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Research paper

Investigation on joint quality of material ASTM A106/API 5L using magnetic impelled arc butt (MIAB) welding

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Abstract

Magnetic impelled arc butt (MIAB) welding is a pressure welding process used for joining of pipes with an external magnetic field affecting arc rotation in the small gap along the pipe circumference. This welding process relies on very complex interactions between arc, magnetic field and upsetting force. In this work, investigations are carried out on MIAB welding after preliminary experimentation to understand the basic mechanisms involved in MIAB welding process. The experimental procedure involves a series of trials to develop and evaluate the knowledge base for MIAB welding of seamless pipe. Further, a mechanical testing is carried out on the MIAB welded joints of ASTM A106/API 5L specimen to evaluate its strength and to assess the weld integrity according to API 1104 standard. In addition to the investigation, conceptual Welding Procedure Specification (WPS) and Welding Procedure Qualification Record (WPQR) are developed and presented for pipe welding and for further application identical to this research. The results of the experiment emphasized that the MIAB welded joints exhibited high strength and good weld integrity on the level of base metal of pipe. Hence, MIAB can be considered as the future fast and cost-effective welding process without expensive usage of filler materials and shielding gas.

Keywords*: MIAB, ASTM A106/API 5L, WPS, solid state welding, arc rotation*

1. Introduction

Magnetic Impelled Arc Butt Welding (MIAB) is an advanced welding process which is an alternative to the conventional welding process such as friction, flash, resistance and butt welding. MIAB welding could be presented as a solid-state pressure welding process for steel tubes and pipes [1-3]. In this process, axially aligned pipe ends are heated by a rotating arc between the two pipes. The arc formation and its speed of rotation are controlled by the electromagnetic force of radial component of induction of the control magnetic field due to the interaction of the arc current and the magnetic field in the gap. The arc heats up the edges of the pipes to cause localized small strip of melting and adjacent softening in the heat affected zone (HAZ) and subsequently the pipes are forged together to obtain the weld [4,5].

In MIAB welding, an external controlled magnetic field moves the arc in the gap between the pipe edges as shown in Figure 1. Two pipes ready for welding are set coaxially. Magnetic systems installed opposite each other form magnetic fluxes in the arc gap. A short circuit excites the welding arc. The pipes to be welded are moved apart for a definite arc gap (1.5 to 2.5 mm). The interaction between the welding arc's axial component of current and a radial magnetic component, directed perpendicular to the welding arc current, leads to the creation of force. This force moves the welding arc along the ends of the pipes. MIAB welding uses a preprogrammed control of arc current, with arc movement that can reach a linear speed of 200 meters per second. This control heats the pipe ends uniformly, thus producing a quality welded joint. In this investigation, the MIAB machine model MD 101 from the E.O. Paton Electric Welding Institute as presented in Figure 2 was used to weld the high temperature seamless pipe.

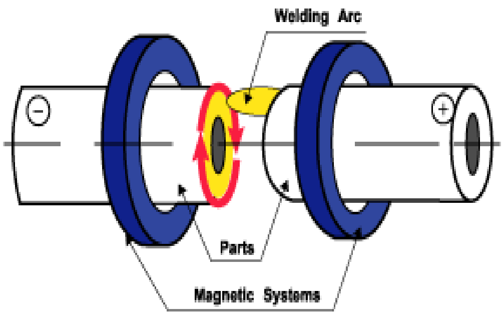


Fig. 1: Two pipes are set coaxially in MIAB welding

Identifying appropriate combinations of welding parameters for welding quality and strength can be a time-consuming process relating to substantial trial and error method [6]. It begins with preparing the written preliminary weld procedure specification (pWPS) and followed by the fabrication of weld test piece that subjected to nondestructive and destructive test such as macro etch examination and tensile tests. The WPS is established upon the weld procedure approval certificate signed by authorized person such as welding engineer and supplemented with the welding procedure qualification record (WPQR) of the material being welded [7]. In welded joint fabrication, the written welding procedure specification (WPS) is the 'recipe' for production of a particular weld quality that compliance with the standard fabrication requirements such as in API 1104. Probably could be said so far in literature, discussion on the WPS that integrated with seamless pipe for high temperature service is almost nonexistent.

Fig. 2: MIAB welding machine model MD 101

Some work has been carried out in the area of MIAB welding. As this process is considered new process there are very few literatures pertaining to MIAB welding process. Taneko et al. [8] used a voltage detector at various locations inside an alloy steel pipe, an oscilloscope and a high speed video camera to measure arc velocities and arc angles. In particular, they studied the relationship between arc velocity, arc angle and the position at which power is supplied to the tubes. They concluded that due to the arc blow effect and the low electrical resistance of the tube, the current increases in the arc closer to the power supply connection on the tube. A study by Xiancong and Ruilin [9] addressed the subject of heat flow in the MIAB weld joint. They considered the rotating arc to be a constant heat source and applied the following heat flow equation for predicting the temperature at time t and distance y from the arc. Leigh et al. [10] presented a new perspective from a development project to implement the technology in the field construction of new pipelines in Australia. In this study, a prototype MIAB welding machine was designed and built which was capable of welding natural gas pipelines and to make welds in DN 150 pipe complying with the performance requirements of the Australian petroleum pipeline standard AS2885.2. Result of investigations conducted by Kachinskiy et al. [11], showed the feasibility of practical application of MIAB welding for welding pipes and pipelines from steel X70. Edson [12], outlined the typical industrial applications within the automotive industry. The application of MIAB welding to weld parts in Ford Transit car rear axle casing containing two circular and two square butt welds. Additional research by Kachinskiy et al. [13] presented the investigation results of the weldability of automobile parts. The weldability of compact hollow automobile parts such as OD 22 x 2.2 mm steering rod, OD 40 x 2.2 mm shock-absorber and OD 34 x 6 mm torque rod were investigated. Since 1994 the pneumatic springs and shock-absorbers welded by MIAB welding was manufactured at automobile plants which more than 7.4 million of welded joints were made.
The use of MIAB welding in the production of truck cab suspension components was described by Hiller et al. [14] of ThyssenKrupp Automotive Systems. Jenicek and Cramer [15] demonstrated that tubular hollow bodies such as nuts, sleeves and bushes could be fastened to sheets using a process with particular economic viability, i.e., an advanced variant of magnetically impelled arc butt welding-bush or nut welding. With extended drawn-arc stud welding devices, aluminum components with an internal thread between M8 and M24 were welded on to perforated sheets made of ENAW-AlMg3 and ENAW-AlMgSi1. Mori and Yasuda [16] evaluated the feasibility of the MIAB welding process with aluminum and aluminum–copper joints. In this set up, it was a challenge to achieve the required flux density at the joint with non-ferrous materials vs. ferrous materials. Hence, an iron core was often inserted inside the pipe. The study reported of MIAB welding method developed for welding non ferro-magnetic metals and examined the welding conditions and procedures of butt welding small diameter pipes of aluminum to aluminum (Al–Al) and to copper (Al–Cu), for obtaining good properties of joint. Arungalai et al. [17] have presented Finite Element Models for predicting electromagnetic flux and electromagnetic force distribution that governs the arc impelling in MIAB welding process. This facilitates effective design of magnetic set up in MIAB welding process.
Although studies [9–17] had reported MIAB welding, there are no reports pertaining to MIAB welding of ASTM A106/API 5L. This material is specially of carbon steel pipes for high temperature service and of seamless manufacture. Thus, based on these motivations the present project aims to produce a WPS for high temperature seamless pipe by using MIAB welding. The flowchart of research investigation is presented in Figure 3.

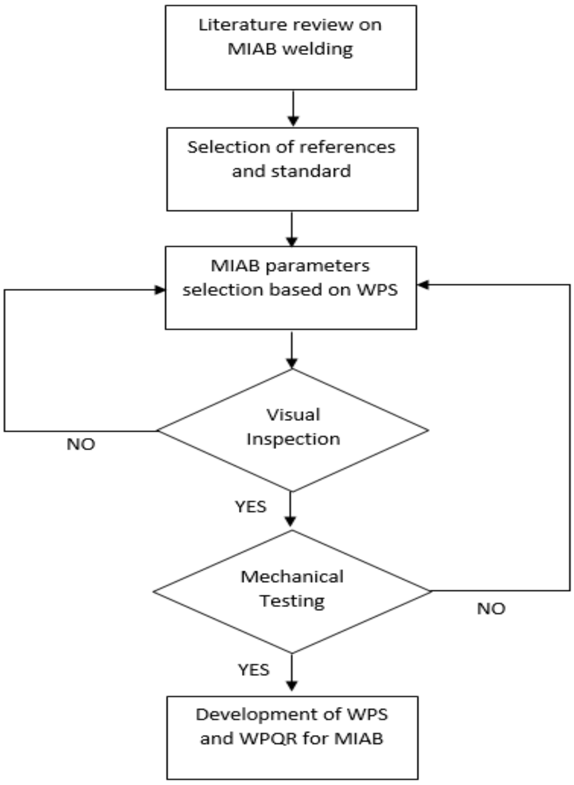


Fig. 3: Flowchart of research investigation

2. Process parameter identification of MIAB for ASTM A106/API 5L

2.1 ASTM A106/API 5L grade B seamless pressure pipe

ASTM A106/API 5L grade B was used in this study. It was specially designed for use in power plants, boilers, petrochemical plants, oil and gas refineries, and ships where the piping must transport fluids and gases that exhibit high pressures and temperatures. This material is suitable for bending, flanging and similar forming operations. The mechanical properties and chemical composition of this material are tabulated in Table 1 and Table 2 respectively.

Table 1: Mechanical Properties of ASTM A106/API 5L

Thickness (mm)	Outside diameter (mm)	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)
3.56	42.2	415	240	31

Table 2: Chemical Composition of ASTM A106/API 5L

C%	Si%	Mn%	P%	S%	Cr%	Ni%	Cu%	Mo%
0.19	0.25	0.73	0.012	0.007	0.002	0.003	0.001	0.001

2.2 Preliminary welding procedure specification (pWPS)

Preliminary welding procedure specification (pWPS) is an important stage in WPS development. It is a document comprising required variables of the welding procedure which needs to be qualified in order to create the qualified welding procedure specification (WPS). In this stage selection of the current, time, upset pressure and surface gap is mostly obtained by trial and error of MIAB welding machine. Somehow an engineer is also referring to parameter recommendation by manufacturer. Initially, a visual inspection is carried out on the MIAB welded joint for the five sets of process parameters. The general observations for each trial are tabulated in Table 3. The result indicates that a good weld with uniform penetration is achieved in case of the trial 5 as shown in Figure 4.

Table 3: Trial Observation of Welded ASTM A106/API 5L

Trial no.	Current (A)			Time (s)				Upset pressure (bar)	Surface gap (mm)	Visual inspection
	I_1	I_2	I_3	T_1	T_2	T_3	T_4			
1	230	170	500	1	2.75	10.5	0.18	4.5	1.2 – 1.4	Achieved weld, non-uniform bead
2	230	180	520	1	2.6	10.5	0.2	4.4	1.2 – 1.4	Achieved weld, excess material expulsion
3	230	190	550	1	2.6	9.0	0.2	4.3	1.2 – 1.4	Achieved weld, excess material expulsion
4	230	210	570	1	2.5	8.5	0.3	4.3	1.2 – 1.4	Achieved weld, excess material expulsion
5	230	215	600	1	2.5	8.0	0.3	4.2	1.2 – 1.4	Good weld, uniform penetration

Fig. 4: Uniform bead and full penetration

2.3 Result of mechanical testing

The mechanical testing such as tensile test, bend test, nick break test, hardness test and macro etch examination were conducted according to API 1104 Standard [18]. The result of tensile test is tabulated in Table 4. It shows that the specimen strength is 459.88 MPa which is complying with the raw material strength of 415 MPa and the specimen broke in base metal as shown in Figure 5. Absolutely, the results are acceptable and proved that the MIAB welding parameters used to weld the ASTM A106/API 5L seemly the right combination.

The result for side bend test in order to determine the soundness of the welded joint is tabulated in Table 5. As can be seen in Figure 6, the sample is in excellent condition without sign of crack or defects in the bend area.

Table 4: Tensile Test Result of Welded ASTM A106/API 5L

Outside diameter (mm)	42.7
Thickness (mm)	3.83
Area (mm)	467
Yield load (N)	215082.17
Yield stress (N/mm^2)	344.93
Maximum load (N)	161322.42
Tensile strength (N/mm^2)	459.88

Fig. 5: Tensile test of the welded specimen

Table 5: Side Bend Test Result of Welded ASTM A106/API 5L

Width (mm)	Thickness (mm)	Result	Remarks
25.0	3.56	Satisfactory	No open discontinuity

Fig. 6: Side bend test of the welded specimen

The nick break test was conducted in order to evaluate the weld discontinuities and defects of the welded sample. As can be seen in Figure 7 the sample is in good condition with no porosity and no lack of fusion at exposed surface of the weld.

Fig. 7: Nick break test of the welded specimen

The method of hardness testing was conducted in accordance to ASTM E92. The indentation was made in the weld, the HAZs and the base metal using the Vickers method HV10 as presented in Figure 8. The measured hardness values on test specimens are as follows:
Weld: 183 – 232 HV10
HAZ: 153 – 170 HV10
Base metal 145 – 169 HV10
Those values proved the weld joint was perform using good welding parameters [19].

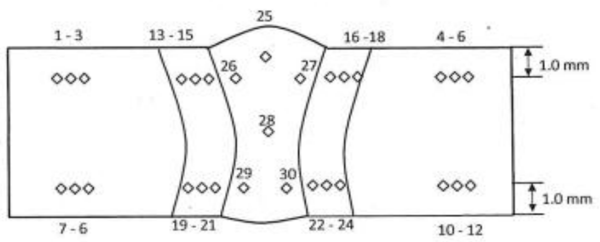


Fig. 8: Vickers hardness test of the welded specimen

For metallographic testing, the specimen was prepared and etched on one side in accordance to API 1104. From the observation it indicates the sample was a complete fusion and free from crack as presented in Figure 9.

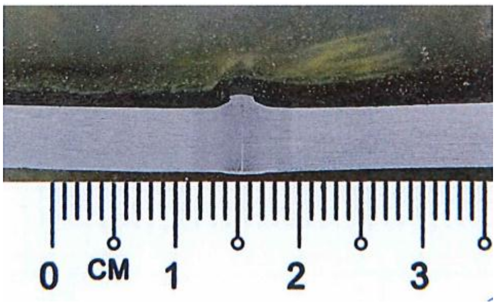


Fig. 9: Visual examination at 10x magnification at cross section

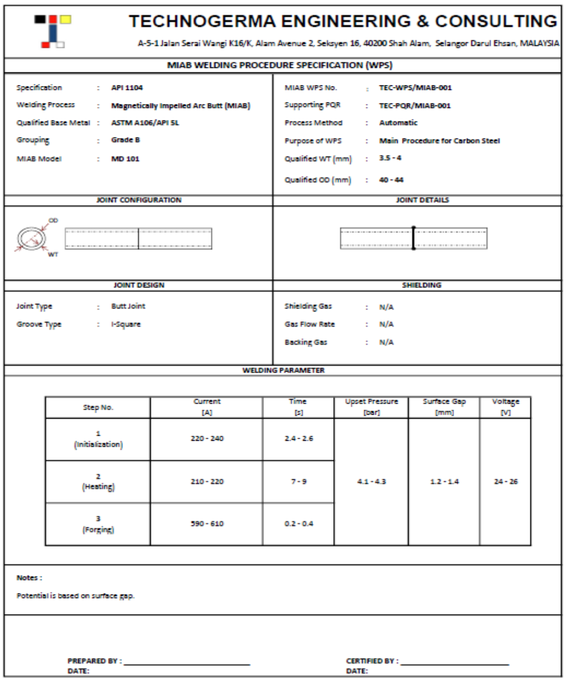
3. Result and discussion

For the actual record of the MIAB welding process parameters applied for testing purposes, Welding Procedure Qualification Record (WPQR) was created. From the visual and mechanical testing, the WPQR was further develop into Welding Procedure Specification (WPS). In a working environment, these parameters would change depending on many factors. Hence, in WPS the parameters were stated in range which would still provide the best weld for this material. Figure 10 represents the WPS developed for a material of ASTM A106/API 5L.

This type of information is useful in piping design when engineers are often faced with difficulty in choosing the welding process. This information contained here will help in establishing the suitability of MIAB welding for piping industry. Welding parameter and production data provided will be useful in applying pipe welding techniques in a practical situation. In addition, it will help engineers to avoid making what could be costly mistakes or to overcome problems when welding defect occur in production.

MIAB welding current can be divided into three stages and the welding time are in four stages. For welding ASTM A106/API 5L with 42.2 mm diameter, 3.56 mm thickness I1 current is employed for around 1 s during which the pipes to be welded are shorted and then retracted when an arc is established between the two pipes. T2 (2.4–2.6 s) is the time period in which the shorted pipes are retracted followed by the arc striking between the pipes. Further, in this stage of time, the arc starts to accelerate rotation along the peripheral edges of the pipe ends. Through this stage of time, I1 current of (220–240 A) is employed. In stage T3 (7–9 s), arc accelerates and rotates with a high speed along the peripheral edges of the pipes while heating up the faying surfaces to the point of solidus condition. A current of 210– 220 A (I2 current) is provided during the T3 stage. Finally, upsetting action takes place in T4 (0.2 – 0.4 s) by supplying a current of 590 – 610 A. Overall MIAB welding time for this sample is around 10 – 12 s.

From the mechanical testing and metallurgical observation of MIAB welded joint (process parameter as per the 5th trial in Table 3), it is perceived that the quality, strength and hardness integrity are within the acceptable limits as per Malaysian industrial application. These results clearly highlight that MIAB welding is suitable for welding high temperature seamless pipe.



TECHNOGERMA ENGINEERING & CONSULTING

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MIAB WELDING PROCEDURE SPECIFICATION (WPS)

Specification : API 1104
Welding Process : Magnetically Impelled Arc Butt (MIAB)
Qualified Base Metal : ASTM A106/API 5L
Grouping : Grade B
MIAB Model : MD 101

MIAB WPS No. : TEC-WPS/MIAB-001
Supporting PQR : TEC-PQR/MIAB-001
Process Method : Automatic
Purpose of WPS : Main Procedure for Carbon Steel
Qualified WT (mm) : 3.5 - 4
Qualified OD (mm) : 40 - 44

JOINT CONFIGURATION

OD
WT

JOINT DETAILS

JOINT DESIGN

Joint Type : Butt Joint
Groove Type : I-Square

SHIELDING

Shielding Gas : N/A
Gas Flow Rate : N/A
Backing Gas : N/A

WELDING PARAMETER

Step No.	Current [A]	Time [s]	Upset Pressure [bar]	Surface Gap [mm]	Voltage [V]
1 (Initialization)	220 - 240	2.4 - 2.6	4.1 - 4.3	1.2 - 1.4	24 - 26
2 (Heating)	210 - 220	7 - 9			
3 (Forging)	590 - 610	0.2 - 0.4			

Notes :

Potential is based on surface gap.

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Fig. 10: New WPS format for MIAB welding

4. Conclusion

In this investigation, MIAB welding process was applied to weld the steel pipe with grade ASTM A106/API 5L which is commonly used in high heat applications. The weld quality was inspected visually and mechanically tested to ensure the quality of the weld. WPS was developed for this process to be applied on working environment according to Malaysia standard. From this investigation, some conclusion arises as follows:

a) By using MIAB process, the welding time can be reduced by 90% compared to conventional welding process.
b) MIAB required simple surface preparation and does not require any bavelling.
c) The spinning arc during the heating process provides the cleaning of the weld surface thus ensuring the welding quality.
d) New WPS and WPQR were developed for MIAB welding.
e) MIAB welding process can be complying to API 1104 standard which is commonly practice in pipeline welding within this region.

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