitates [19]. Because the toughness of 5083 aluminum depends heavily on how these precipitates are dispersed, a high concentration of Mg_2Si typically leads to a decrease in overall toughness. This drop in strength in the weld zone is often tied to the fact that these precipitates enlarge as they disperse. The specimens showed significantly more grain growth in the weld metal than in the HAZ. As the welding current increased, the grains not only became more numerous but also grew larger in size. Specifically, the Cr_2O_3 active flux produced larger Mg_2Si particles, with only minor differences seen across the various current levels. In contrast, the MnO_2 flux resulted in finer Mg_2Si grains, and we noticed that the grain boundaries increased as the current went up. Throughout the weld area, the grains were clearly marked by Mg_2Si particles that had undergone thickening. However, the area was still dominated by the bright phase of 5083 aluminum, known as Mg_2Al_3. To better understand how these structural changes impacted the material's properties, we conducted hardness testing across the base metal, HAZ, and weld metal. The specific microstructures for the HAZ and weld metal are illustrated in Figures 3 and 4, respectively.



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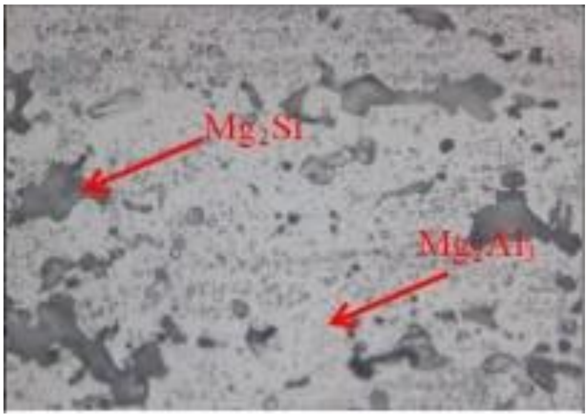

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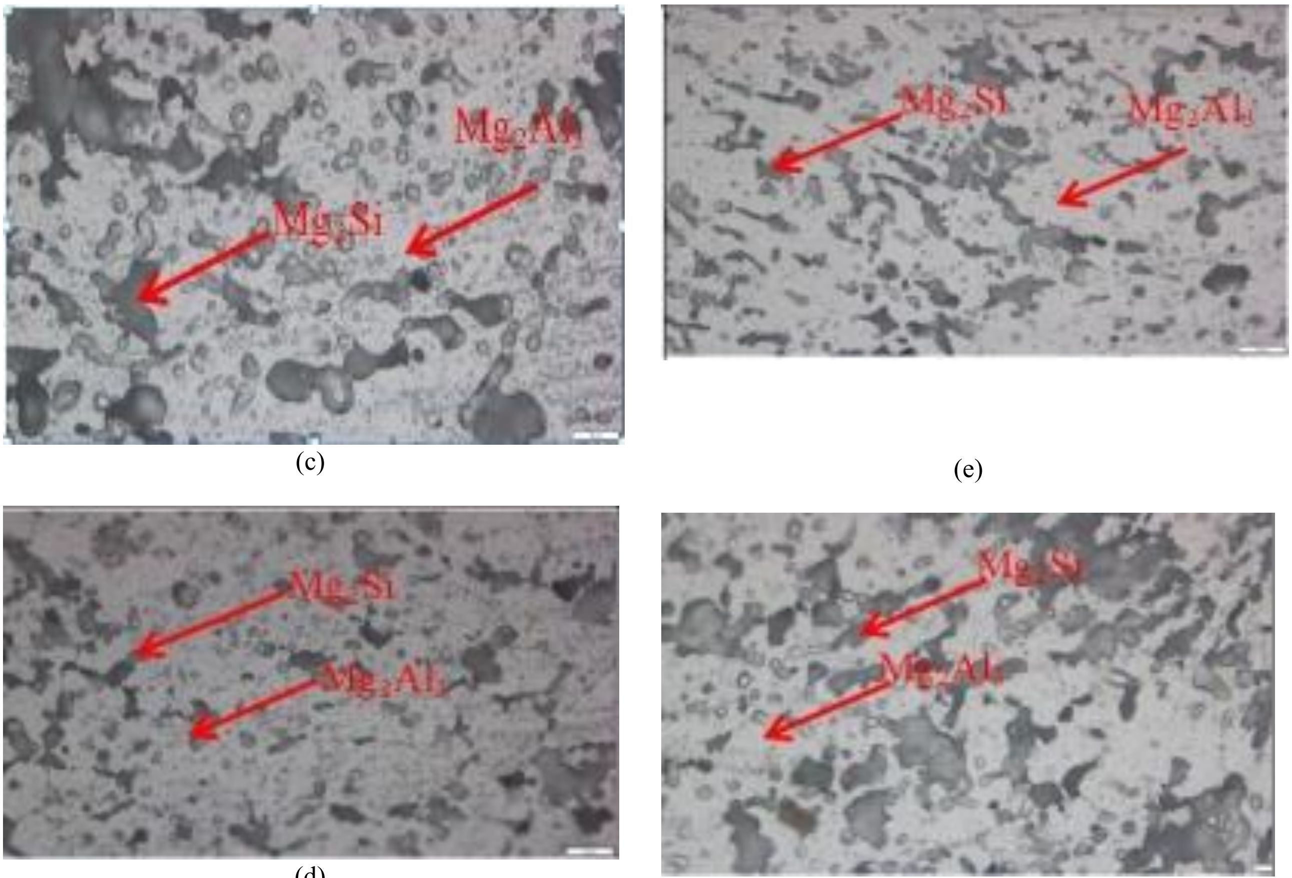
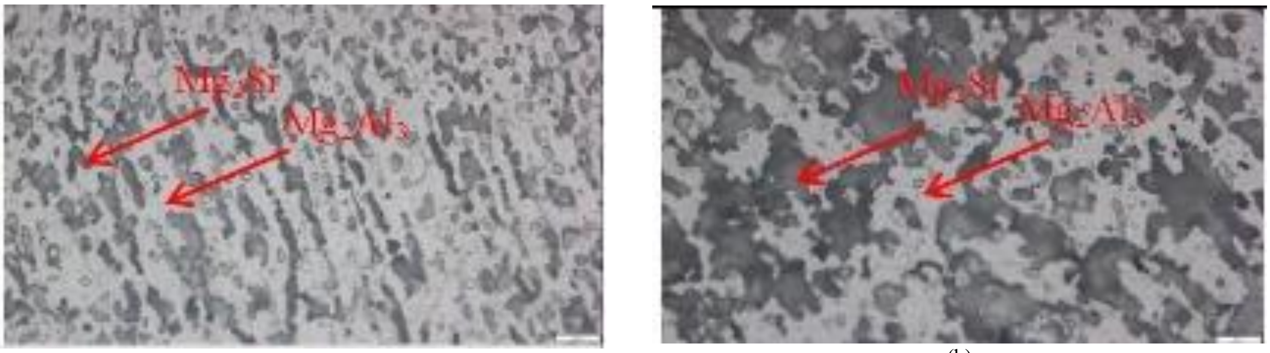


(c) (e)

(d) (f)

Figure 3. Microstructural evolution of the Heat Affected Zone (HAZ) in Al-5083 A-TIG welds. Sub-figure (a–c) illustrate the HAZ under Cr_2O_3 active flux at 100 A, 130 A, and 160 A, respectively. Sub-figure (d–f) depict the HAZ under MnO_2 active flux at corresponding current intensities

For the hardness testing, this study used the Vickers method with a diamond pyramid indenter, applying a 1 kgf load for 15 seconds. The results were measured the base metal, the HAZ, and the weld metal. As shown in Figure 5, there is a clear downward trend in hardness as that moves from the base metal to the HAZ, and finally to the weld metal. Across all tested regions, the MnO_2 flux at 100 A consistently yielded the highest hardness values, measuring 77.62 kgf/mm^2 in the base metal, 74.16 kgf/mm^2 in the HAZ, and 71.46 kgf/mm^2 in the weld metal. In contrast, the Cr_2O_3 flux at 160 A resulted in the lowest values, dropping as low as 54.8 kgf/mm^2 in the weld metal. This pattern makes sense because the base metal is the least affected by the heat of the welding process, allowing it to retain its original strength. The weld metal, however, receives the most intense heat, which significantly softens the material. These results was confirmed that as heat input increases, both the tensile strength and hardness of the aluminum weld zone typically decrease [21].



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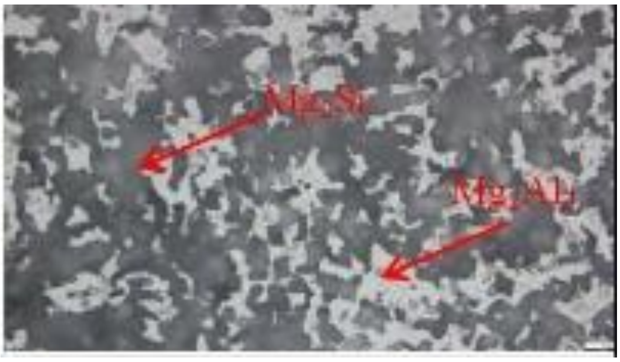

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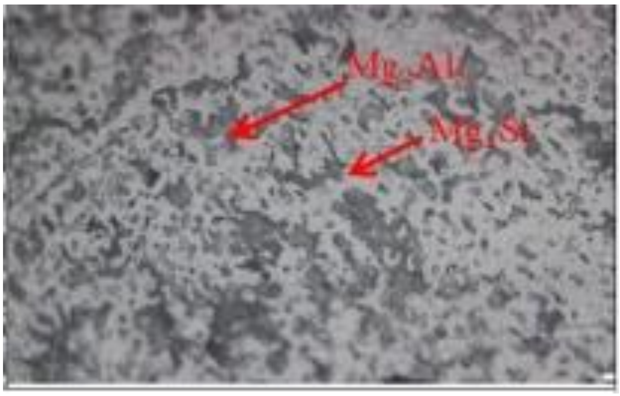

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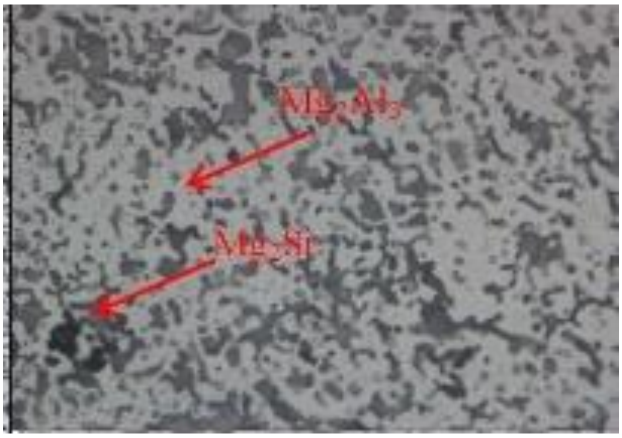

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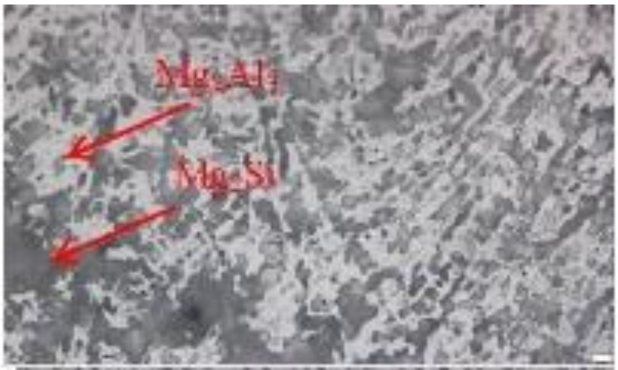
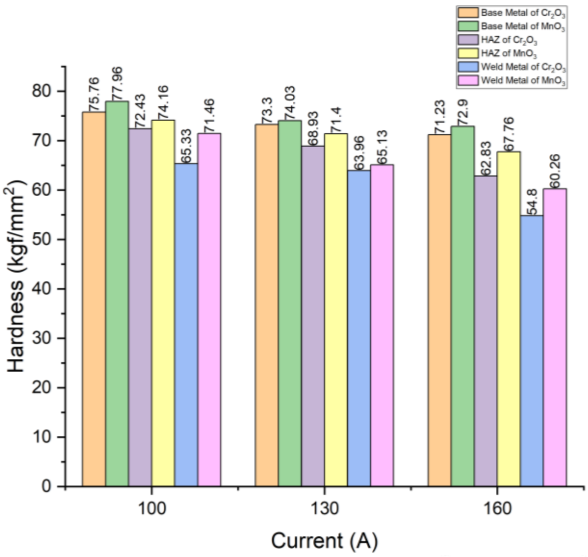


(f)

Figure 4. Representative microstructure of the weld metal (fusion zone) in Al-5083 A-TIG joints. Sub-figures (a–c) display the solidification morphology using Cr_2O_3 active flux at 100 A, 130 A, and 160 A. Sub-figures (d–f) illustrate the weld metal structure using MnO_2 active flux at 100 A, 130 A, and 160 A



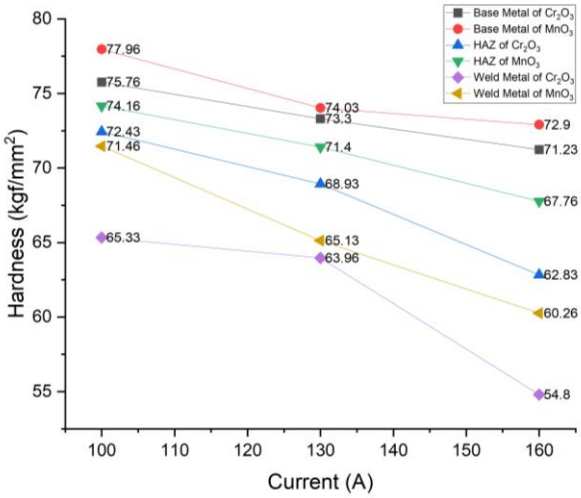


Figure 5. The bar and graphic dagram of hardness values for 5083 aluminium A-TIG joint with Cr2O3 and MnO2 active flux of base metal, HAZ, and weld metal

IV. Conclusion

The results showed that Cr2O3 active flux at 160 A produced the deepest penetration at 5.7 mm, while MnO_2 at 100 A had the shallowest at 3.38 mm. While the microstructure of the base metal remained largely unchanged for both active fluxes, this study observed significant grain growth in the Heat Affected Zone (HAZ). As the current increased, so did the heat input, leading to a noticeably larger HAZ. This grain growth was even more pronounced in the weld metal than in the HAZ or base metal, with each increase in current causing visible microstructural shifts for both types of active flux. In terms of material properties, the highest hardness was found in the base metal using MnO_2 at 100 A of 77.96 kgf/mm^2, whereas the lowest was in the weld metal using Cr_2O_3 at 160 A of 54.8 kgf/mm^2. Ultimately, while a higher current provides the benefit of deeper penetration, it comes at the cost of reduced hardness. This is largely because the increased heat input causes the grains to grow and the Mg_2Si precipitates to spread more widely throughout the structure.

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