# IMPACT OF ARGON GAS SHIELDING FLOW RATE ON THE HARDNESS OF WELD JOINT

**M.N. Abd Rahman[1], N.H. Zulkipli[1], M.S. Kasim[2], M.R. Jamli[1] and E. Budi[3]**

[1]Faculty of Manufacturing Engineering,
Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.

[2]Advanced Manufacturing Centre,
Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.

[3] Faculty of Mathematics and Science,
Universitas Negeri Jakarta, Jl. Rawamangun Muka,
Jakarta Timur, 13220 Indonesia.

Corresponding Author's Email: [1]mdnizam@utem.edu.my

**Article History**: Received 10 May 2021; Revised 15 December 2021; Accepted 24 March 2022

**ABSTRACT:** Metal inert gas (MIG) welding technique is one of the most widely utilized permanent metal joining technique in various applications due to its adaptability towards automation. One of the critical process parameters in MIG is shielding gas flow rate. One of the main purposes of shielding gas is to prevent the formation of oxidation and porosity at the weld pool. However, study on the optimum level of shielding gas flow rate is lacking. This study investigated the impact of argon gas flow rate, as a shielding gas, on the weld zone hardness of a 3 mm thick mild steel plate. The flow rates of argon shielding gas were evaluated at five levels (0 SCFH, 15 SCFH, 30 SCFH, 45 SCFH, and 60 SCFH). Vickers hardness test was performed and an optical micrograph was captured for all samples. One-way ANOVA analysis was conducted to ascertain the statistical difference of hardness among the samples at a 95% confidence level. The results indicated that the argon flow rate has a significant positive impact on the hardness of the weld zones as the shielding gas flow rate increases from 0 to 45 SCFH. However, the hardness significantly dropped at 65 SCFH. The drop in hardness was attributed to an increase in the presence of porosity. It is postulated that the high shielding gas flow rate resulted in turbulence flow that promotes air entrapment in the weld joint during solidification. The high flow rate also induced rapid solidification of weld joint that reduces the chance of air escaping from the weld pool.

**KEYWORDS**: *Argon Shielding Gas; Shielding Gas Flow Rate; Welding Joint Hardness; Weld Porosity*

## 1.0 INTRODUCTION

Metal inert gas (MIG) welding process is a vastly popular metal joining technique in various industries such as sheet metal fabrication, nuclear reactors, petrochemical, and chemical industries [1]. Shielding gas in MIG has a significant impact on the welding process performance. One of the shielding gas functions is to shield the welded joint from contamination that manifests itself as oxidization and porosity [2-3]. The common sources of contamination are gases in the ambient air such as nitrogen and oxygen. The shielding gas minimized the possibility of the adverse effect of the surrounding reactive gases on the weld pool [4]. Asides from that, shielding gases also influence arc stability and the melting efficiency in the MIG welding process by influencing the formation and structure of the arc plasma [5]. This plasma consists of melted metals, ionized gas, vapors, gaseous atoms, and molecules that can be regulated by the utilization of appropriate shielding gas [6]. The reaction between the shielding gas and weld joint could influence its mechanical properties such as toughness, hardness, and strength. One of the common welding defects attributed to the shielding gas is porosity. The presence of porosity in the welded joint can have an adverse effect on the mechanical properties of the welded joint [7-8]. Due to the significant influence of shielding gas on the welding process and quality of the welded joint, its composition and flow rate need to be controlled.

There are some studies done on the effect of shielding gas flow rate on the welding process and characteristics of the weld zones. A study by Zhang et al. [9] suggested that the flow rate of shielding gas has a significant influence in determining mechanical properties of the welded joint, weld penetration, and arc stability. It was also reported that insufficient shielding gas flow rate can result in porosity, influence weld bead appearance, and significantly weaken the weld joint [10]. Some of the common gasses utilized as shielding gases are argon, helium, carbon dioxide, and oxygen. Cai et al. [11] studied the effect of several shielding gas types involving argon and helium on welding characteristics of aluminum alloy. The effect of shielding gas consists of argon, carbon dioxide, and oxygen on weld bead geometry was also studied [12]. The effect of argon, carbon dioxide, and helium as shielding gas on post-weld thermal properties was studied by Ley et al. [10]. It was also reported that helium and argon as shielding gas could affect the weld pool dynamics and weld bead profiles [13].

In addition to the importance of shielding gas on the welding process and characteristics of the weld joint, it also has a significant impact on manufacturing operating costs. It was reported that the cost of shielding gas as a percentage of the overall cost of the welding process is 5-7 % and this number can go up to 25 % taking into account the wastage during the welding process [14]. Due to this, it is imperative to set the shielding gas flow rate at its optimum level to ensure the quality of the welded joint and also minimize the cost associates with its usage.

Even though there are studies done on the shielding gas composition and flow rate, there is a lack of study on the effect of argon shielding gas flow rate on weld joint quality. The aim of this study is to investigate the effect of shielding gas (argon) flow rate on the welding joint hardness. The optimum shielding gas flow rate is not only critical in ensuring welded joint quality but also important in optimizing the cost of the welding operation.

## 2.0 METHODOLOGY

The material used in this study was a mild steel plate of 150 × 60 × 3 mm. The chemical composition of the material is listed out in Table 1.

Table 1: Chemical composition of mild steel in wt. %

| Element | C | Mn | Si | S | P | Fe |
|---|---|---|---|---|---|---|
| wt. % | 0.17 | 0.80 | 0.4 | 0.04 | 0.04 | Balance |

The plates were cleaned from rust and other foreign materials by brushing and the plates were chamfered on one edge for butt-joint welding formation. A jig was used to hold the plates in place for the butt-joint welding process. MIG welding process was carried out using a continuous solid electrode wire and robotic arc welding KUKA Robot. The composition of the electrode throughout this study is as shown in Table 2. The welding parameters are listed in Table 3. The value of current, voltage, and welding speed are fixed as shown in Table 3 throughout the experiments. The only parameter that was varied during the study is the shielding gas flow rate. The shielding gas (argon) flow rate was varied and evaluated at five levels (0 SCFH, 15 SCFH, 30 SCFH, 45 SCFH and 60 SCFH). The range of the flow rate was selected to sufficiently evaluate the low and high flow rate of the shielding gas. Five replications were carried out for each shielding gas flow rate setting.

Table 2: The composition of the wire electrode

| Element | C | Mn | Si | S | P |
|---|---|---|---|---|---|
| Wt.% | 0.08-0.11 | 1.2-1.5 | 0.7-0.9 | 0.025 | 0.025 |
| Element | Cr | Ni | Mo | Cu | |
| Wt.% | 0.2-0.4 | 0.6-0.9 | 0.15 | 0.25-0.45 | |

Table 3: MIG welding process parameters

| | |
|---|---|
| Current (A) | 120 |
| Voltage (V) | 17.9 |
| Speed (cm/min.) | 0.5 |
| Argon (Shielding gas) Purity | 99.999 |
| Shielding flow rate (SCFH) | 0, 15, 30, 45, 60 |

The samples were prepared for metallographic studies as per the ASTM metallographic sample preparation standard. Optical micrograph examination of the Weld Zone (WA) of the welded joints was accomplished using an optical microscope Zeiss Axiomat 2. Investigation on the hardness of the WA zones was done using Mitutoyo Vickers Hardness Testing Machine at a load of 0.2 kg and 15 sec of dwell time. Five hardness measurements were taken for each specimen. The distance between indentations was set at 1 mm to minimize the strain hardening effect due to indentations.

## 3.0 RESULTS AND DISCUSSION

The hardness measurement data are shown in Table 4, in a grouping of the respective shielding gas flow rates. The one-way ANOVA analysis was carried out, using MINITAB software, to test the statistical difference in hardness among the samples with different flow rate based on a 95% confidence interval. The summary of the one-way ANOVA analysis is tabulated in Table 5. Based on one-way ANOVA analysis, the p-value of 1.4 x E-26 indicated that there are statistical differences in hardness among the samples with different shielding flow rates. In other words, the change in the shielding gas flow rate significantly affecting the hardness of the sample.

This is further illustrated by the Means Scale and Comparison Chart in Figure 1, generated using Minitab statistical software which clearly shows that there are significant statistical differences among the means with P-value of less than 0.00l.

Table 4: Hardness of the WA for respective shielding gas flow rates

| | 0 SCFH | 15 SCFH | 30 SCFH | 45 SCFH | 60 SCFH |
|---|---|---|---|---|---|
| Hardness (HV) | 228.73 | 234.2 | 245.3 | 258.53 | 240.27 |
| | 227.63 | 233.33 | 245.17 | 257.83 | 240.67 |
| | 227.63 | 234.7 | 245.8 | 257.93 | 240.7 |
| | 227.33 | 234.8 | 246.73 | 257.37 | 240.43 |
| | 227.4 | 233.93 | 245.2 | 257.77 | 240.87 |

Table 5: One-way ANOVA analysis

| Source of Variation | SS | df | MS | F | P-value | F crit |
|---|---|---|---|---|---|---|
| Between Groups | 2643.4 | 4 | 660.8578 | 2450 | 1.4E-26 | 2.866 |
| Within Groups | 5.3956 | 20 | 0.26978 | | | |
| Total | 2648.8 | 24 | | | | |

The boxplot of the WA hardness for various shielding gas flow rates is shown in Figure 2. The graph indicates that the WA hardness is at its the highest level when the argon gas flow rate is at 45 SCFH. The increasing trends of hardness values are evidenced as the shielding gas flow rate increases from 0 SCFH to 45 SCFH. However, as the flow rate increases to 60 SCFH, the hardness values drop.

The increase in hardness as the shielding gas flow rate increases from 0 to 45 SCFH is expected. This is due to fact that shielding gas protect the weld joint from contamination which could result in the formation of porosity due to the entrapment of gases (typically, nitrogen, oxygen, and hydrogen) in the weld pool as reported by various researchers [8, 14-16].

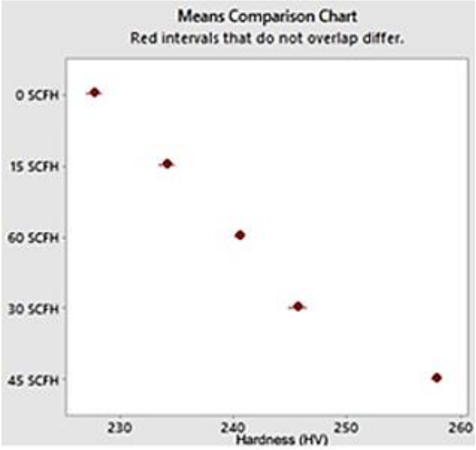

Figure 1: Means scale and comparison chart of hardness measurement for various shielding gas flow rates

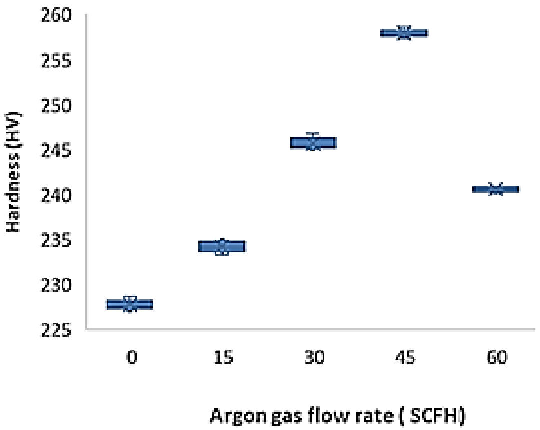

Figure 2: Hardness of WA for various argon flow rate

However, Figure 2 also indicates that the hardness value drops significantly as the shielding flow rate is further increased to 60 SCFH. The optical micrograph images of Vickers indentation at the WA zones as shown in Figure 3 could give a possible explanation for the drop in the hardness value.

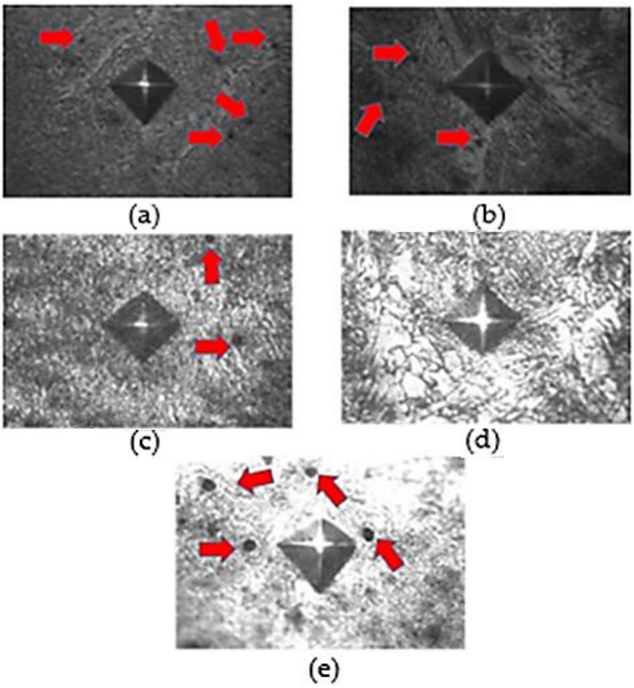

Figure 3: Optical micrograph images of Vickers indentation at the WA zones indicating porosities (red arrows) for various argon gas flow rates: (a) 0 SCFH, (b) 15 SCFH, (c) 30 SCFH, (d) 45 SCFH and (e) 60 SCFH

Based on qualitative observation in the amount of porosity in the WA region as depicted in Figure 3, as the argon gas flow rate increases from 0 to 45 SCFH, the amount of porosity tends to decrease. However, as the flow rate exceeded the 45 SCFH level and set at 60 SCFH, increase in the amount of porosity is observed. The optical micrograph of the WA zone in Figure 4, also shows the same phenomena where the number of porosity increases as the flow rate increased from 45 to 60 SCFH.

In their study on the hardness of laser welding fusion region, Pastor et al. [17] reported a similar finding on the correlation between porosity and hardness; the presence of porosities can significantly lower the hardness of the specimen.

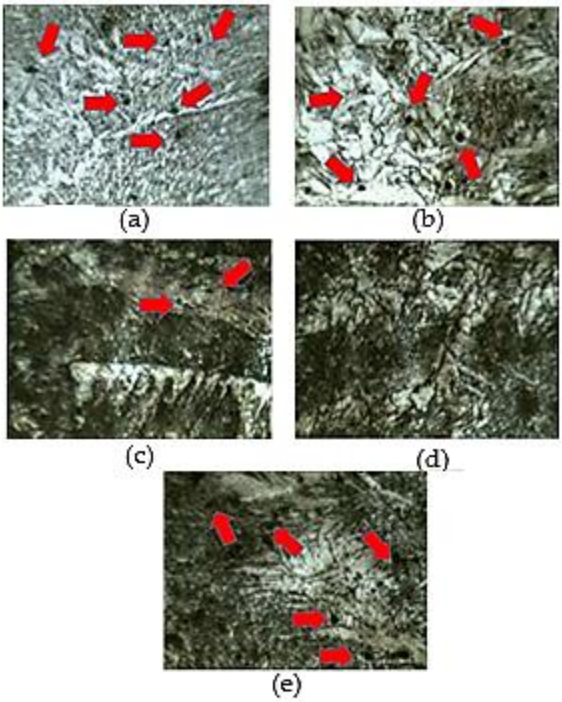

Figure 4: The optical micrograph of the WA zone indicating porosities (red arrows) for various argon gas flow rates: (a) 0 SCFH, (b) 15 SCFH, (c) 30 SCFH, (d) 45 SCFH and (e) 60 SCFH

It is postulated that the increase in the amount of porosity at the high shielding gas flow rate can be attributed to the rapid solidification process due to higher heat transfer rate away from the weld joint that prevented gases from escaping sufficiently from the weld pool [2]. The high shielding gas flow rate could also cause turbulence flow which resulted in higher possibility for air or gas inclusion in the weld joint during welding process [8]. In contrast to laminar flow, gas in turbulent flow undergoes irregular fluctuations in speed and mixing. This could promote the mixing of air and gasses in the fusion area during weld joint formation.

The data from this study suggested that the increase of argon flow rate from 45 SCFH to 60 SCFH resulted higher formation of porosity and reduction in the hardness of the WA zone. This observation can be attributed to the rapid solidification and turbulence formation causing excessive entrapment of gases when the shielding gas flow rate was set at 60 SCFH.

## 4.0 CONCLUSION

The argon shielding gas flow rate has a significant effect on the hardness of WA. It is statistically evident that, the change of shielding gas flow rate from 0 to 45 SCFH caused significant increase in the hardness of weld joint. The study also suggested that increasing the shielding gas flow rate beyond 45 SCFH can adversely affect the hardness of weld joint. Qualitative observation on the amount of the porosity at the weld joint suggested that the decrease in hardness was due to the formation of porosity. It is postulated that the increment in porosity at the high shielding gas flow rate (60 SCFH) is due to rapid solidification and turbulence that increased the probability of air/gas entrapment in the weld joint zone during solidification.

## ACKNOWLEDGMENTS

This study was carried out in Universiti Teknikal Malaysia Melaka. The authors wish to express our sincere gratitude to the Universiti Teknikal Malaysia Melaka.

## REFERENCES

[1] S.S. Karganroudi, V.B.F. Kemda and N. Barka, ”A novel method of identifying porosity during laser welding of galvanized steels using microhardness pattern matrix,” *Manufacturing Letters*, vol. 25, pp. 98-101, 2020.

[2] X. Zhan, Q. Gao, C. Gu, W. Sun, J. Chen and Y. Wei, “The porosity formation mechanism in the laser-MIG hybrid welded joint of Invar alloy,” *Optics & Laser Technology*, vol. 95, pp. 86-93, 2017.

[3] N. Anbarasan and S. Jerome, “Effect of flow rate and argon-hydrogen shielding gas mixture on weld bead morphology of Inconel 718,” in International Conference on Advances in Materials and Manufacturing, Hyderabad, 2016, pp. 26990–26996.

[4] P. Kah and J. Martikainen, “Influence of shielding gases in the welding of metals”, *The International Journal of Advanced Manufacturing Technology*, vol. 64, no. 9, pp. 1411–1421, 2013.

[5] T. Nakamura and K. Hiraoka, “Effect of coaxial welding wire structure on arc instability in argon shielding gas,” *Science and Technology of Welding and Joining*, vol. 16, no. 8, pp. 717-721, 2011.

[6] T.S. Chern, K.H. Tseng and H.L. Tsai, “Study of the characteristics of duplex stainless steel activated tungsten inert gas welds,” *Materials & Design*, vol. 32, no. 1, pp. 255-263, 2011.

[7] E.G. He, J. Liu, J. Lee, K.H. Wang, D.J. Politis, L. Chen and L.L. Wang, “Effect of porosities on tensile properties of laser-welded Al-Li alloy: an experimental and modelling study,” *The International Journal of Advanced Manufacturing Technology*, vol. 95, no. 1, pp. 659-671, 2018.

[8] D. Chen, X. Zhan, T. Liu, Y. Zhao, N. Qi and L. Sun, “Effect of porosity morphology and elements characteristics on mechanical property in T-joints during dual laser-beam bilateral synchronous welding of 2060/2099 Al-Li alloys,” *Optics & Laser Technology*, vol. 140, pp. 1-10, 2021.

[9] X. Zhang, E. Ashida, S. Shono and F. Matsuda, “Effect of Shielding Conditions of Local Dry Cavity on Weld Quality in Underwater Nd: YAGLaser Welding,” *Journal of Materials Processing Technology*, vol. 174, no. 1–3, pp. 34-41, 2006.

[10] F.H. Ley, S.W. Campbell, A.M. Galloway and N.A. Mcpherson, “Effect of Shielding Gas Parameters on Weld Metal Thermal Properties in Gas Metal Arc Welding,” *The International Journal of Advanced Manufacturing Technology*, vol. 80, no. 5, pp. 1213–122, 2015.

[11] C. Cai, S. He, H. Chen and W. Zhang, "The influences of Ar-He shielding gas mixture on welding characteristics of fiber laser-MIG hybrid welding of aluminum alloy," *Optics & Laser Technology*, vol. 113 pp. 37-45, 2019.

[12] M. Shoeb, M. Parvez and P. Kumari, "Effect of MIG Welding Input Process Parameters on Weld Bead Geometry on HSLA Steel," *International Journal of Engineering Science and Technology*, vol. 5, no. 1, pp. 200–212, 2013.

[13] B. Mvola and P. Kah, "Effects of shielding gas control: welded joint properties in GMAW process optimization," *The International Journal of Advanced Manufacturing Technology*, vol. 88, no. 9, pp. 2369–2387, 2017.

[14] R.W. Messler Jr, *A Practical Guide to Welding Solutions: Overcoming Technical and Material-Specific Issues*. Weinheim: Wiley-VCH, 2019.

[15] P.I. Oliveira, J.M. Costa and A. Loureiro, "Effect of laser beam welding parameters on morphology and strength of dissimilar AA2024/AA7075 T-joints," *Journal of Manufacturing Processes*," vol. 35, pp. 149-160, 2018.

[16] P. Murali and R. Gopi, "Experimental investigation of tungsten inert gas welding (TIG) using Ar/Ar-$CO_2$ shielding gas on alloy steels," *Materials Today: Proceedings*, vol. 39, pp. 812-817, 2021.

[17] M. Pastor, H. Zhao and T. DebRoy, "Continuous wave-Nd: yttrium–aluminum–garnet laser welding of AM60B magnesium alloy," *Journal of Laser Applications*, vol. 12, no. 3, pp. 91-100, 2000.