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Original Article

Welding quality and sustainability of alternative LPG valve boss welding processes

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Abstract

This work aimed to evaluate the welding quality and the sustainability of an automatic metal active gas with mixing gases (MAG-M) process for welding the valve boss on liquefied petroleum gas (LPG) upper cylinder half, in comparison to the presently used automatic submerged arc welding (SAW) process. The weld quality of MAG-M welding samples met the ASME standards, comparably to the SAW welding samples. In addition, the MAG-M welding process for welding LPG valve bosses is preferable over the SAW welding process on the condition that >73,339 pieces are processed. However, the welding fumes and noises from this process have stronger environmental and social effects than those from SAW welding. Besides, the SAW process is preferable in LPG valve boss production up to 73,339 pieces. The solid waste or slag generated in this welding process should be managed.

Keywords: LPG valve boss, welding quality, MAG-M, SAW, sustainability

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1. Introduction

Liquefied petroleum gas (LPG) cylinder production is composed of several sheet metal forming, surface treatment and testing processes, and the processing starts with blanking, deep drawing and piercing, trimming and joggling. The welding is next operation for the valve boss, valve guard ring, foot ring and the two halves. The finished cylinder is then heat treated, tested, shot blasted, and painted. The valve boss is attached before final testing (Repkon Company, 2017). Normally, submerged arc welding and Metal Inert Gas (MIG)/ Metal Active Gas (MAG) welding techniques are applied for joining the parts of LPG cylinders (Repkon Company, 2017; Sahamitr Pressure Container Public Company Limited [SMPCPLC], 2017).

Submerged arc welding (SAW) is a process that melts and joins metals by heating with an arc established between a consumable wire electrode and the metals (Kou, 2002). It is a fusion welding process in which heat is produced

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by maintaining an arc between the workpiece and the continuously fed filler wire electrode. SAW process employs a continuous bare electrode wire in solid form and a blanket of powder flux. The flux amount is of sufficient depth to submerge completely the arc column, so that there is no spatter or smoke and the weld is shielded from the atmospheric gases (Rajput, 2007). However, the quantity of slag produced during the SAW process is very high. It is non-biodegradable, thus causing environmental pollution. Treating waste slags may be done with a novel technology for recycling, as reported by Garg and Singh (2016). In the LPG cylinder production, the SAW welding process is applied to welding the body halves on the seam welding machine, and generally to welding of the valve boss to the upper cylinder half (Repkon Company, 2017; SMPCPLC, 2017), with slag waste as a crucial problem that demands solutions.

MIG welding is an alternative welding process without slag waste. The MIG process melts and joins metals by heating them with an established arc between a continuously fed filler wire electrode and the metals, with the shielding provided externally by flow of an inert gas (Argon). When an active gas is used this is known as MAG welding. As a further distinct alternative, MAG-M welding uses argon-based gas mixed with active gases such as CO_2 or O_2. In addition, the MIG welding process has been conventionally applied to welding the foot rings and valve guard rings with the body halves, in gas container manufacturing (Repkon Company, 2017). It was also recommended for welding the valve bosses (World LP Gas Association [WLPGA], 2013). Therefore, workers are familiar with this welding process. Nowadays all commercial metals and alloys can be welded in all positions with the MIG welding process by choosing appropriate process parameters for the particular joint design and process variables. However, MIG welding may produce spatter and fumes.

Typically, the weld quality of welded specimens has been primarily assessed to help select a welding process. Macrostructures, microstructures and mechanical properties of welding joints are characterized (Fang *et al.*, 2013). Holuba, Dunovskýb, Kovandac and Kolaříkd (2015) assess the welding quality based on EN ISO 5817 in the quality level "B".

Nevertheless, sustainable manufacturing has globally become a goal for governments and industries. Chang *et al.* (2015) stated that sustainability is composed of economic, environmental, and social dimensions. The mining and minerals industry is primary interested in three dimensions of sustainability issues (Azapagic, 2004). In the past, technologic and economic indicators were the dominating criteria for process selection, while environmental or social issues were mostly neglected in decisions. Sproesser *et al.* (2016) considered sustainable welding with regard to economic and environmental dimensions. Choi, Kaebernick and Lai (1997) also considered the environmental impact assessment of toy train manufacturing. Regarding the social dimension, Chang *et al.* (2015) focused on two critical social conditions, namely ‘fair salary’ and ‘health and safety’ for welders as the stakeholders, and compared manual and automatic MIG welding processes. Alkahla and Pervaiz (2017) characterize three dimensions of sustainability for the SMAW process. They found that 80 – 85% of the overall cost in welding operation is related to labor and other overhead, while fume inhalation by the welder is among the major health hazards present in the SMAW operation. The environmental aspects focused on energy consumption.

The SAW process has been conventional in welding the LPG valve boss to the upper cylinder half. This process generates slag, which negatively impacts the environment. The alternative MAG-M welding process is interesting because the workers are familiar with it; it is already used to weld the LPG valve guard and the foot ring. However, a comparison between MAG-M and SAW welding processes for the welding of LPG valve boss has not been performed so far, for sustainable process selection. Therefore, this study evaluates the MAG-M process in a case study (welding the valve boss to the upper cylinder half) in comparison to traditional SAW welding. The weld quality of welded pieces is the first priority. Sustainability in terms of cost, environmental, and social dimensions is also considered.

2. Experimental Procedure

2.1. Weld quality

Fillet welding of the valve boss to the upper cylinder haft is investigated, and the welding parameters in both MAG-M and SAW welding processes are shown in Table 1. Both welding processes are automated.

Visual inspection, microstructure, hardness test, and radiographic test are used to assess the weld quality of welded specimens. Micro-hardness test was conducted with a Vickers micro-hardness tester (Eseway 400D series), which used 2 kgf load for 10 s loading time.

Iridium 192 source was used in radiography. The distance between the X-ray emitter of radiographic testing (RT) and weld sample was maintained at 1 m. The exposure time was 30 min and the resonance signal was 740 mR/hour.

2.2 Sustainability considerations

Sustainability was considered in three dimensions, namely cost, environmental, and social. Welding costs for each welding process included fixed and variable costs. Fixes costs were composed of annual welding equipment costs, and variable costs were the operating costs. In this work, the weld circumferential length was 138 mm per valve boss piece. The operating costs were calculated by a simple approach, using traditional formulae:

Electric power (THB.) : $(I\times V\times P_e\times t\times N)/(10^3\times 3{,}600)$ (1)

Wire Electrode (THB.) : $t\times N\times F_w\times W_w\times P_w$ (2)

Flux. (THB.) : $t\times N\times F_f\times W_f\times P_f$ (3)

Shielding gas. (THB.) : $t\times N\times V_g\times P_g$ (4)

Slag Elimination (THB): $S_l\times E_l$ (5)

Spatter Elimination(THB): $S_p\times E_p$ (6)

Total operating cost (m_p) : (1)+(2)+(3)+(4)+(5)+(6)

where n_p is equipment cost (THB), t_s is service life (10 years), CRF is capital recovery fund (0.1457 for the interest of 7.5%

Table 1. Welding parameters

	MAG-M	SAW
Basic Data		
Fillet weld	Valve boss to the upper cylinder haft	Valve boss to the upper cylinder haft
Base material	- SG 295 JIS G3116 Gas Cylinder Hot Rolled 2.00-2.20 mm. Thick - S20C JIS G4051 Carbon steels for machine structural use.	- SG 295 JIS G3116 Gas Cylinder Hot Rolled 2.00-2.20 mm. Thick - S20C JIS G4051 Carbon steels for machine structural use.
Wire electrode type	AWS. A 5.18 ER 70-S6	AWS. A 5.18 ER 70-S6
Type of shielding gas and Flow rates (L/Min.)	60 % Ar : 40 % CO_2 (20)	-
Type of Flux	-	AWS A 5.17 F7A2-EM12K
Chemical composition of flux(%wt)		24($Al2O_3$+MnO_2), 32(CaO + MgO), 25 (SiO_2+TiO_2)
Process Parameter		
Average welding speed (cm/min)	38	56
Number of passes	1	2
Angle of welding (Degrees)	40	45
Volts	26	28
Amperes	185	200
Polarity	DCEP.	DCEP.
Wire electrode dimension (mm.)	1.2	1.2
Wire electrode speed (m/min)	8	4

and service life of 10 years), F_w is feed rate of wire electrode (mm/s), W_w is mass per length of wire electrode (kg/mm), F_f is feed rate of flux (mm/s), W_f is mass per length of flux (kg/mm), P_g is gas cost (THB/m^3), t is welding time (s/pass), N is number of welding passes (pass/piece), V_g is gas flow (l/min), I is welding current (A), V is welding voltage (V), P_w is wire electrode cost (THB/kg); P_f is flux cost (THB/kg), and P_e is electric power cost (THB/kWh), S_l is the quantity of slag (kg/piece), S_p is the quantity of sputtering (kg/piece), E_l is slag elimination cost (THB/kg), and E_p is spattering elimination cost (THB/kg). The weld circumferential length was 138 mm per valve boss piece.

The total annual cost with respect to welding process p and welding quantity q is given by equation.

$$\text{Total annual cost (p)} = m_p q + n_p \quad (7)$$

The intercept n_p represents annual equipment cost (fixed cost) of the considered welding process p. The slope m_p corresponds to total operating cost (variable cost). The breakeven point is at the intersection of such straight lines for the two welding processes compared.

Environmental issues are considered as in Choi *et al.* (1997). The energy consumption, solid waste (slag), and air emissions (fumes) generated by each welding process are calculated with the formula (8) for energy consumption (kWh per day), (9) for solid waste (kg per day), and (10) for air emissions (mg per day);

$$IV\ (\text{kW/machine}) \times t \times N_m \quad (8)$$

$$S \times P \quad (9)$$

$$A \times t\, x60x60 \times N_m \quad (10)$$

The calculation is based on targeted production P =10,500 pieces/day and Operating time t = 22 hr/day. The numbers of welding machines (N_m) based on the production targets are 5 and 6 for MAG-M and SAW welding processes, respectively. The energy consumption is only calculated from welding operation, excluding warm-up of welding machine. Solid waste (S) focuses on slag generated in kg per piece. In addition, air emissions (A) generated in the form of fumes are set at 13.5 mg/s and 0.5 mg/s for MAG-M and SAW welding processes (Spiegel-Ciobanu, 2012), respectively. The noise estimate is obtained by reference to the data of Čudina, Prezelj, and Polajnar, (2008), Horvat, Prezelj, Polajnar, and Čudina, (2011), and Smagowska, (2013).

The social dimension is considered in terms of the health risk (GZ) from welding fumes to welders for the MAG-M and SAW welding processes, based on literature references (Chang *et al.*, 2015; Spiegel-Cibanu, 2012). The following equation is used for assessment of the potential health risk (GZ) (Chang *et al.*, 2015).

$$GZ=(E_p x W_p) x L x R x K_b \quad (11)$$

where E_p means emission of specific substance per functional unit, W_p is potential effect for specific substances in fume, L is ventilation factor (based on sufficient ventilation or not), R is spatial factor (outside or in rooms) and K_b is the factor of relative distance of head/body and fume source.

The current study did not measure fume and noise in the factory, instead prior reports are referred to as regards these. This is a scope limitation of the current study.

3. Results and Discussion

3.1 Weld quality

3.1.1 Weld bead inspections

Figure 1 shows the appearances of representative beads. The regular bead form the MAG-M welding process is shown in Figure 1(a). The SAW process also produced a smooth, regular, and well-formed bead, shown in Figure 1(b).

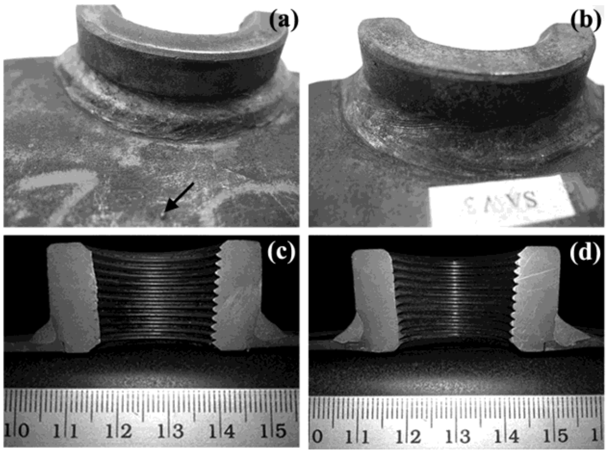

Figure 1. Bead appearances of (a) MAG-M (b) SAW welding samples, and cross-sections of fillet welding by (c) MAG-M (d) SAW.

There were no cracks on the bead surfaces in either case, but spatters were seen on MAG-M welding samples. The subjective appearance of the weld bead made with the SAW process is better than from the MAG-M process. The macro cross-sections in Figure 1(c)-(d) provide a clearer direct view of the shapes of weld beads. The surfaces of the beads are slightly concave in the MAG-M welded sample (Figure 1(c)) and clearly concave in the SAW sample (Figure 1(d)). The throat and leg sizes of the weld beads are shown in Table 2, and they comply with the ASME standards (The American Society of Mechanical Engineers [ASME], 2010).

Table 2. Leg and throat sizes of weld beads

Welding process	Leg 1 (mm)	Leg 2 (mm)	Throat (mm)
MAG-M	7.44±0.22	7.28±0.33	5.57±0.40
SAW	7.50±0.20	7.33±0.29	4.84±0.32

From inspections of the visual and macro-cross section we can evaluate the quality of each weld bead, using the checklist of Table 3.

By this examination, the weld quality of test samples on using the SAW welding process is better than that from the MAG-M process. However, the welded samples from the MAG-M process are acceptable by the ASME standards (ASME, 2010). The acceptance criteria of the standard are complete fusion and freedom from cracks in HAZ, with linear indentations at the root not exceeding 1/32 in (0.8 mm). The concavity or convexity should not exceed 1/16 in (1.5 mm) and the difference in the lengths of the legs of the fillet should not exceed 1/8 in (3 mm).

On the other hand, metal spatter was generated by the MAG-M welding on the joint surfaces (pointed out by a black arrow), as shown in Figure 1(a). Welding technicians of the factory had accepted these metal spatters because these could be scraped off. If the metal spatters would require cleaning off with a grinder, the welding technicians would not accept the welding method. Welding spatters deteriorated the weld bead appearance when the CO_2 content was higher than 20% (Zong, Chen, Wu, & Kumar, 2016). Carbon and low-alloy steels are often welded with CO_2 as the shielding gas, the advantages being high welding speed, good penetration, and low cost. However, CO_2 shielding produces a high level of spatter, so a relatively low voltage is used to maintain a short buried arc to minimize spatter (Kou, 2002).

Table 3. Inspection checklist

Defect type	SAW	MAG-M
1. Cracks (Longitudinal or Transverse)	No	No
2. Incomplete Fusion	No	No
3. Incomplete Joint Penetration	No	No
4. Irregular bead profile	No	No
5. Overlap (Roll Over/Cold Roll)	No	No
6. Slag Inclusion	No	No
7. Surface Porosity	No	No
8. Undercut	No	No
9. Spatter	No	Accepted
10. Fillet Weld Leg is Undersized	No	No
11. Fillet Welds Concave	Yes	Yes

3.1.2 Microstructures

The locations of microstructure examination are shown in Figure 2(a). The microstructure examinations of base meatal (BM) for upper cylinder haft and valve boss base metals are at locations number 1 and 10, respectively. The locations 5 and 8 are for heat affected zone (HAZ), and weld metal (WM) examinations, respectively. Various micro-phases are observed in the different zones. The BM is characterized to be ferrite phase in the light areas and pearlite (P) in the dark areas, as shown in Figure 2(b)-(c).

The HAZ of MAG-M welded samples was mainly composed of bainite (B), acicular ferrite (AF), and grain boundary ferrite (GBF), seen in Figures 2(d). Small amounts of widmanstatten ferrite (WF) were also observed in the HAZ. It is rather difficult to specify regarding these morphologies, which of the AF, B, and WF structures would be similar to those in the reports of Ghomashchi, Costin and Kurji (2015) and Zhang *et al.* (2016). The microstructure in the HAZ of SAW welded specimens (Figures 2(e)) was different from that in MAG-M welded specimens. The microstructure in HAZ of SAW welded samples was mainly composed of coarser widmanstatten ferrite (WF) and pearlite. The WM of both welded samples contains polygonal ferrite (PF), grain boundary ferrite (GBF), widmanstatten ferrite (WF), and acicular ferrite (AF), as shown in Figure 2(f) and 2(g). In addition, AF and GBF of SAW welded specimens were also coarser than in the MAG-M welded specimens, which is related to the high heat input according to Liu *et al.* (2017).

Microstructure transformations normally caused by elevated temperature depend also on exposure time, cooling rate, and chemical composition. Welding parameters are very important to control the obtained microstructures. In the present work, welding parameters used in the SAW process are different from those in the MAG-M welding process, particularly as regards welding current, voltage, speed, and pass. These parameters affected the heat transfer to the welding samples. Liu *et al.* (2017) showed that the high heat input of vertical electro-gas welding (VEGW) produced

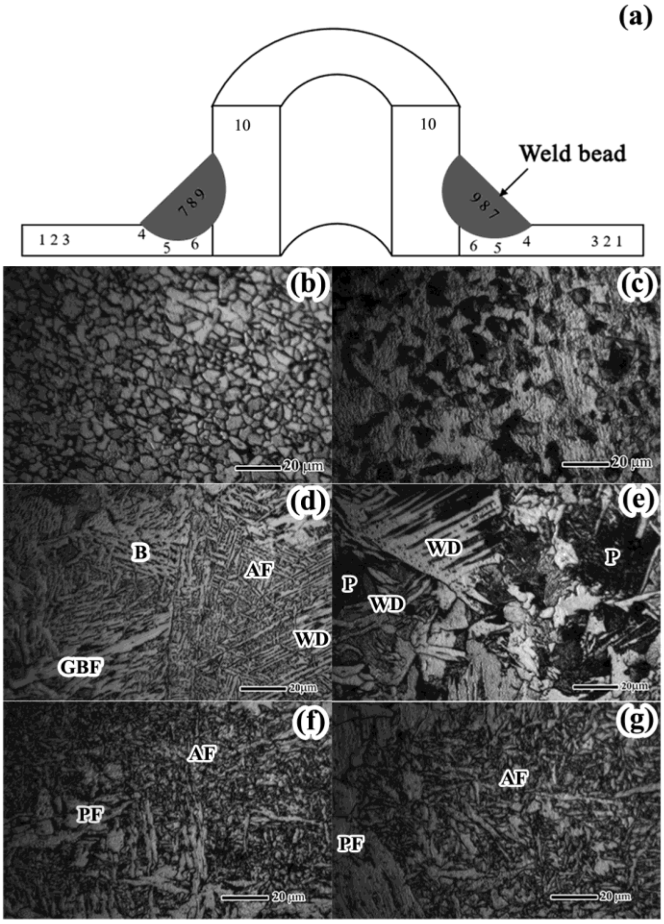

Figure 2. (a) locations of microstructure examination and hardness test, BM of (b) valve boss, and (c) upper cylinder half, HAZ of (d) MAG-M (e) SAW, and WM of (f) MAG-M (g) SAW.

coarser microstructure than that in a SAW joint. Zhang *et al.* (2016) also reported that the size of GBF and WF increased with temperature. Moreover, heat input increases when the number of welding passes is increased. If the SAW joint welds in one pass, the heat input to the SAW joint will be lower than that in one welding pass of MAG-M joint. However, the higher heat input of SAW joint with two passes implies that SAW welded samples had higher temperatures during welding than those in MAG-M joints with only one pass, leading to coarser microstructure in the HAZ zone.

In addition, the SAW weld is shielded by flux, while the MAG-M process is operated under shielding gas. The flux acts as a thermal insulator and promotes deep penetration of the heat, preventing spatter and sparks. Besides, the chemical composition of flux affects microstructures of welding samples. An increase in weld Mn content from the flux promotes the formation of fine-grained structure (Singh, Khan, Siddiquee, & Maheshwari, 2016). Ti content in flux of SAW joint plays a very important role for the heterogeneous nucleation of acicular ferrite (Paniagua-Mercadoa, Lopez-Hirataa, Dorantes-Rosalesa, Diazb, & Valdez, 2009). In the case of MAG-M process, shielding gases are primarily utilized for molten pool protection against atmospheric gas and play an important role in determining weld penetration profiles, helping to maintain arc stability.

3.1.3 Hardness test

The locations of hardness test profiles are shown in Figure 2(a). Typical micro-hardness profiles of MAG-M and SAW welding samples are shown in Figure 3. The average hardness of HAZ and WM zones are very closely similar for the two types of weld joints. This result does not agree with the previous study of Gowrisankar, Bhaduri, Seetharaman, Verma and Achar (1987). They found that hardness of the welds increased with the number of passes during welding. However, they had only investigated the SAW process with different multi-passes, but did not compare to other welding processes. In this work, the hardness of both HAZ and WM zones in a SAW joint with two passes were not different from those in a MAG-M joint with one pass, so the number of passes did not affect hardness. The micro-hardness of the BM (Valve boss) is about 129-140 HV for both weld joints. WM and HAZ of MAG-M weld joints show high average micro-hardness values, 217-219 HV for WM and 152-154 HV for HAZ. It can be concluded that the MAG-M joint shows relatively uniform micro-hardness in the WM zone. The micro-harnesses of the SAW joint are 216–224 HV for WM and 160-164 HV for HAZ. This confirms that the MAG-M joint exhibits less micro-hardness fluctuations in HAZ zone than the SAW joint, which may be due to the multi-pass

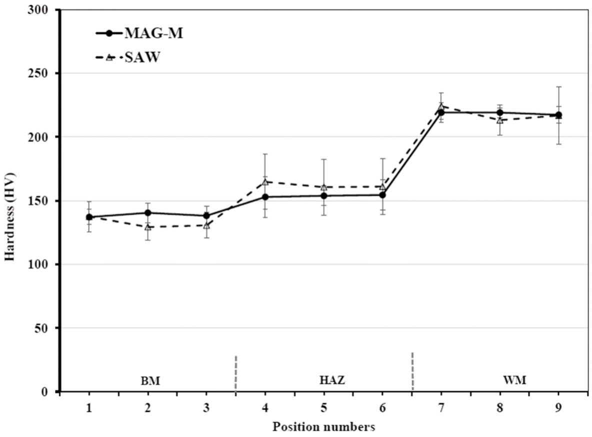

Figure 3. Hardness profiles of MAG-M and SAW joints.

nature of SAW that makes the welding zone suffer repeated metallurgical changes and degrades the uniformity of microstructure, as stated by Liu *et al.* (2017). Thus, we can state that the microstructure homogeneity of MAG-M is better than that of SAW.

3.1.4 Radiographic test

Figure 4 shows the radiographs of the welds joining the valve boss to the upper cylinder half, from MAG-M and SAW. Both weld joints were free from black spots (porosity) and from cracks, as required by ASME standard (ASME, 2010). Film density of the MAG-M welded joint in Figure 4(a) is not smooth, as pointed out by the white arrows, indicating an irregular bead profile. The X-ray radiograph (Figure 4(b)) of the SAW welded sample shows a circular dark line around the outside edge of weld, implying external undercut. The darkness and density of the line indicates the depth of the undercut (Lampman, 1997). The revealed level of defects is acceptable by the criteria in ASME (2010).

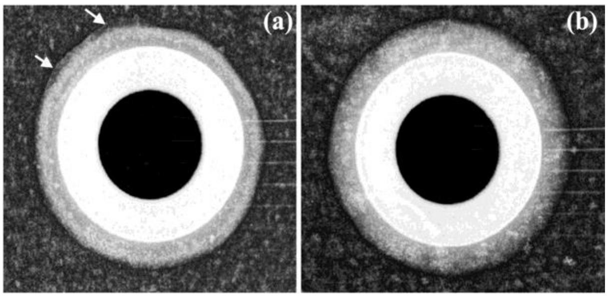

Figure 4. Radiographic testing of (a) MAG-M, and (b) SAW welded samples.

3.2 Sustainability issues

A number of factors affect the welding cost. The fixed costs are composed of welding equipment costs, while the operating costs include electrical power, wire, flux, and shielding gas consumed. Expenses of slag and spatter elimination after welding are also considered, as shown in Table 4.

Table 4. Equipment and Operating Costs for the welding of valve bosses. (Given in Thai Baht, THB.)

Item	MAG-M	SAW
Equipment cost (THB)	900,000	450,000
Annual equipment cost (THB /year)	131,130	65,565
Operating cost (THB/piece)		
Electric Power	0.170	0.180
Wire Electrode	0.440	0.830
Flux	-	0.860
Shielding gas	0.280	-
Slag Elimination	-	0.014
Spatter Elimination	0.100	-
Total operating Cost	0.990	1.884

The MAG-M welding process has higher equipment costs and lower operating costs, in the case of welding the valve boss. Figure 5 shows the breakeven point for MAG-M and SAW welding processes at 73,339 pieces per year, indicating that the MAG-M welding process should be preferred when producing >73,339 pieces per year, while SAW welding is suitable with lesser item count. Correia and Ferraresi (2007) reported that the total cost of SAW welding process was lower than that of MAG welding process, which is consistent with this case study in the lower range of produced item count.

On the basis of the discussion in Section 2, energy consumption, solid wastes, air emissions, and noise generated by each welding process (for the case of LPG valve boss welding) were evaluated as summarized in Table 5. The MAG-M welding process has lower energy consumption and less solid waste than SAW. The solid waste in this case is slag, generated by SAW welding. The MAG-M generates no slag, but it produces more noise and air emissions in the form of fumes. The traditional SAW welding process is preferable to MAG-M welding when producing <73,339 pieces, but the slag is a point of concern. Expenses from slag management could be included in the investment cost. Slag recycling as an alternative was proposed by Garg and Singh (2016). However,

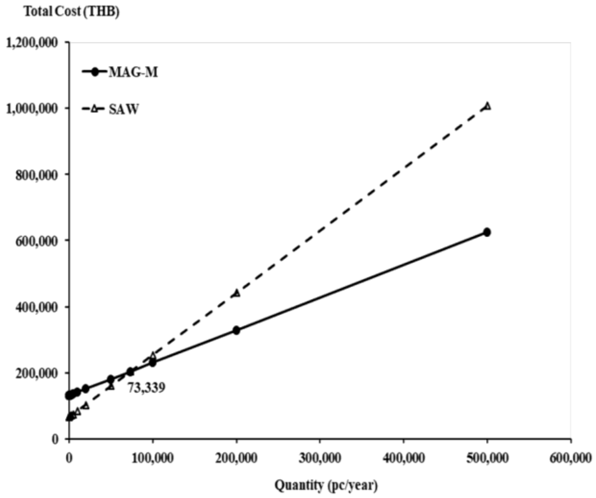

Figure 5. Breakeven point between MAG-M and SAW welding process.

Table 5. Assessment results for two alternative welding processes.

Welding process	Energy consumption (kWh)	Slag (kg)	Fume (mg)	Noise (dB)
MAG-M	313	N/A	13,650	>89 (Čudina et at., 2008;- Horvat *et al.*, 2011)
SAW	437	94.5	2,340	74.5 (Smagowska, 2013)

the fumes generated from SAW welding are 83% less than those from MAG-M welding. In case of producing >73,339 pieces, the MAG-M welding process is selected. The energy consumption of MAG-M welding is 28% less than that of SAW welding. The fumes and noise from MAG-M welding are a limitation or downside of this process. So, a fume collector system is recommended to transfer hazardous fumes for release outside. On the other hand, decreasing the CO_2 fraction in mixture gas could decrease the fume release during welding (Pires, Quintino, Miranda, & Gomes, 2006). Administrative and engineering controls should be implemented for reducing welder noise exposure.

The social dimension of MAG-M and SAW welding processes was assessed based on data in references (Chang *et al.*, 2015; Choi *et al.*, 1997). The health risks from welding fumes to the welders using GMAW or SAW welding have been evaluated in terms of GZ (Chang *et al.*, 2015; Choi *et al.*, 1997), and the GZ scores for the MIG (Automatic) and the SAW were 12 and 1, respectively. These GZ values, however, are affected by workplace specific factors. The health risks from welding fumes to welders using MAG-M should be higher than those from SAW welding, assuming that the welders have their heads between the fume source and the plume, which gives the Kb (distance of head and fume source) factor the value 2 (Chang *et al.*, 2015). If the head is outside the plume (Kb=1), the GZ would decrease to 6. Therefore, it is suggested that welders using the preferable MAG-M welding process (for producing > 73,339 pieces) work outside the plume.

4. Conclusions

An investigation of weld quality and sustainability compared MAG-M and SAW welding processes in the case of welding LPG valve bosses. The results can be summarized as follows.

(1) Weld quality with MAG-M met the requirements of ASME standard per inspection checklist, and was comparable to SAW welding. Microstructures in HAZ and WM zones of MAG-M welded samples were smaller than those in SAW welded samples. There was no porosity or cracks in HAZ and WM zones with either type of welding, as observed by radiographic test. The average hardness of both HAZ and WM zones in MAG-M welded samples were similar to those in SAW welded samples.

(2) Sustainability in the cost dimension showed breakeven at 73,339 pieces for the two alternatives. The MAG-M welding process for welding LPG valve bosses is preferable beyond this item count. However, the welding fumes and noises from this welding process have stronger environmental and social effects than the SAW welding process has, and SAW is preferable with item counts below the breakeven point. The solid slag waste generated by SAW welding should be managed properly.

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References

Alkahla, I., & Pervaiz, S. (2017). Sustainability assessment of shielded metal arc welding (SMAW) process. *IOP Conference Series: Materials Science and Engineering, 244*, 1-8. doi:10.1088/1757-899X/244/1/01 2001

Azapagic, A. (2004). Developing a framework for sustainable development indicators for the mining and minerals industry. *Journal of Cleaner Production*, *12(6)*, 639–662. doi:10.1016/S0959-6526(03)00075-1

Chang, Y. J., Sproesser, G., Neugebauer, S., Wolf, K., Scheumann, R., Pittner, A., Rethmeier, M., & Finkbeiner, M. (2015). Environmental and social life cycle assessment of welding technologies. *12th Global Conference on Sustainable Manufacturing. Procedia CIRP*, *26*, 293-98. doi:10.1016/j.procir. 2014.07.084

Choi, A. C. K., Kaebernick, H., & Lai, W. H. (1997). Manufacturing processes modelling for environmental impact assessment. *Journal of Materials Processing Technology, 70*, 231-38. doi:10.1016/ S0924-0136(97)00067-8

Correia, D. S., & Ferraresi, V. A. (2007) Welding process selection through a double criteria: Operational costs and non-quality costs. *Journal of Materials Processing Technology*, *184*, 47-55. doi:10.1016/j. jmatprotec.2006.11.006

Čudina, M., Prezelj, J., & Polajnar, I. (2008). Use of audible sound for on-line monitoring of gas metal arc welding process. *Metalurgija, 2,* 81-85.

Fang, C., He, B., Zhao, Z., Hu, X., Jiang, J., & Shi, Z. (2013). Comparative study on processing property between CWW C02 gas shielded welding and SAW. *Journal of Iron and Steel Research International*, *20(4)*, 81-86. doi: 10.1016/S1006-706X(13)60087-4

Garg, J., & Singh, K. (2016). Slag recycling in submerged arc welding and its effects on the quality of stainless steel claddings. *Material and Design, 108,* 689-98. doi:10.1016/j.matdes.2016.07.028

Ghomashchi, R., Costin, W., & Kurji, R. (2015). Evolution of weld metal microstructure in shielded metal arc welding of X70 HSLA steel with cellulosic electrodes: A case study. *Materials Characterization, 107,* 317-26. doi:10.1016/j.matchar.2015.07. 032

Gowrisankar, I., Bhaduri, A. K., Seetharaman, V., Verma, D. D. N., & Achar, D. R. G. (1987). Effect of the number of passes on the structure and properties of submerged arc welds of AISI type 316L stainless steel. *Welding Research Supplement, MAY,* 1147-s-1154-s.

Holuba, L., Dunovskýb, J., Kovandac, K., & Kolaříkd, L. (2015). SAW - Narrow gap welding CrMoV heat-resistant steels focusing to the mechanical properties testing. *Procedia Engineering*, *100,* 1640–1648. doi:10.1016/j.proeng.2015.01.538

Horvat, J., Prezelj, J., Polajnar, I., & Čudina, M. (2011). Monitoring gas metal arc welding process by using audible sound signal. *Journal of Mechanical Engineering, 57,* 267-278. doi:10.5545/sv-jme.2010.181

Kou, S. (2002). *Welding metallurgy* (2nd ed.). New Jersey, NJ: John Wiley and Sons.

Lampman, L. (1997). *Weld integrity and performance*. New Jersy, NJ: ASM International.

Liu, W., Pan, H., Li, L., Lv, H., Wu, Z., Cao, F., & Zhu, J. (2017). Corrosion behavior of the high strength low alloy steel joined by vertical electro-gas welding and submerged arc welding methods. *Journal of Manufacturing Processes*, *25*, 418-425. doi:10.1016/j.jmapro.2016.12.011

Paniagua-Mercadoa, A. M., Lopez-Hirataa, V. M., Dorantes-Rosalesa, H. J., Paulino Estrada Diazb, & Valdez, E. D. (2009). Effect of TiO2-containing fluxes on the mechanical properties and microstructure in submerged-arc weld steels. *Materials Characterization, 60*, 36-39. doi:10.1016/j.matchar.2008.06.003

Pires, I., Quintino L., Miranda R. M., & Gomes, J. F. P. (2006). Fume emissions during gas metal arc welding. *Toxicological and Environmental Chemistry*, *88*(3), 385-394. doi:10.1080/02772240600720472

Rajput, R. K. (2007). *A textbook of manufacturing technology (manufacturing processes)*. New Delhi, India: Laxmi.

Repkon Company. (2017, June 24). LPG production line. Retrieved from http://www.repkon.com.tr/PDF/LPG.pdf

Sahamitr Pressure Container Public Company Limited. (2017, June 24). Manufacturing processes. Retrieved from http://www.smpcplc.com/index.php?option=com_content&view=article&id=82&Itemid=8&lang=en.

Singh, B., Khan, Z. A., Siddiquee, A. N., & Maheshwari, S. (2016). Effect of CaF_2, FeMn and NiO additions on impact strength and hardness in submerged arc welding using developed agglomerated fluxes. *Journal of Alloys and Compounds, 667*, 158-169. doi:10.1016/j.jallcom.2016.01.133

Spiegel-Ciobanu, V. E. (2012). Occupational health and safety regulations with regard to welding and assessment of the exposure to welding fumes and of their effect. *Welding and Cutting*, *11*(1), 60-65.

Sproesser, G., Schenker, S., Pittner, A., Borndörfer, R., Rethmeier, M., Chang, Y. J., & Finkbeiner, M. (2016). Sustainable welding process selection based on weight space partitions. *13th Global Conference on Sustainable Manufacturing - Decoupling Growth from Resource Use, Procedia CIRP 40,* 127-32. doi:10.1016/j.procir.2016.01.077

Smagowska, B. (2013). An Objective and subjective study of noise exposure within the frequency range from 10 kHz to 40 kHz. *Archives of Acoustics, 38*(4), 559–563. doi:10.2478/aoa-2013-0066

The American Society of Mechanical Engineers. (2010). *Boiler and pressure vessel code an International code. Section IX*. New York, NY: Author.

World LP Gas Association. (2013). *Guide to good industry practices for LP gas cylinder management*. Neuilly-sur-Seine, France: Author.

Zhang, J., Feng, P. H., Pan, Y. C., Hwang, W. S., Su, Y. S., & Lu, M. J. (2016). Effects of heat treatment on the microstructure and mechanical properties of low-carbon steel with magnesium-based inclusions. *Metallurgical and Materials Transactions A, 47A* (9), 5049-57. doi:10.1007/s11661-016-3657-6

Zong, R., Chen, J., Wu, C., & Kumar, G. P. (2016). Influence of shielding gas on undercutting formation in gas metal arcwelding. *Journal of Materials Processing Technology, 234*, 169–176. doi:10.1016/j.jmatprotec.2016.03.020