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Comparison Analysis of the Gmaw Pulsed Welding Process on Gmaw Modified Short Circuit in Offshore Piping System

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Abstract

Welding is a process which commonly performed in fabrication industries such as shipyard or offshore industries. GMAW is one of most popular welding method that commonly used in structural fabrication and has a several transfer mode. Each of transfer mode has an advantage and weakness. This research would be doing analysis on the result of A106 carbon steel welding process that always used in the offshore piping system. The welding process uses pulsed transfer mode will be compared to the modified short circuit. The result is a modified short circuit that using 80%Ar+20%Co2 shielding gas gives the best result according to technical and cost aspect, that is good weld bead profile and more efficient at welding expense. Pulsed transfer modes that used gives a better result than modified short circuit transfer mode which using 100% Co2 as a shielding gas. The result of using pulsed transfer mode is more consistency level on weld bead and less spatter level which produces.

Keywords: GMAW, pulsed, short circuit, A106, Regulated Metal Deposition, offshore piping system.

1. INTRODUCTION

Welding is a joining process of two metal that uses heat to melt base metal and filler metal to create a joint. [1]. The welding process is a complex process which has several variables which affect the result of technic or cost aspect. Those variables can be a result of the welding process (hardness value, weld bead profile, and spatter level) or expense (tool prices, shielding gas, and welder salary). GMAW welding process has several variations of transfer mode such as a short circuit, spray, pulsed, and globular [2]. Each of transfer mode has advantages and weakness in its application [3]. One of the transfer modes that has most advantages is a pulsed transfer mode. This transfer mode has spray and globular advantages but also can resolve the weakness both of that transfer modes. Pulsed transfer mode gives a more stable arc on welding process[4]. It makes pulsed transfer mode more efficient than other transfer modes [5].

Nowadays as technology develops led to the emergence of new innovation in the welding process. One of that innovation is a modified short circuit using Regulated Metal Deposition (RMD) machine from Miller Corporation.[6]. The potential of that innovation led this research being held to compare conventional transfer mode (pulsed) and newest transfer mode (modifies short circuit).

This research will discuss the comparison of welding process result using modified short circuit transfer mode against pulsed transfer mode. So that it can know which the best transfer mode for applying in piping (offshore's piping system) welding process.

2. MATERIAL AND TOOLS

2.1. Seamless A106 Carbon Steel

A106 carbon steel is one of the most pipes that used on the piping system in the offshore structure where this pipe is used to drain fluid (water, oil, and gas)[7]. Parameter and material properties will be shown in Table 1.

Table 1 Welding parameters and material properties

Pipe diameter	8 Inch
Material	ASTM A106
Electrode diameter	1.2 mm
Material thickness	12.7 mm
Length of weld	150 mm per sequence
Bevel	30^o per section (60^o total section)
Gap	3-4 mm
Current	70-90 A (Short circuit modified) 90-125 A (Pulsed)

There are three pipes that will be welded with the same gas composition. The compositions are Ar+Co2 (80%+20%) dan 100% Co2 without argon as shielding gas in modified short circuit transfer mode (RMD) and 100% Co2 without argon as shielding gas in pulsed transfer mode. There are three 3 variations on this research that is RMD Ar+CO2 (80%+20%), RMD CO2 (100%), dan Pulsed CO2 (100%). The pipe will be welded four sequences on 2R and 5R positions such as presented in Figure 1.

(a) 2R Position (b) 5R Position

Fig 1. Welding positions

2.2. Regulated Metal Deposition (RMD) welding tools

Regulated Metal Deposition (RMD) is a patented software by Miller where welding current of GMAW short circuit will be controlled by this software[8]. RMD welding tools similar to general GMAW welding tools like shown in Figure 2.

Fig 2. GMAW RMD welding tools

The System of RMD is modifying the short circuit transfer mode in GMAW welding process[9]. The welding current will be controlled by RMD software as presented in Figure 3.

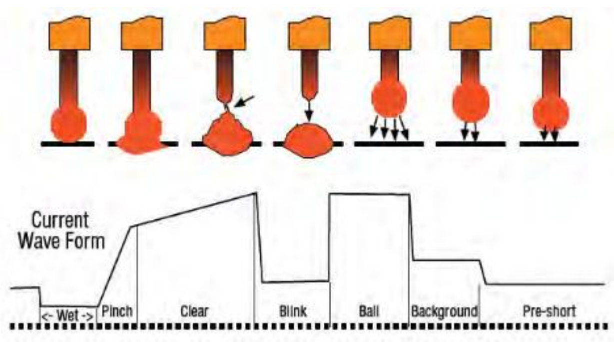


Fig 3. Work principle of RMD

From Figure 3 droplet transformation which controlled by RMD in the welding process can be known. Classic short circuit transfer mode is popular with the highest spatter level caused by an unstable arc. RMD software can solve the problem by controlling welding current when short circuit transfer mode is used. RMD welding result will be collected from previous research about gas composition [6]. The collected data are weld bead profile, spatter level, root pass reinforcement, macroetch, hardness value, and speed travel. This data is used as comparison analysis against pulsed transfer modes welding results.

2.3. Pulsed welding tools

Pulsed transfer mode welding process will use conventional welding tools which has a pulsed setting. The welding machine in this research is EWM welding machine made in German[10]. The welding tools can be seen in Figure 4.

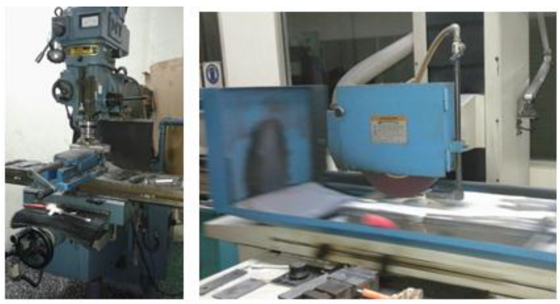
(a) GMAW machine (b) Pulsed fiture

Fig 4. Conventional pulsed welding tool

Using welding tools are showing in Figure 4, the transfer mode will be set on pulsed transfer mode. The current on pulsed transfer mode is 90-125 A.

2.4. Hardness test speciment

The welded pipe will be cut to make hardness specimens. Grinding and milling process is done to forming into specimens as shown in Figure 5



(a) Milling (b) Grinding

Fig 5. Hardness speciment forming process

2.5. Macroetch speciment

The specimens macroetch will be taken before hardness test to clearly welding area (HAZ, weld metal, base metal) that tested.

(a) Methanol and nitrit acid (b) visual of weld area

Fig 6. Macroetch specimen forming process

In figure 6 (a) methanol and nitrite acid are used in hardness test specimens and the result can be seen in Figure 6 (b). In Figure 6 (b) is showing the area of welds such as HAZ, weld metal, and base metal. Hardness can be conducted using a Vickers hardness test machine to find the hardness value from the variation of welding that used in this research.

3. METHOD

3.1. Factor rating method

Factor rating method is one of operating management method that commonly used on the decision making process. This method can transform the subjective data into the objective result as score [11]. In this method, the qualitative and quantitative factor would convert into score would then can be multiplied to the determined percentage in each rating factor. [12].

In this research, the factor rating method will be used to find out which the best transfer mode in the GMAW welding process on the piping system. The output from this method is a score card as presented in Table 2, where the scoring process is conducted based on the determined percentage (4 points will be given for the best result and 1 point for the bad result). A Score card is the final recap of score that given on each transfer modes parameter.

Table 2 Score card

Parameter	Pecentages (%)	Trransfer Mode	
		RMD Short circuit (Percentage X Score)	Pulsed (Percentage X Score)
Hardness Value	30%		
Consistency level	15%		
Root pass penetration reinforcement	10%		
Weld deposition thickness	10%		
Spatter level	10%		
Cost	25%		
Total			

The final result in this result is obtained from the total score on the score card for each transfer mode variation. Transfer mode that has the highest points of the score is the best transfer mode in GMAW welding process that used on the piping system based on technic and cost aspect.

3.2. Scoring system

Scoring is conducted based on percentage of each welding parameter to be analyzed[13]. The range is 1-4, where 1 point for the bad result and 4 point for the best result. Example from the scoring process can be seen in Table 3.

Table 3 Score in root pass penetration parmeter

Root Penetration reinforcement	Score
0.6 - 1.5 mm	4
1.5 - 2.0 mm	3
2.0 - 2.5 mm	2
2.5 - 3.0 mm	1

3.3. Visual Inspection

Visual inspection is conducted to make a documentation picture and root pass penetration reinforcement measurement. The measuring process using welding gauge at 4 point as previous research [6] which presented in Figure 7.

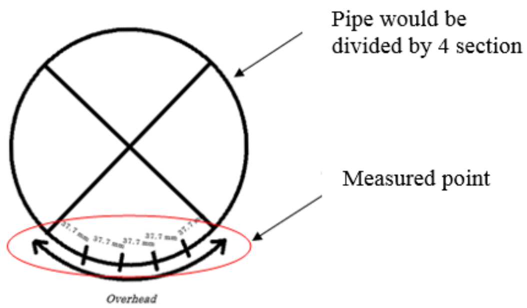


Fig 7. Root reinforcement measured point

3.4. Welding process

A welding process in this research is using GMAW pulsed and modified short circuit transfer mode. Current setting in each transfer mode based on current range per transfer mode (15-22 V and 50-220 A[14] for short circuit, while for pulsed transfer mode are 50-220 A and 23-35 V[15]). A modified short circuit transfer mode, the current will be controlled by RMD welding machine.

3.5. Spatter quantity counting

The quantity of spatter that produced at welding process is counted by manual counting with classifying spatter based on diameter. The range of spatter diameter is ≤1.3 mm, 1.3 mm-2 mm, ≥2 mm as shown in Figure 8.

(a) ≤1.3 mm (b) 1.3 mm-2 mm (c) ≥2 mm

Fig 8. Classify of spatter diameter

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Calculation of spatter level is using equation 1 and 2 [6]. The illustration of the equation can be seen in Figure 9:

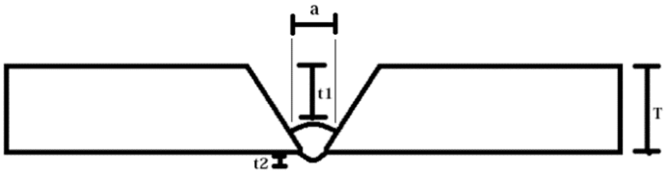


Fig 9. Weld deposition calculation

$$DR = \tfrac{1}{2} \times a \times t \times l \times \rho cs \qquad (1)$$

$$\text{Spatter Level} = \frac{(\Pi \times r^3 \times \rho cs \times \text{Spatter quantity}) \times 100\%}{DR} \qquad (2)$$

Where:

r	= Spatter diameter (mm)
ρcs	= *carbon steel* density (0.00785 g/mm)
DR	= *Deposition rate* or *Weld deposition* (g)
T	= Material thickness (mm)
T = (T-t1) + t2	= Weldbead thickness
a	= wide of weldbead las (mm)
l	= length of welding track (mm)

3.6. Hardness Test

Vickers hardness is used to collecting hardness value in each transfer mode variation. [16]. Macroetch data would be used in weld deposition thickness analyze. Figure 10 is showing the sample of macroetch (hardness test specimen).

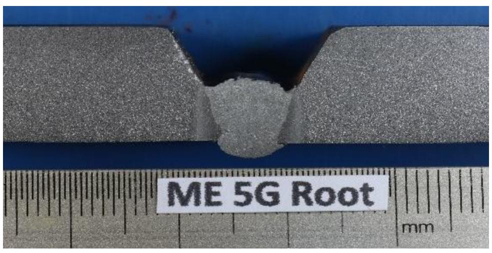


Fig 10. Macroetch

4. RESULTS

4.1. Weld bead profile

Weld bead profile data were documentation images of root pass outer and root pass penetration (Figure 11 to Figure 13). Weld bead profile analysis was conducted to find out the level of weld bead consistency. The value of consistency level was 0%-95% (5% was considered manual welder operation factor or without robot equipment).

(a) Root pass outer 2R position (b) Root pass penetration 2R position

(c) Root pass outer 5R position (d) Root pass penetration 5R position

Fig 11. Visual Inspection Short Circuit modified Ar+Co2 (80%+20%) Documentation

(a) Root pass outer 2R position (b) Root pass penetration 2R position

(c) Root pass outer 5R position (d) Root pass penetration 5R position

Fig 12. Visual Inspection Short Circuit modified Co2 (100% Ar free) Documentation

(a) Root pass outer 2R position (b) Root pass penetration 2R position

(c) Root pass outer 5R position (d) Root pass penetration 5R position

Fig 13. Visual Inspection Pulsed Co2 (100% Ar free) Documentation

Figure 11 to Figure 13 show that both pipes have been connected well without incomplete fusion even though GMAW welding in this research did not use backing on the joining process.

4.2. Root pass penetration height

Measurement by using welding gauge on root pass penetration is displayed in Table 4. The standard of root pass penetration height is based on NACE standard [17]

Table 4 Root pass penetration height measurement results

Transfer mode	Position	Root Pass Penetration Height (mm)											
		Pipe 1				Pipe 2				Pipe 3			
		1	2	3	4	1	2	3	4	1	2	3	4
RMD Ar+CO2 (80%+20%)	2R	1.0	2.0	1.0	1.0	0.2	1.0	0.8	0.5	1.5	2.0	1.0	1.0
	5R	1.0	0.8	0.0	0.2	2.0	1.0	1.2	0.5	2.0	1.8	2.0	2.5
RMD CO2 (100%)	2R	1.0	1.8	0.8	0.0	0.2	0.8	0.8	1.5	0.5	0.8	0.5	0.0
	5R	0.5	0.2	0.2	-0.2	0.8	2.8	1.8	1.0	0.0	2.2	1.2	0.8
Pulsed CO2 (100%)	2R	1.0	1.0	1.0	1.2	2.0	1.5	2.0	2.0	0.0	0.8	0.8	0.6
	5R	1.7	1.6	2.0	2.0	0.0	0.0	0.5	0.5	0.2	0.4	0.8	0.8

Table 4 on root pass penetration height shows that the resulting maximum height still accepted by standard [18] even though there was an underfill on pipe 1 RMD using 100% Co2 shielding gas.

4.3. Amount of Spatter

The results of spatter measurement produced by each welding type are shown in Table 5.

Table 5 Amount of spatter per each transfer mode

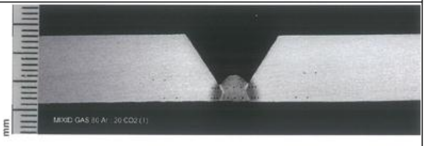
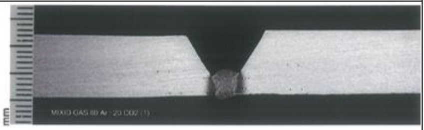
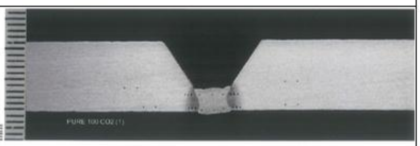
Transfer Mode	Spatter Diameter	Pipe			Spatter Total per Diameter
		1	2	3	
RMD Ar+CO2 (80%+20%)	≤ 1.3 mm	105	116	109	330
	1.3mm-1.5mm	12	20	13	45
	≥ 2mm	4	4	3	11
RMD CO2 (100%)	≤ 1.3 mm	282	341	310	933
	1.3mm-1.5mm	40	61	68	169
	≥ 2mm	13	18	38	69
Pulsed CO2 (100%)	≤ 1.3 mm	114	121	152	387
	1.3mm-1.5mm	30	25	33	88
	≥ 2mm	13	10	16	39

In general, the least amount of spatter is produced by welding with RMD transfer mode using Ar+Co2 (80%+20%) as shown in Table 5. Meanwhile, the greatest amount of spatter is produced by RMD transfer mode using 100% Co2 shielding gas.

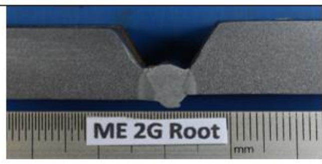
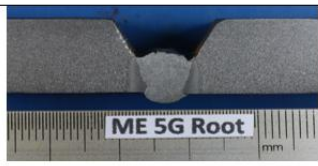
4.4. Weld deposition thickness

By using macroetch images, weld deposition thickness of each transfer mode and position is measureable. The results of weld deposition thickness measurement per welding type are shown in Table 6 and Table 7.

Table 6 Short circuit modified transfer mode macroecth

Transfer Mode	Position	*Macroetch*
RMD Ar+CO2 (80%+20%)	2R	
	5R	
RMD CO2 (100%)	2R	
	5R	

Tabel 7 Macroetch pulsed transfer mode

Transfer Mode	Position	*Macroetch*
Pulsed CO2 (100%)	2R	
	5R	

Based on macroetch images in Table 6, it can be seen that the connection of each transfer mode has no incomplete fussion welding defect. Thickness would be measured by using the macroetch images on weld bead thickness analysis [6].

4.5. Hardness Value

The results of Vickers hardness test on each welding type and position are shown in Table 8.

Tabel 8 Hardness value

Transfer Mode	Position	Average Per Pipe (HV)	
		HAZ	WM
RMD (80%+20%)	2R - Pipe 1	199.17	205.67
	5R -Pipe 1	201.58	220
	2R - Pipe 2	173.58	220.67
	5R -Pipe 2	160	207.67
RMD (100% CO2)	2R - Pipe 1	203.92	190
	5R -Pipe 1	197.33	170.5
	2R - Pipe 2	180.33	200.5
	5R -Pipe 2	195.08	184.83
Pulsed (100% CO2)	2R - Pipe 1	194.10	206.37
	5R -Pipe 1	174.68	194.95
	2R - Pipe 2	169.43	180.03
	5R -Pipe 2	169.78	176.08

The maximum hardness value on HAZ is shown in Table 8 was produced by welding with short circuit modified transfer mode (100% Co2 shielding gas) on 2R position, which was 203.92 HV. Meanwhile, on the metal weld, it was produced by welding with short circuit modified transfer mode (80% Ar + 20% Co2 shielding gas) on 2R position, which was 220.67 HV

The minimum hardness value on HAZ was contributed by welding with short circuit modified transfer mode (80% Ar + 20% Co2 shielding gas) on 5R position, which was 160 HV. The minimum hardness value on metal weld was contributed by short circuit modified transfer mode (100% Co2 shielding gas), which was 170.5 HV.

4.6. Cost

To analyze economic factors, the data to be used is displayed in Table 9

Table 9 Welding parameter price data

Parameter	Price
Machine price (Rp per unit)	Rp. 179.536.149,- (RMD/*short circuit modified*)
	Rp. 200.646.557,- (*Pulsed*)
Shielding gas price (Rp per *clynder*)	Rp. 582.324,- (Argon)
	Rp. 413.787,- (Co2)
Welder salary (Rp per hour)	Rp. 30.000,-
Filler metal price	Rp. 20.000,- per Kg

In addition to cost data, other data required for analyzing economic factors of welding is welding travel speed. Welding travel speed data for each transfer mode and position are shown in Table 10.

Table 10 Welding travel speed per transfer mode

Transfer Mode	Position	Welding Speed per Pipe (mm/min)		
		1	2	3
RMD Ar+CO2 (80%+20%)	2R	115	83	83
	5R	91	85	89
RMD CO2 (100% Ar free)	2R	79	63	63
	5R	81	65	53
Pulsed (100% Ar free)	2R	60	56	61
	5R	46	47	43

In general, as shown in Table 10, the average welding speed of short circuit modified transfer mode (80% Ar + 20% Co2 shielding gas) was 83-115 mm/min. Thus, there is a possibility that this transfer mode provides the fastest welding travel speed compared to other welding processes. Meanwhile, the welding travel speed of pulsed transfer mode was about 43-61 mm/min. Thus, there is a possibility that this transfer mode provides the slowest welding travel speed compared to other welding type variants.

5. ANALYSIS AND DISCUSSION

5.1. Weldbead profile review

Weld bead profile analysis was conducted visually to determine the form of weld bead produced by each transfer mode and its level of consistency. The summary of weld bead consistency level analysis is shown in Table 11.

Table 11 Weld bead consistency level percentage

Transfer Mode	Position	*Weld Bead* Consistency Level (%)		Avg	Total Avg
		Root Pass Outer	*Root Pass penetration*		
RMD Ar+CO2 (80%+20%)	2R	85%	90%	87.5%	86.3 %
	5R	80%	90%	85.0%	
RMD CO2 (100%)	2R	75%	80%	77.5%	76.3 %
	5R	75%	75%	75.0%	
Pulsed CO2 (100%)	2R	80%	95%	87.5%	81.3 %
	5R	75%	75%	75.0%	

Based on Table 11, it can be seen that welding with short circuit modified transfer mode using 80%Ar+20%Co2 shielding gas provides a bigger consistency level compared to other welding types. It is caused by Ar gas addition on the shielding gas, which results in a more stable welding arc as in the previous research on shielding gas composition in GMAW welding [6]. It is definitely easier for the welder to maintain the weld bead form and consistency. On the other hand, although a special machine has been used for pure 100% Co2 shielding gas, the level of consistency is lower than other welding types. On GMAW pulsed welding, it can be seen that this transfer mode provides a more consistent result even though the shielding gas used was 100% Co2. Therefore, there is a possibility to increase the consistency level by adding Ar gas on the shielding gas of the pulsed transfer mode[19].

Scoring on weld bead profile analysis was conducted by using factor ranking method and the results were inputted into the score card to determine the best welding transfer mode.

5.2. Root pass penetration height inspection

The total average height of each transfer mode was calculated from the measurement results to find out whether the root reinforcement height meets the standard or not. The average height calculation is shown in Table 12.

Table 12 Root pass penetration height

Transfer Mode	Position	Root Pass Penetration Height (mm)												Avg	Total Avg
		Pipe 1				Pipe 2				Pipe 3					
		1	2	3	4	1	2	3	4	1	2	3	4		
RMD Ar+CO2 (80%+20%)	2R	1.0	2.0	1.0	1.0	0.2	1.0	0.8	0.5	1.5	2.0	1.0	1.0	1.1	1.2
	5R	1.0	0.8	0.0	0.2	2.0	1.0	1.2	0.5	2.0	1.8	2.0	2.5	1.3	
RMD CO2 (100%)	2R	1.0	1.8	0.8	0.0	0.2	0.8	0.8	1.5	0.5	0.8	0.5	0.0	0.7	0.8
	5R	0.5	0.2	0.2	-0.2	0.8	2.8	1.8	1.0	0.0	2.2	1.2	0.8	0.9	
Pulsed CO2 (100%)	2R	1.0	1.0	1.0	1.2	2.0	1.5	2.0	2.0	0.0	0.8	0.8	0.6	1.2	1.0
	5R	1.7	1.6	2.0	2.0	0.0	0.0	0.5	0.5	0.2	0.4	0.8	0.8	0.9	

Table 12 shows that all welding types meet the root reinforcement height standard. However, on root pass penetration height measurement, there is underfill in the welding process with short circuit modified method using 100% Co2 shielding gas. Hence, this welding process has the lowest score in the scoring process (1 point). Meanwhile, welding process with Pulsed and short circuit modified transfer modes using 80%Ar+20%Co2 shielding gas have the highest score (4 points). The assessment results then were inputted into the score card.

5.3. Spatter level comparison

The weight of spatter measurement results was calculated by multiplying it with carbon steel density (0.00785 g/mm) and compared to the total average of weld deposition to obtain spatter level of each welding transfer mode type. Weld deposition calculation using equation 1 is as follows:

$$DR = \frac{1}{2} \times a \times t \times l \times \rho cs$$

$$DR = \frac{1}{2} \times 3.98 \times 5.94 \times 600 \times 0.00785$$

$$DR = 111.4453 \text{ g per pipe}$$

To obtain Weld deposition per transfer mode:

$$DR = 111.4453 \times 3$$

$$= 334.335 \text{ g}$$

Furthermore, by using equation 2, the weld deposition obtained is compared to the quantity of spatter that has been calculated. The calculation is shown in Table 13:

Table 13 Spattering level percentage

Transfer Mode	Spatter Diameter	Total *Spatter* per Diameter	Spatter weight per *weld deposition*	Percentage *Spattering* Per Diameter	Percentage *Spattering Total*
RMD Ar+CO2 (80%+20%)	≤ 1.3 mm	330	0.0210	2.10%	3.53%
	1.3mm-1.5mm	45	0.0104	1.04%	
	≥ 2mm	11	0.0039	0.39%	
RMD CO2 (100%)	≤ 1.3 mm	933	0.0593	5.93%	12.27%
	1.3mm-1.5mm	169	0.0391	3.91%	
	≥ 2mm	69	0.0243	2.43%	
Pulsed CO2 (100%)	≤ 1.3 mm	387	0.0246	2.46%	5.87%
	1.3mm-1.5mm	88	0.0204	2.04%	
	≥ 2mm	39	0.0137	1.37%	

Spatter level percentage shown in Table 13 was converted into a chart to make it easier to see the spatter level difference of each transfer mode used in welding. Spatter level percentage chart of can be seen in Figure 14.

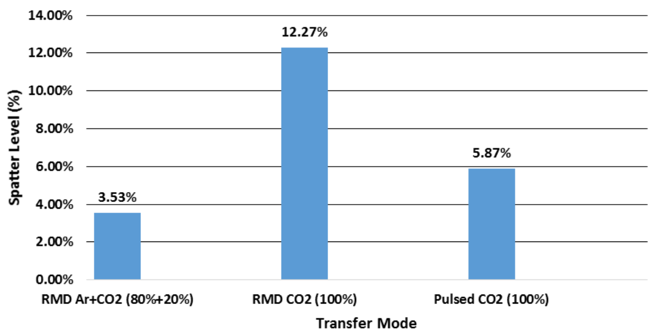


Fig 14. Spattering Percentage Comparison Chart

The results are shown in Table 13 and Figure 14 provides information on the spatter level per transfer mode. The highest spatter level was produced by welding with short circuit modified transfer mode (RMD) using 100% Co2 shielding gas, which was 12.27%. It means that 12.27% out of 100% electrodes that changed into weld deposition was wasted in the form of spatter. Although it used the same gas (100% Co2), welding with Pulsed transfer mode only produced 5.87% spatter level (less than half of spatter level produced by short circuit modified transfer mode). The lowest spatter level was produced by short circuit modified transfer mode using RMD Ar+CO2 (80%+20%) shielding gas composition, which was 3.53%. The addition of Ar as the shielding gas lessen the spatter.

The tentative conclusion of the results is that GMAW welding with pulsed produced a lower level of spatter compared to short circuit modified transfer mode that uses the same 100% Co2 shielding gas.

5.4. Weld deposition examination

Weld deposition is calculated based on macroetch images to observe the thickness of weld bead produced. The results of macroetch are shown in Table 14

Table 14 Weld deposition thickness

Transfer Mode	Position	Thickness (mm)
RMD Ar+CO2 (80%+20%)	2R	5
	5R	5
RMD CO2 (100%)	2R	5
	5R	5
Pulsed CO2 (100%)	2R	7.5
	5R	8.5

In Table 14, it can be seen that welding with short circuit modified transfer mode produced the same deposit thickness, which was 5 mm for welding on 2R and 5R position. It means that the use of RMD machine with short circuit modified transfer mode allows the welder to weld at a constant level so that the weld deposits can be maintained. Meanwhile, the use of pulsed transfer mode produced thicker deposits compared to short circuit modified transfer mode.

The thickness of weld deposits in pulsed transfer mode is possibly caused by the travel speed, which is slower than the pulsed transfer mode. Besides that, pulsed transfer mode provides higher weld deposition than the short circuit. This causes a buildup of more weld metal and produces thicker weld beads.

5.5. Hardness value examination

Hardness value testing was conducted after the macroetch. The testing was conducted by using Vickers Hardness Test machine with ASME Sec.IX standard. The average hardness values obtained from the testing are shown in Table 15.

Table 15 Hardness value

Transfer Mode	Position	Averages per Pipe (HV)		Averages Total (HV)	
		HAZ	WM	HAZ	WM
RMD (80%+20%)	2R - Pipe 1	199.17	205.67	183.58	213.5
	5R –Pipe 1	201.58	220		
	2R - Pipe 2	173.58	220.67		
	5R -Pipe 2	160	207.67		
RMD (100% CO2)	2R - Pipe 1	203.92	190	194.17	186.46
	5R -Pipe 1	197.33	170.5		
	2R - Pipe 2	180.33	200.5		
	5R -Pipe 2	195.08	184.83		
Pulsed (100% CO2)	2R - Pipe 1	194.10	206.37	177.00	189.36
	5R –Pipe 1	174.68	194.95		
	2R – Pipe 2	169.43	180.03		
	5R -Pipe 2	169.78	176.08		

Based on Table 14, it can be seen that the greatest hardness value of HAZ was produced by welding with short circuit modified transfer mode (RMD) using 100% Co2 shielding gas with no Argon. Meanwhile, welding with pulsed transfer mode using 100% Co2 shielding gas with no Ar as the shielding gas produced the least hardness value, which was 177 HV.

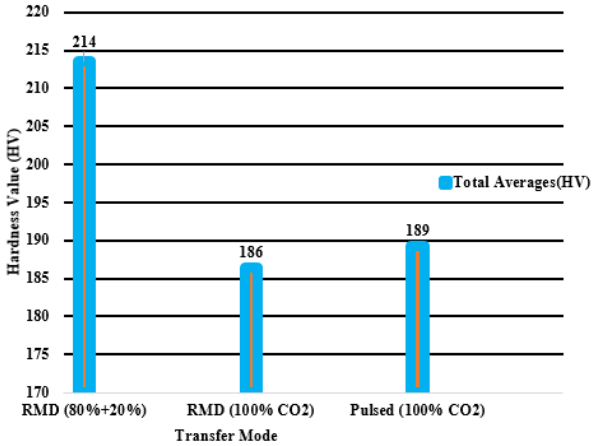


Fig 15. Hardness value chart on weld metal

Based on the chart as shown in Figure 15, it can be seen that the greatest hardness value on weld metal was produced by welding with short circuit modified transfer mode (80% Ar + 20%Co2), which was 213.5 HV. Meanwhile welding with pulsed and short circuit modified transfer modes using 100% Co2 shielding gas with no Ar produced hardness value with no significant difference.

Welding process with short circuit modified transfer mode using 80% Ar + 20% Co2 shielding gas produced the greatest hardness value on weld metal due to the addition of Ar as the shielding gas increases the hardness value of weld metal[20]. Besides that, according from previous research by Islamy [21], the value of hardness will be increased when the welding current decrease. Meanwhile, the welding process with pulsed and short circuit modified transfer modes that are using the same 100% Co2 with no Ar as the shielding gas produced almost similar hardness value. It is caused by the stronger welding current in the pulsed transfer mode than in the short circuit modified transfer mode (100% Co2). It is in accordance with the research by Putra (2011)[22]. However, the speed travel used in the pulsed welding is slower so that the resulting heat input is almost similar to the one produced by short circuit modified transfer mode with a weak welding current but faster speed travel.

5.6. Expenditure analysis

Expenditure to be calculated includes machine price, shielding gas price, and welder salary on each type of welding. By using the data on Table 9 and Table 10, the scores of each expenditure parameter are shown in Table 16.

Table 16 Score of each type of welding on expenditure parameter

Transfer Mode	Score				Average
	Tools Price	Shielding Gas Price	Welder Salary	Electrode Efficiency	
RMD Ar+CO2 (80%+20%)	3	1	4	4	3
RMD CO2 (100%)	3	4	3	2	3
Pulsed CO2 (100%)	2	4	1	2	2.25

Table 16 shows that in terms of machine price, the RMD machine for GMAW welding with short circuit modified transfer mode is Rp. 21.110.408 cheaper compared to EWM machine with pulsed feature. Meanwhile, the most expensive cost for shielding gas is contributed by RMD with 20% addition of Ar as the shielding gas.

On the cost calculation for welder salary, the pulsed transfer mode contributed more expensive compared to the RMD transfer mode. The welding speed of pulsed transfer mode is slower than the RMD transfer mode so that the welding process is longer and the expenditure for welder salary is greater.

In electrode efficiency expenditure, the RMD transfer mode with 80% Ar+20% Co2 shielding gas gives a better efficiency level. This is due to the lack of spatter produced so that less metal filler used is wasted.

The average score shows that the use of RMD machine with short circuit modified transfer mode provides less expenditure on the welding process (economic aspect).

5.7. Scoring recapitulation and best transfer mode selection

After analyzing and assigning values to the welding parameters for each type of welding, the scoring in the score card table for the selection process of the best welding method for pipe was recapitulated. Scoring that has been given to each parameter is then multiplied by the weight given. The final score card can be seen in Table 15.

Tabel 15. Final score card

Parameter	Percentage (%)	Transfer Mode (Percentage x Score)		
		RMD Ar+CO2 (80%+20%)	RMD CO2 (100%)	Pulsed CO2 (100%)
Hardness Value	30%	0.9	0.6	0.6
Consistency Level	15%	0.6	0.45	0.45
Root pass penetration height	10%	0.4	0.1	0.4
Weld Deposition Thickness	10%	0.4	0.4	0.4
Spatter Level	10%	0.3	0.1	0.2
Cost	25%	0.75	0.75	0.562
Total	100%	3.35	2.4	2.612

Based on a calculation using the score card in Table 15, it can be seen that the welding method with short circuit modified transfer mode (80% Ar + Co2 20% shielding gas) has the highest final score for analysis of welding results. Welding in the short circuit modified transfer mode using 80% Ar + 20% Co2 shielding gas has a high scoring point on the weld bead profile analysis due to the welding current adjustment on the RMD machine and the use of Ar gas as the shielding gas that gives a stable welding arc and less spatter. As a result, the weld bead produced is more consistent and meets the standards.

Welding with pulsed transfer mode is ranked second after the short circuit modified transfer mode using 80% Ar + 20% Co2 shielding gas. The welding process with pulsed transfer mode provides a fairly good weld result compared to the short circuit modified transfer mode using 100% Co2 shielding gas with no Ar. However, it is possible that the welding mode is able to compete with the short circuit modified transfer mode using 80% Ar + 20% Co2 shielding gas if Ar is added to stabilize the welding arc.

Whereas for the short circuit modified transfer mode using 100% Co2 with no Ar as the shielding gas actually produces a welding process that is almost the same as the pulsed transfer mode. However, this transfer mode still has a problem with the welding arc where the RMD machine cannot handle the unstable arc problem completely, which causes the resulting weld bead to be slightly inconsistent. Therefore, this transfer mode is not recommended if it is using 100% Co2 as a protective gas compared to the pulsed transfer mode.

By using the score card in Table 15 as a reference for selecting the best welding method, it can be concluded that the recommended pipe welding method is the short circuit modified transfer mode using 80% Ar + 20% Co2 shielding gas because it has advantages in technical and economic aspects while the conventional transfer mode (pulsed) is in the second place. There is a possibility to improvise the welding results of the pulsed transfer mode with the addition of Ar to produce a better connection quality.

6. CONCLUSION

According to analysis and discussion, the conclusion from this research is:

Welding with modified short circuit transfer mode RMD Ar+CO2 (80%+20%) gives the more consistent (86.3%) on weld bead profile compared to modified short circuit transfer mode RMD 100% Co2 pure Ar (76.3%) and pulsed transfer mode (81.3%).

The height of root pass penetration from all transfer mode were accepted by standard, However, on root pass penetration height measurement, there is underfill in welding process with short circuit modified method using 100% Co2 shielding gas.

The most minimum level of spatter level spatter was produced by modified short circuit transfer RMD Ar+CO2 (80%+20%) which was 3.53% from weld bead averages. Meanwhile, the maximum level of spatter which is 12.27% was produced by using modified short circuit transfer mode RMD 100% Co2.

Pulsed transfer mode only produced 5.87% spatter level (less than half of spatter level produced by short circuit modified transfer mode RMD with 100% Co2.

Measurement using macroetch gives the thickest weld deposition were given by using pulsed transfer mode, which was 8 mm. Meanwhile, the modified short circuit only produce 5 mm. Nevertheless, all of transfer mode variation gives a good connection.

Hardness value by using pulsed and short circuit modified transfer modes that are using the same 100% Co2 with no Ar as the shielding gas produced almost similar hardness value which was 186.46 HV for pulsed transfer mode and 189.36 HV for modified short circuit transfer mode RMD 100% Co2. Meanwhile, the highest value of hardness was given by using modified short circuit transfer mode RMD Ar+CO2 (80%+20%) which was 213.5 HV

Economic analysis on several parameters such as tools price, shielding gas, welder salary, and electrode efficiency are showing RMD welding machine that used cheaper than the conventional machine (pulsed machine) which was averages 3 points for RMD and 2.25 points for pulsed).

By using score card, the best transfer mode and would be recommended to be used in joining process on piping or another metal material is a modified short circuit transfer mode RMD Ar+CO2 (80%+20%) based on technic and economic aspect.

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