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Effect of Welding Process to the Porosity Formation in Carbon Steel

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Abstract. The effect of the welding process on porosity formation in SPCC carbon steel was studied by comparing MIG, MAG, and TIG welding processes. In this work, the main consideration relates to the welding processes, which are welding current, welding speed, and heat input were investigated. Industrial x-ray observation was performed to study the distribution of porosity within the weld bead. Analysis of bead geometry shows the deepest penetration in TIG welding. The most significant size of porosity was shown in MAG welding compared to MIG and TIG welding. The result indicates that an increase in heat input affects the size of porosity distribution and depth penetration of the weld bead.

1. Introduction

Considering the demand for a low cost-effective with reliable technique, arc welding processes like metal active gas (MAG), metal inert gas (MIG), and tungsten inert gas (TIG) welding process were widely used in many industries to weld carbon steel. However, metals experienced a challenging task, which can cause low weld forming quality during or after the welding process; for example, porosity and cracking that can influence the mechanical properties [1]. Thus, to obtain the positive welding performance, the welding parameters such as current and voltage, travel angle, and also travel distance must be considered.

Heat input is one of the factors that influence the porosity formation inside the weld bead of welded materials. A study reported that the heat content in metal droplets contributes approximately 40% of the total heat input into the weld zone during the welding process [2]. Heat input cannot be determined directly, but it can be distinguished from the arc voltages, current, and travel speed values [3] as given in (1). Increasing heat input is believed to reduce the tendency of porosity formation within the weld bead of welded metals, which is associated with a lowering in the cooling rate process during the welding. Thus, reduced the molten pool solidification process [4].

$$\text{Heat input, } Q = \frac{\text{Current (A)} \times \text{Voltage (V)}}{\text{Travel speed (mm/s)}} \quad (1)$$



2. Experimental Set-up

2.1. Materials selection

In this study, SPCC carbon steel plates with dimension $180\text{ mm} \times 100\text{ mm} \times 5\text{ mm}$ and $100\text{ mm} \times 75\text{ mm} \times 3\text{ mm}$ were used for bead-on-plate welding. Pure argon shielding gas was used in both MIG and TIG welding processes. While for MAG welding, CO₂ was used as shielding gas.

2.2. Methodology

DCEP (Direct current electrode positive) was used in MIG and MAG welding process while DCEN (Direct current electrode negative) was used in TIG welding. Parameters of the welding processes are shown in Table 1.

Table 1. Parameter of the welding processes

Parameter	MIG Welding	MAG Welding	TIG Welding
Welding speed (mm/s)	3-4	3-4	3-4
Current (A)	160-180	160-180	160-180
Voltage (V)	23-25	23-25	23-25

Next, the metallographic of the MIG, MAG, and TIG welding samples were observed under an optical microscope with 2% of Nital solution as an etching solution. Figure 1 shows the dimensions of MIG, MAG, and TIG welding samples. The formation of porosities was then analyzed by x-ray inspection.

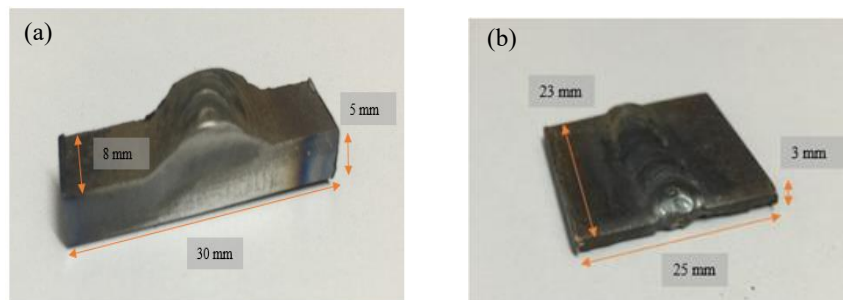


Figure 1. Samples dimension of (a) MIG welding, MAG welding (b) TIG welding

3. Results and Discussion

3.1. Effect of Heat Input

Figure 2 shows the average data of heat input in each welding process calculated as (1). TIG welding shows the highest value of heat input, compared to MIG and MAG welding. Increasing heat input will decrease the cooling rate as well as the solidification process on the molten pool. As a result, low porosity formation and high depth penetration can be achieved.

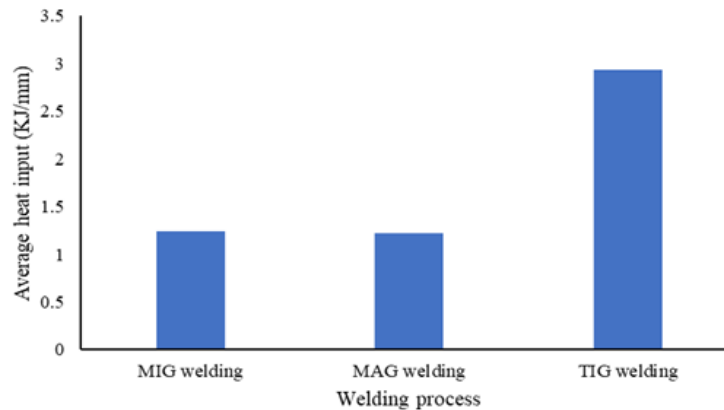


Figure 2. Average value of heat input in welding processes

3.2. Weld Bead Penetration

Figure 3 shows the cross-section of the weld bead profile for MIG, MAG, and TIG welding. Full penetration with a value of 0.4 cm was obtained in TIG welding, which is higher than the others. This phenomenon occurred due to high heat input that significantly produces an extensive depth penetration due to a tremendous amount of heat transfer into the weld zone [5]. The width of the sample also one of the factors that affect the length of weld penetration of carbon steel. The higher the width of the sample, the more penetration can exist.

MAG welding created a deep penetration on the cross-section of the sample by cause of carbon dioxide that was used as shielding gas. The usage of CO₂ appears to have a higher penetration compared to other gases due to increased oxidation potential and outstanding thermal conductivity of CO₂ [6].

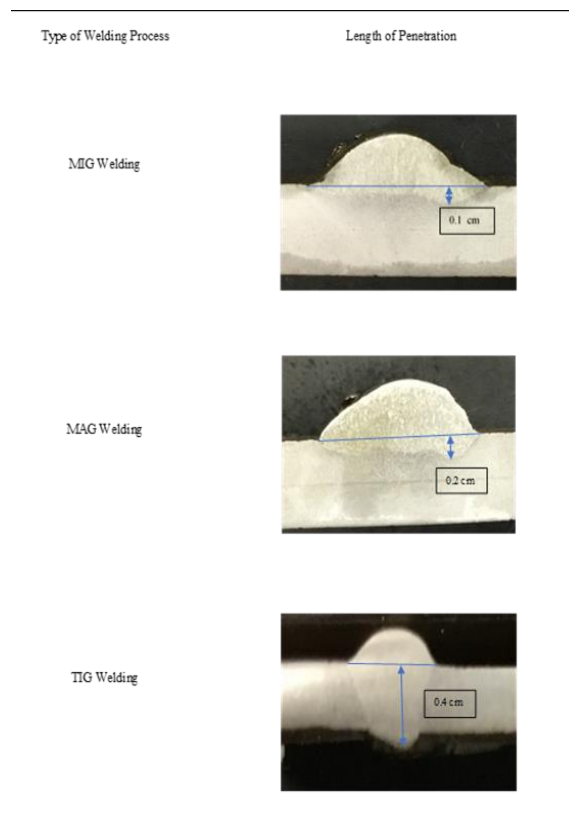


Figure 3. Observation of the weld bead penetration

3.3. Tendency of Porosity Distribution

Figure 4 shows the average number of porosity distribution within the weld bead. The weld bead is divided into three position segments, which are +1 (upper segment), 0 (middle segment), and -1 (lower segment). MIG shows the higher porosity at +1 due to the low weld solidification process. Under the influence of melt flow and crystallization of the weld melt, the bubbles tended to move upwards. However, as related in Figure 2, the pores disable to escape sufficiently mainly existed in the upper region [4].

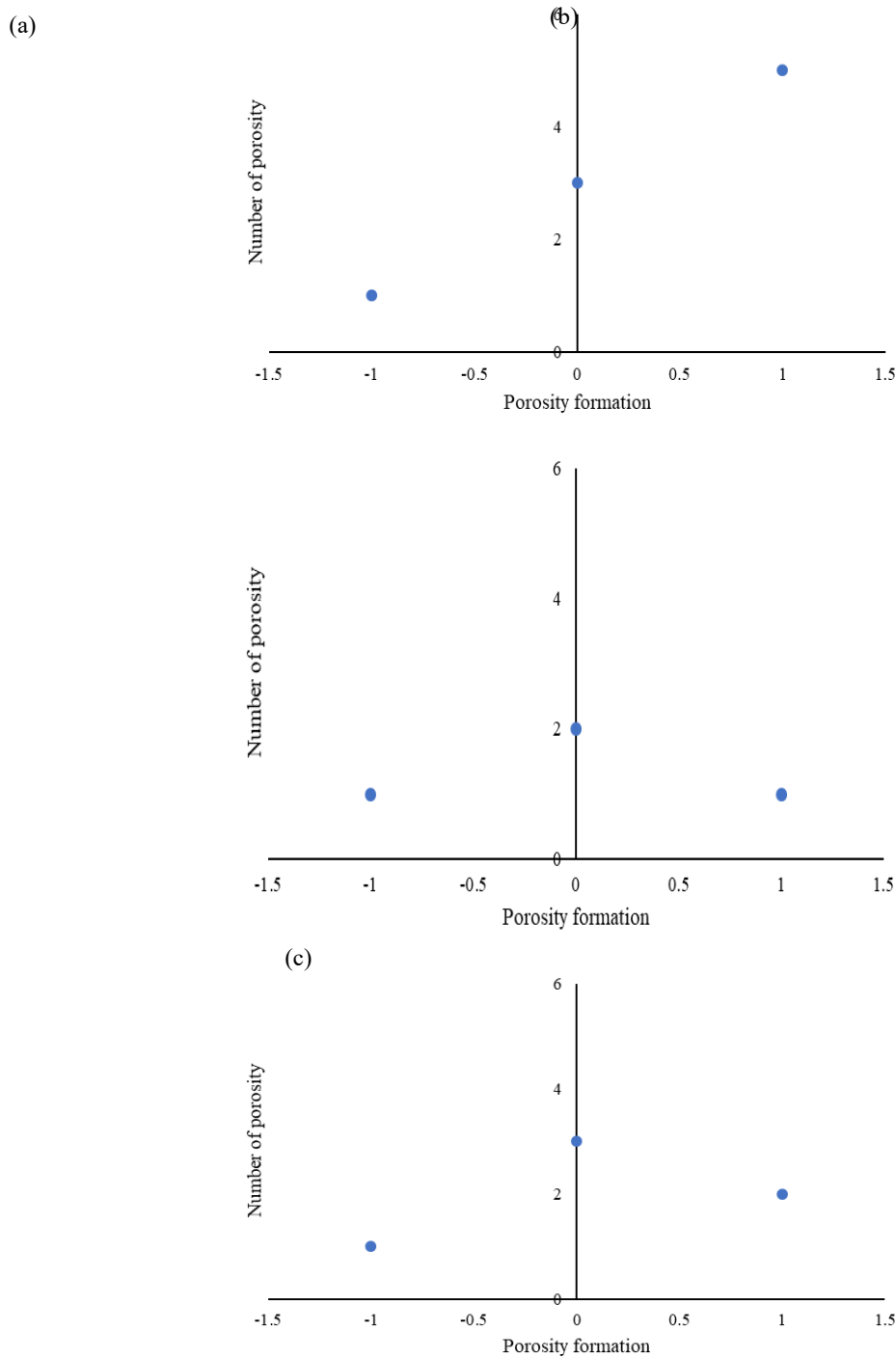


Figure 4. Average number of porosity position in (a) MIG welding (b) MAG welding and (c) TIG welding

3.4. Porosity Evaluations

Based on Figure 5, sample 1 in MIG welding shows the highest number of porosity. In contrast, sample 4 indicates the lowest porosity compared to the other sample with the different welding processes. Compared with other welding processes, MIG welding shows a higher average of porosity. The increasing porosity inside the welded carbon steel in MIG welding is due to low heat input absorbed by carbon steel and low in-depth penetration. Thus, it can increase the tendency of porosity formation inside the weld bead of the welded carbon steel.

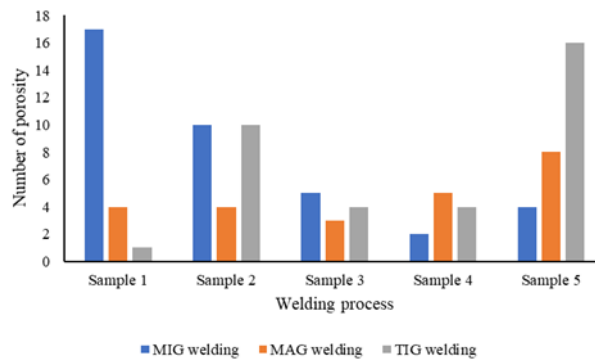


Figure 5. Number of porosities based on welding processes

Figure 6 imply the average size of porosity in MIG, MAG, and TIG welding process. A higher value of porosity size was measured in MAG welding, followed by MIG and TIG welding. The molten pool solidification process influenced the size of porosity formation inside the weld bead of welded carbon steel. The decrease in molten pool heat input will reduce the solidification process time [4]. Thus, enhance the porosity size formation due to the gases within the weld pool to escape adequately during the weld pool solidification process.

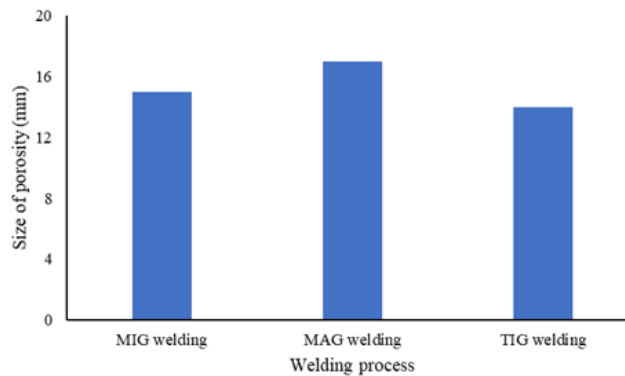


Figure 6. Average size of porosity based on welding processes

4. Conclusion

Increasing heat input decreases the cooling rate and delays the solidification process of the weld pool. Thus, extensive result in the depth penetration of the weld bead produces. Low heat input and depth penetration of welded carbon steel using MIG welding is believed to increase the tendency of porosity formation on the upper region of the carbon steel weld bead. A larger size of porosity in MAG welding due to decreasing in molten pool heat input will reduce the process of the molten pool to solidified.

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