Characterization of Dissimilar Materials Joining using Gas Metal Arc Welding

Khairunnisa Abu Khair* and Norizah Hj Redzuan

School of Mechanical Engineering, Faculty of Engineering
Universiti Teknologi Malaysia
81310 UTM Johor Bahru
Johor, Malaysia

ABSTRACT

Galvanized steel (GS) and mild steel (MS) were joined using the gas metal arc welding (GMAW) method with steel filler rod and carbon dioxide as the shielding gas. The welding process was carried out considering a range of the welding voltages (and currents) that was gradually varied from 16 V to 18.5 V with an increment of 0.5 V. The mechanical properties of the MS and GS with GMAW weld joints were investigated by performing the tensile and hardness tests. In addition, the cross section of the weld area was also inspected under the stereo microscope to observe the weld quality in terms of the weld penetration and discontinuities. Results showed that the dissimilar materials of GS and MS could be successfully joined by GMAW technique by applying the welding voltage and current of 18.0 V and 31 A, respectively. The ultimate tensile strength (UTS) of the successful joint specimen is 324.7 MPa at which fracture occurs at the MS base metal during the tensile test. Its maximum hardness value was found to be around 400 Hv, which is located at the center of weld area.

Keywords: *Gas metal arc welding, dissimilar materials joining, galvanized steel, mild steel*

1.0 INTRODUCTION

The development trend of the modern car includes a number of desirable features related to reduced weight, conserving energy, anti-corrosion, anti-pollution, anti-noise, safety and comfort [1]. In the automotive industry, many manufacturers used galvanized steel (GS) for components such as the frames, engine cradles and suspension link in which the thickness ranges from 1.6 to 4 mm. In addition, the use of thin sheets for other areas is relatively common. For example, the auto body skin can be found to be as thin as 0.7 mm.

Automobile industry requires four important aspects that include anti-corrosion, shaping, painting, and welding of which improving anti-corrosion of cars becomes the main reason that drives the galvanized sheet production to increase rapidly [1]. In 2015, around 90 million vehicles were produced worldwide. The use of steel that constitutes about 900 kg on average per vehicle consume a total of approximately 80 million tons of steel for the automotive sector [2]. The application of steels with high strengths to automotive bodies has helped to increase their durability while reducing their weight [3].

*Corresponding email: khairunnisaabukhair@gmail.com

However, the welding technology that relates GS with other metals has been an important research field at present. Among the many manufacturing technologies, joining has been identified as a key enabling technology to innovative and sustainable manufacturing. The different properties of the different materials are jointly utilized to achieve the product performance needed. These components of dissimilar materials to be joined together considering different joining processes have unique strengths and limitations for joining them [4].

The joining of dissimilar metals is difficult due to the formation of intermetallic layers which depends on the interaction of joining materials and process parameters used during welding [5]. Most automotive manufacturers use the GMAW process, either pulsed or constant voltage (CV), for welding hot-dipped galvanized steels. Both processes have proven difficult when it comes to gaining consistency in weld quality at similar travel speeds as those used to weld MS. The faster the travel speed on the hot-dipped GS, the faster the weld pool tends to freeze. That is especially troublesome since zinc vaporizes at a much lower temperature than steel. The temperature differentiation can lead to gas pockets becoming entrapped because the weld solidifies before the zinc gas can escape [6]. The aim of this study is to determine the characteristic of GS and MS joining, by using a destructive testing method.

2.0 EXPERIMENTAL DETAILS

2.1 Gas Metal Arc Welding Process

Mild steel (MS) is well known for its low carbon content, in which it contains from 0.15 to 0.45% carbon. The density of MS is approximately 7.85 g/cm3 (7850 kg/m^3) and its *Young's* modulus is about 210 GPa with the melting point of around 1510^{o}C [7]. Meanwhile, the galvanized steel (GS) is a zinc coated steel, in which the main purpose of the coating is to prevent steel corrosion. The galvanized sheets have a zinc thickness of about 19 µm per side for general purpose applications. The yield point of GS ranges from 245 N/mm^2 to 365 N/mm^2 while its tensile strength is from 270 N/mm^2 to 490 N/mm^2, depending on the type of classification [8].

GS and MS plate specimens with a thickness of 1.0 mm for both materials were joined together using a lap joint with a lap distance of 10 mm. Each specimen size is 100 mm (width) × 100 mm (length) as shown in Figure 1. In the test specimen as shown in Figure 1(a), number 1 shows a region for the tensile test, number 2 is the area for the hardness test while number 3 is for the macrophotograph analysis [9]. The filler rod used is steel with a diameter of 0.8 mm. Shielding gas used in this study is carbon dioxide (CO_2). The surface of the GS and MS specimens has to be cleaned using acetone to remove grease and residues before welding. The parameters used to obtain the suitable welding currents and voltages are tabulated in Table 1. The welding process was repeated three times for each parameter.

Table 1: Welding voltages and currents for the given samples

Sample	Voltage (V)	Current (A)
1	16.0	32.6
2	16.5	34.0
3	17.0	42.5
4	17.5	44.8
5	18.0	49.3
6	18.5	53.3

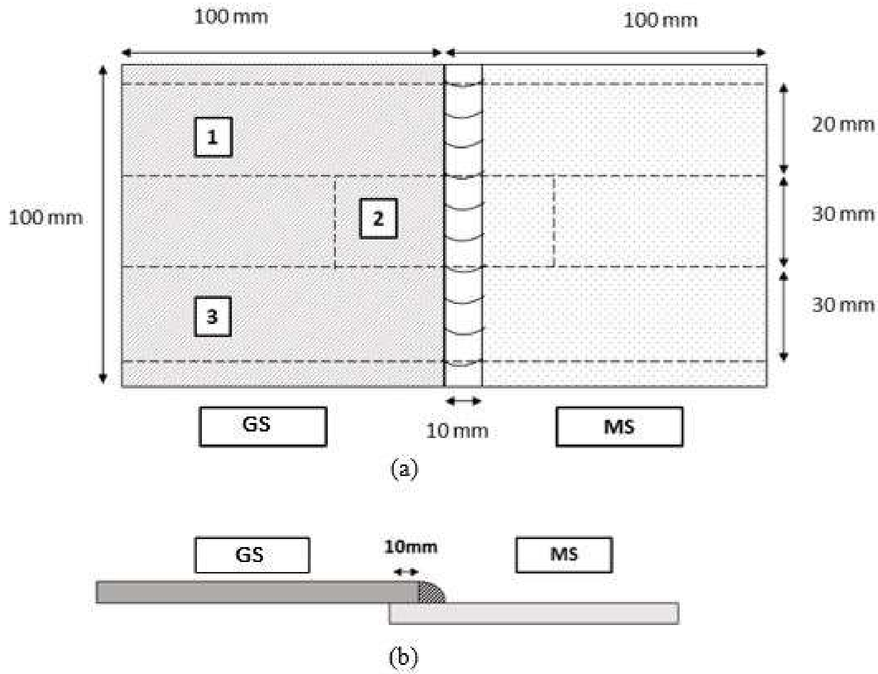

Figure 1: Dimensions of the welding plates

2.2 Tensile Test

The test specimens were tested using the *Universal Testing Machine* (*INSTRON 600 Dx*), having a capacity of 600 kN. The loading rate used in this testing is 1 mm/min. The load was then applied until the specimen breaks. The corresponding results of the ultimate tensile strength (UTS) and fracture position obtained from each specimen are given in Table 2.

2.3 Vickers Hardness Test

A *Matsuzama Vickers Hardness* machine was employed to measure the hardness of the weldment and base metal. A diamond shape indenter with a load of 10 kg was applied to the sample for a period of 12 s in perpendicular direction to the weld. The hardness variation across the weld region was measured at a distance of 2 mm on the weld area and 5 mm on the base metal area.

2.4 Macrophotograph Analysis

The cut portion of the weld joints was grounded using different polishing papers starting from P400, P800, P1000 and P2000. Then, the specimens were polished using Al_2O_3 solution to eliminate or reduce the scar on the specimen. Macrophotograph of the welded areas were observed under the stereo microscope.

3.0 RESULTS AND DISCUSSIONS

3.1 Tensile Test Results

The ultimate tensile strength (UTS) for all the specimens are listed in Table 2 based on the corresponding welding voltages. Experiment number 4C reveals the highest strength of 340.43 MPa whereas experiment numbers 1B, 1C, 2B, 3A, 3C, 4A, 5A, 5B, 6B and 6C have a moderate strength in the region of around 300 MPa. The remainder of the samples have a strength of less than 300 MPa. The weld samples failed at the weldment area for experiment numbers 1A, 2A and 2C, where the other samples failed at the MS base metal. The failure in the welded area is due to welding discontinuities.

Table 2: Transverse tensile test results based on the given parameters

Voltage (V)	Experiment No.	UTS (MPa)	Fracture Position
16.0	1A	287.18	Weldment area
	1B	322.20	MS base metal
	1C	328.63	MS base metal
16.5	2A	157.48	Weldment area
	2B	316.22	MS base metal
	2C	244.57	Weldment area
17.0	3A	341.11	MS base metal
	3B	293.21	MS base metal
	3C	329.24	MS base metal
17.5	4A	305.25	MS base metal
	4B	172.10	MS base metal
	4C	340.43	MS base metal
18.0	5A	322.03	MS base metal
	5B	324.35	MS base metal
	5C	290.05	MS base metal
18.5	6A	295.10	MS base metal
	6B	324.06	MS base metal
	6C	316.97	MS base metal

The tensile strength of the weld metal or weld joints is obtained by pulling (extending) a specimen until it reaches the state of failure. It is important that the tensile properties of the base metal, the weld metal, the bond between the base and weld metals and the heat-affected zone (HAZ) conform to the design considerations of the weldment [10].

3.2 Vickers Hardness Results

Figure 2 shows the hardness distribution for specimens 2C and 5B. The maximum hardness value at the weld area of specimen 2C is nearly equal to the hardness value at the HAZ of specimen 5B.

The hardness value at the weld area for specimen 2C is around 200 Hv using 16.5 V applied voltage while for specimen 5B, it is around 380 Hv at 18.0 V. The hardness value of the MS base metal for specimen 5B at which fracture occurs is around 80 Hv while specimen 2C has a hardness value of around 100 Hv which is higher than that of specimen 5B. The increase in the hardness value is probably due to the microstructure changes after being heated during the welding process. The possible reason for specimen 2C to exhibit low hardness value compared to specimen 5B is the application of lower supply weld voltage that in turn produces low heat during the welding process.

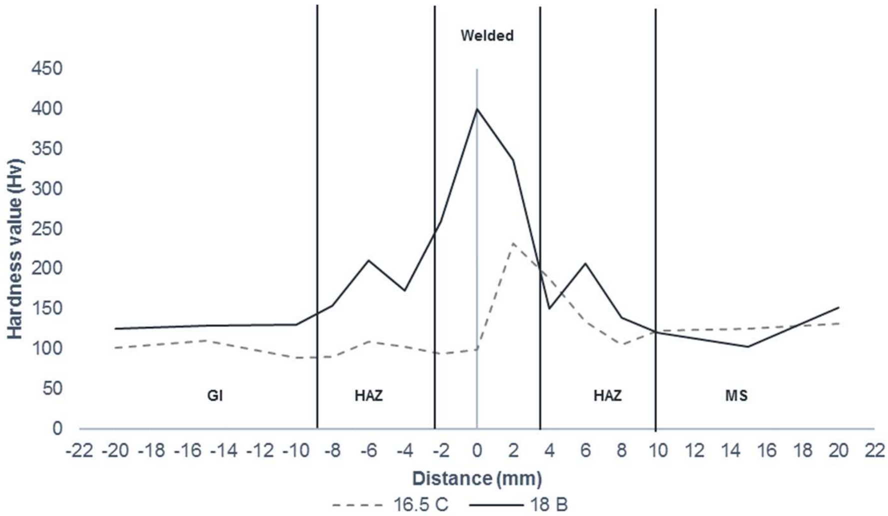

Figure 2: Hardness distribution of samples 2C and 5B

3.2 Macrophotograph Analysis

Figure 3 shows the cross section of specimen 5B. It can be clearly seen that the weld area has an excessive penetration with a depth of about 0.03 mm. According to EN ISO 15614-1:2004+A2:2012, an excessive penetration of below 0.05*t* is acceptable, thereby it implies that the welding specimen 5B produces a satisfactory result [9].

Figure 4 shows the cross section of the weld area for specimen 2C using a welding voltage of 16.5 V. From the observation, there is an impurity found in the specimen with a length of around 2.0 mm in the weld area. The impurity in the weld area is called slug inclusion. The possible reasons that lead to slug inclusion are improper cleaning of the zinc coating layer on GS and low heat produced during welding [11]. Normally, slug inclusion does not occur in GMAW, but the presence of zinc results in the occurence of impurity in the weld area.

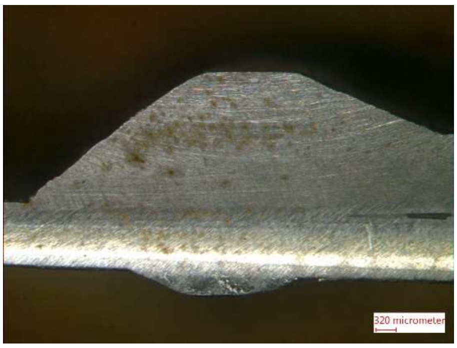

Figure 3: Cross section of specimen 5B

Figure 4: Cross section of specimen 5B

4.0 CONCLUSION

GS and MS plates with a thickness of 1.0 mm were successfully joined using the GMAW technique with a suitable welding voltage of 18.0 V and the corresponding current of 31 A. The bonding strength of the deemed successful joint is 324.7 MPa and fracture occurs at the MS base metal during the tensile test. Its maximum hardness value is around 400 Hv, which is located at the center of weld area. High welding voltages of 18.0 V and 18.5 V give consistent result in terms of achieving the ultimate tensile strength (UTS) of around 290 MPa and 330 MPa, respectively. The hardness distribution when using a high applied voltage is showing an increasing trend from the base metal to weld area. Meanwhile, low welding voltages such as 16.0 V and 16.5 V will cause weld discontinuities that include porosity and slug inclusion due to insufficient heat that is produced during the welding process that will in turn reduce the strength of the welding joint. If porosity persists, the gas supply should be checked to ensure that there is no excessive moisture present in the weld.

ACKNOWLEDGMENTS

The authors would like to express their deep appreciation to the Universiti Teknologi Malaysia (UTM) for providing the support and facilities at the Material Science Laboratory (E03), Solid Mechanics Laboratory (E04) and Fabrication Laboratory (P23), School of Mechanical Engineering, UTM.

REFERENCES

1. Bian J., Zhu Y., Liu X-H. and Wang G-D., 2006. Development of Hot Dip Galvanized Steel Strip and Its Application in Automobile Industry, *Journal of Iron and Steel Research International*, 13(3): 47–50.
2. Worldsteel Association, 2015. *Advanced Steel Applications*, http://worldsteel.org. [Accessed: 27 December 2017].
3. Arif N. and Chung H., 2015. Alternating Current-Gas Metal Arc Welding for Application to Thick Plates, *Journal of Materials Processing Technology*, 222(9): 75–83.
4. Martinsen K., Hu S. J. and Carlson B.E., 2015. Joining of Dissimilar Materials, *CIRP Annals - Manufacturing Technology*, 64(2): 679–699.
5. Tadamalle A.P., Reddy Y.P., Ramjee E. and Reddy K.V., 2017. Characterization of Stainless Steel and Galvanized Iron 0.5 mm Thick Laser Weld Joints, *International Journal of Advanced Manufacturing Technology*, 90(1–4): 383–395.
6. Hobart Brothers Company, 2013. *Welding Galvanized Steel: Filler Metal and Equipment Advancements for The Automotive Industry*, [Accessed: 7 December 2017], http://www.hobartbrothers.com/news/160/523/welding-galvanized-steel-filler-metal-and-equipment-advancements-for-the-automotive-industry.html.
7. Smith W.F and Hashemi J., 2006. *Foundations of Materials Science and Engineering,* 4th Edition, McGraw-Hill.
8. Modern Steel Construction, 2003. *Galvanized Steel*, [Accessed: 17 January 2017], http://msc.aisc.org/globalassets/modern-steel/steelinterchange/2003/052003_2003v05_si_web.pdf.
9. British Standard, 2012. *Specification and Qualification of Welding Procedures for Metallic Materials – Welding Procedure Test*. (ISO 15614-1).
10. Jenney C.L. and O'Brien A. (Eds.), 1991. *Welding Handbook*, 9th Edition Vol. 3, American Welding Society, Miami, FL 33126.
11. American Welding Society, 2008. *Welding Inspection Technology*, 5th Edition, American Welding Society Education Services.