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ASSESSING THE INFLUENCE OF WELDING CURRENT ON WELD QUALITY IN MANUAL ARC WELDING MACHINES THROUGH ULTRASONIC TESTING

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Abstract – *Welding is a critical manufacturing process, akin to milling, turning, and grinding, essential for producing mechanical products. The integrity and durability of welds are crucial for ensuring the quality and longevity of these products. The significant impact of selecting the appropriate welding current on the quality of welds produced by manual arc welding machines was explored by conducting experimental weld passes on various standard weld samples and employing ultrasonic testing to detect internal defects. The study aims to establish a clear relationship between welding current settings and weld quality. The findings contribute to formulating optimal welding parameters, enhancing the quality and reliability of welding in industrial applications.*

Keywords: mechanical engineering, ultrasonic testing, welding, weld quality.

I. INTRODUCTION

Manual arc welding method as the most prevalent welding method employed in construction and manufacturing industries to ensure consistent weld quality. To this end, numerous countries worldwide have established welding strength standards, including ISO, EN (Europe), AWS (USA), JIS (Japan), and TCVN (Vietnam). Among these, TCVN 12728:2019 is considered one of the prevailing Vietnamese standards for technical requirements pertaining to the design, fabrication, installation, and repair of boilers [1].

ASME's Boiler and Pressure Vessel Code (BPVC) has pioneered modern standards-development, maintaining a commitment to enhance public safety and technological advancement to meet the needs of a changing world. More than 100,000 copies of the BPVC are in use in 100 countries around the world [2].

Numerous factors influence weld quality, including welding current, the welder's technique (angle and speed of the welding rod), and electrode selection. Among these, choosing the appropriate welding current is a critical factor in achieving high-quality welds, minimizing defects, and enhancing structural integrity. Despite the significance of welding current, limited research has explored its impact on weld quality in manual arc welding machines. Non-destructive testing (NDT) methods such as visual inspection and dimensional measurements often fail to detect internal weld defects. Ultrasonic testing, on the other hand, stands out as an effective NDT method capable of identifying internal weld defects that other methods cannot. This study aims to establish the relationship between welding current and weld quality in manual arc welding machines by evaluating weld quality using ultrasonic weld testing.

II. EXPERIMENT

A. Welding inspection procedure

Welded joints are subjected to loads as shown in Table 1, The durability coefficient of welded joints subjected to high pressure such as designed pressure vessels depends on the inside diameter of the device and the weld strength coefficient. Pressure equipment requirements in the same level 1–2, the welded structure must be ultrasonic to check the weld. The quality of welds plays a crucial role in manufacturing, ensuring the durability and safety of products.

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The welding inspection procedure takes four steps:

Step 1 – Visual inspection: Observying the shape, size, and surface of the weld to detect defects;

Step 2 – Dimensional inspection: Using measuring tools, such as rulers and durometers, to verify the size and hardness of the weld;

Step 3 – Destructive testing: Cuting samples from the weld to evaluate its mechanical properties, including tensile strength, ductility, and impact resistance;

Step 4 – Non-destructive testing: Using techniques such as dye penetrant testing, ultrasonic testing, and radiography to identify defects with the weld.

Table 1: Ultrasonic welding conditions

Requirement	Grade 2	Grade 1
Design Pressure (kPa)	≤ 750, for fire-tube boilers and other boilers	> 750, for fire-tube boilers, other boilers, and all water-tube boilers
Design Pressure (kPa) x Di (mm) x 10^-3	≤ 900	> 900
Welded Joint Efficiency Factor (η)	a) 0.85, when using ultrasonic testing or X-ray b) 0.75 when not using an X-ray	1.0, when there is an ultrasound or X-ray 100% of the butt weld

B. Measuring welding current

In the process of determining optimal welding parameters for each specimen, the actual output current of the Hong Ky HK-H250D welding machine was measured using a Kyoritsu 2127R ammeter. This machine utilized Kim Tin KT-6013 (3.2 mm) welding rods. The method employed for measuring the welding current is depicted in Figure 1. These measurements formed the basis for our experimental assessment, where the welding current was adjusted according to the parameters specified. The outcomes of these adjustments are comprehensively detailed in Table 2, illustrating the effects of various settings on the actual output current.

The experiment of measuring the welding current on the manual arc welding machine with the selected parameters above gives us the results as shown in Table 2.

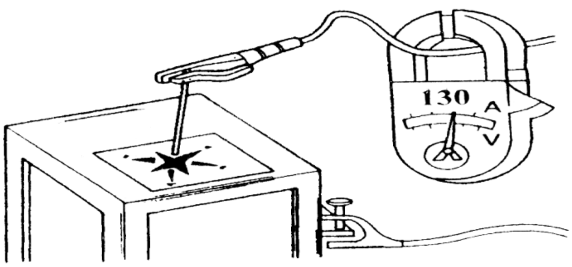

Fig. 1: The welding current measured with Kyoritsu 2127R Ammeter

Table 2: Parameters after actual measurement compared

Welding Machine Setting Im (A)	Measured Current Itt (A)
110	95
120	110
130	116
140	128
160	133
180	152

Weld specimens, composed of low-carbon steel with dimensions of 200 x 100 x 10 mm (length x width x thickness) were fabricated using a Hong Ky HK-H250D welding machine. The designs of the specimens included various joint types to evaluate the machine's versatility and effectiveness. These types were Butt weld specimens (as depicted in Figure 2), T-joint weld specimens (as depicted in Figure 3), and Lap weld specimens (as depicted in Figure 4). Each specimen type was selected to mirror common welding applications, allowing for comprehensive testing of the welding machine's performance across different joint configurations [2, 3].

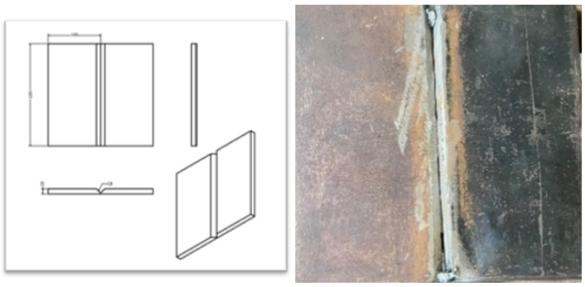

Fig. 2: Butt joint design and fabrication

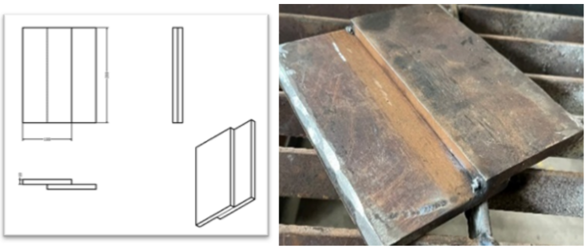

Fig. 3: Lap joint design and fabrication

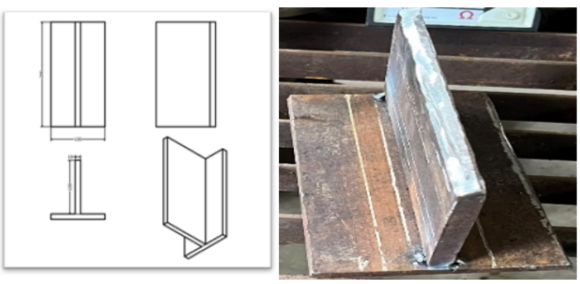

Fig. 4: T-joint joint design and fabrication

To ensure optimal welding quality, it is crucial to maintain an appropriate distance of approximately 3–4 mm between the electrode tip and the workpiece. This distance is essential for sustaining a stable arc throughout the welding process. The electrode should be moved along the weld seam at a controlled speed to achieve a uniform and deeply penetrating weld. The angle of the electrode, critical for achieving the desired weld geometry and quality, varies depending on the type of electrode and the welding position. Typically, common angles used are as follows: Angle α ranges from 750^o to 850^o, and angle β is maintained at 90^o, as illustrated in Figure 5. Before beginning the welding process, it is important to carefully select and set the welding parameters on the machine tailored to each specific type of sample [4].

III. RESULTS AND DISCUSSION

This study aims to evaluate the quality of welds produced under varying current intensities across three different types of weld joints: T-joints, Butt joints, and Lap joints. Each joint

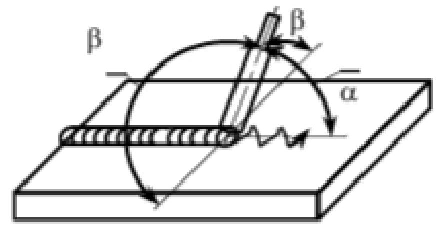

Fig. 5: Welding electrode angle

type will undergo welding at two distinct current settings to assess the influence of electrical intensity on the structural integrity and quality of the welds. Following the welding process, each sample will undergo ultrasonic testing to detect any internal inconsistencies, such as porosity or cracks. This non-destructive technique will allow for an accurate assessment of the welds, comparing defect prevalence across different joint types and current settings. The results informs better welding practices, ensuring higher quality and reliability in welded fabrications.

A. Welded T-joint

In the welding experiment, a T-joint sample was welded using two predetermined electrical current settings to explore the impact of current intensity on the weld quality. The sample was welded at nominal settings of 100 A and 160 A, with a welding rod of 3.2 mm in diameter. However, the actual currents measured during the welding process were slightly lower, with 95 A recorded for the 110 A setting and 133 A for the 160 A setting. The T-joint weld sample is shown in Figure 6.

In the assessment of the T-joint weld sample created with a welding current of 95 A, an ultrasonic testing and visual inspection procedure was implemented to evaluate the integrity of the weld. Through visual inspection, the weld joint has not cracked. However, the techniques were not good enough for perfect weld. The results from this non-destructive testing, visualized in

Fig. 6: Welded T-joint samples at current (a) 95 A and (b) 133 A

Figure 8 highlighted a significant defect within the weld. The 6 dB drop method was employed to measure the defect's characteristics, which indicated a length of 74 mm, a depth of 5.8 mm, and a height of 8.2 mm. The analysis of the ultrasonic waveform identified the defect as a lack of fusion at the weld root. Lack-of-fusion defects are critical flaws that occur when there is insufficient melting between the weld metal and the base metal or previous weld layers. This can lead to areas within the weld where parts are not bonded, significantly weakening the weld's overall structural integrity. Such defects are especially problematic because they compromise the joint's mechanical strength and can act as initiation points for fractures under operational stresses [5].

Delay: 0,00 mm	Reject: 0%	Range: 224,98 mm
Gain: 55,4 dB	PRF: 140 Hz	PULSE_ECHO
Velocity: 3226 m/s		Filter: 1.5-8.5 MHZ
Zero: 7,301 µs	Energy: 100 V	RECT: FULL
Angle: 71,0°	DAMP: 50 Ω	Thick: 10,00 mm
	Pulser: SQUARE	
Screen Type: Standard		

Gate	Start	Width	Level	Alarm	Status	Leg	
1	19,87	43,05	20 %	OFF		L2	

Fig. 7: Ultrasonic testing results of the T-joint welded at 95 A

In the assessment of the T-joint weld sample welded at a current of 133 A, ultrasonic testing and visual inspection played a critical role in evaluating the internal integrity of the weld. Through visual inspection, the weld joint has not cracked. The ultrasonic scan, as depicted in Figure 8, revealed a defect characterized by a depth of 7.39 mm and an amplitude below 20%. Waveform analysis further identified this defect as porosity, a common issue in welding that arises due to trapped gas in the molten weld pool, which solidifies before the gas can escape. Porosity in welds can compromise the mechanical strength and durability of the joint, depending on the size, distribution, and amount of porosity present. However, in this case, the defect amplitude, which measures the reflection intensity of the ultrasound wave at the defect location compared to the base material, was below 20%. According to the ASME Section VIII standards, a defect with an amplitude less than 20% is generally not considered severe enough to compromise the structural integrity of the weld significantly [6].

Delay: 0,00 mm	Reject: 0%	Range: 224,98 mm
Gain: 55,4 dB	PRF: 140 Hz	PULSE_ECHO
Velocity: 3226 m/s		Filter: 1.5-8.5 MHZ
Zero: 7,301 µs	Energy: 100 V	RECT: FULL
Angle: 71,1°	DAMP: 50 Ω	Thick: 10,00 mm
	Pulser: SQUARE	
Screen Type: Standard		

Gate	Start	Width	Level	Alarm	Status	Leg	
1	33,32	23,00	20 %	OFF		L2	

Fig. 8: Ultrasonic testing results of the T-joint welded at 133 A

B. *Welded Lap joint*

In the experimental setup, a Lap joint weld sample was fabricated using two different welding current settings to analyze the impact on weld quality and integrity. The sample was welded with a 3.2 mm diameter electrode at nominal currents of 130 A and 180 A. However, the actual currents measured during the welding process were 116 A and 152 A, respectively. The T-joint weld samples are shown in Figure 9 [7].

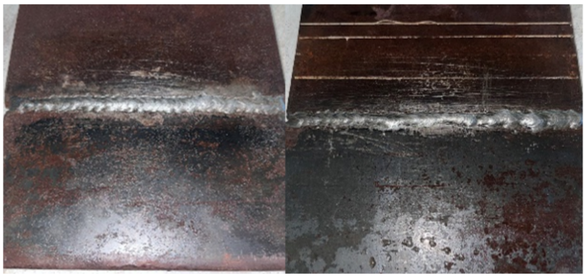

Fig. 9: Welded Lap joint samples at current (a) 116 A and (b) 152 A

Delay: 0,00 mm	Reject: 0%	Range: 224,98 mm
Gain: 58,2 dB	PRF: 140 Hz	PULSE_ECHO
Velocity: 3226 m/s		Filter: 1.5-8.5 MHZ
Zero: 7,301 µs	Energy: 100 V	RECT: FULL
Angle: 71,0°	DAMP: 50 Ω	Thick: 10,00 mm
	Pulser: SQUARE	
Screen Type: Standard		

Gate	Start	Width	Level	Alarm	Status	Leg	
1	19,87	43,05	20 %	OFF		L2	

Fig. 10: Ultrasonic testing results of the Lap joint welded at 116 A

In analyzing the Lap joint weld sample fabricated at a welding current of 116 A, the integrity of the weld was assessed through ultrasonic testing and visual inspection. Through visual inspection, two weld joints have not cracked. The method employed to measure these dimensions was the 6 dB drop method. The scan results, depicted in Figure 10, revealed a critical defect characterized by a length of 25 mm, a depth of 7.83 mm, and a height of 4.5 mm. The waveform analysis from the ultrasonic test indicated a lack-of-fusion defect at the weld root. Lack-of-fusion is a serious flaw that occurs when the weld metal does not adequately merge with the base metal or the previous weld passes along the weld interface. This results in an incomplete bond, creating a structural weakness that is particularly vulnerable to stress and can significantly compromise the weld's load-bearing capacity [2].

However, in the assessment of the Lap joint weld sample conducted at a higher welding current of 152 A, the results, illustrated in Figure 11, identified a defect with a depth of 6.44 mm. Critically, the defect amplitude registered below 20%, which is a significant metric in determining the acceptability of the weld under industry standards. Waveform analysis conducted during the ultrasonic inspection indicated that the nature of the defect was porosity, a common issue characterized by the presence of small cavities or holes within the weld. Porosity typically results from trapped gases in the weld pool as it solidifies, and while it can compromise the mechanical properties of the weld to some extent, the severity is largely dependent on the extent and distribution of the porosity.

Delay: 0,00 mm	Reject: 0%	Range: 224,98 mm
Gain: 58,2 dB	PRF: 140 Hz	PULSE_ECHO
Velocity: 3226 m/s		Filter: 1.5-8.5 MHZ
Zero: 7,301 µs	Energy: 100 V	RECT: FULL
Angle: 71,0°	DAMP: 50 Ω	Thick: 10,00 mm
	Pulser: SQUARE	
Screen Type: Standard		

Gate	Start	Width	Level	Alarm	Status	Leg	
1	19,87	43,05	20 %	OFF		L2	

Fig. 11: Ultrasonic testing results of the Lap joint welded at 152 A

C. *Welded Butt joint*

This study fabricated welded Butt joint samples using two different electrical current settings to analyze the effects on weld quality and consistency. The samples were welded with a 3.2 mm diameter electrode at nominal currents of 120 A and 150 A. However, the actual currents measured during the welding process were 110 A and 128 A, respectively. These deviations were noted to understand the welding machine's performance under the set conditions and to evaluate the impact of actual current on the quality of the welds. The process of welding these butt joints at controlled currents was meticulously carried out, and the final welds were visually inspected and documented in Figure 12.

Fig. 12: Welded Butt joint samples at current (a) 110 A and (b) 128 A

In evaluating the integrity of welded Butt joint samples under different welding currents, through visual inspection, two weld joints have not cracked. Two instances were critically assessed using ultrasonic testing and the 6 dB drop method for defect quantification. For the welded butt joint sample welded at a current of 110 A, the defect identified had dimensions of 10 mm in length, 5.64 mm in depth, and 3.6 mm in height (as shown in Figure 13). The waveform analysis indicated the presence of porosity and slag inclusions within the weld. Porosity refers to the formation of small gas pockets within the weld bead, while slag inclusions are non-metallic solid material trapped within the molten weld. According to the ASME Section VIII standards, which set stringent criteria to ensure the safety and durability of welded structures, the defect length of 10 mm exceeds the permissible limits. Consequently, despite the moderate welding current, this weld must be rejected due to its inability to meet the required standards of structural soundness [2, 7].

In the case of the sample welded at a higher current of 128 A, the detected defect was significantly larger, with measurements of 25 mm in length, 7.83 mm in depth, and 4.5 mm in height. The ultrasonic testing's waveform analysis

Delay: 0,00 mm	Reject: 0%	Range: 224,98 mm
Gain: 58,2 dB	PRF: 140 Hz	PULSE_ECHO
Velocity: 3226 m/s		Filter: 1.5-8.5 MHZ
Zero: 7,301 µs	Energy: 100 V	RECT: FULL
Angle: 71,0°	DAMP: 50 Ω	Thick: 10,00 mm
	Pulser: SQUARE	
Screen Type: Standard		

Gate	Start	Width	Level	Alarm	Status	Leg	
1	19,87	43,05	20 %	OFF		L2	

Fig. 13: Ultrasonic testing results of the Butt joint welded at 110 A

pointed to a lack-of-fusion defect at the weld root. Lack-of-fusion is a severe flaw where the weld metal does not adequately fuse with the base metal, leading to a weak bond that greatly affects the load-bearing capacity of the weld and overall structural reliability. This type of defect is particularly problematic because it directly undermines the joint's ability to withstand operational stresses. This defect's length surpasses the limits set by ASME Section VIII standards, necessitating the rejection of this weld as well [2, 7].

Delay: 0,00 mm	Reject: 0%	Range: 224,98 mm
Gain: 58,2 dB	PRF: 140 Hz	PULSE_ECHO
Velocity: 3226 m/s		Filter: 1.5-8.5 MHZ
Zero: 7,301 µs	Energy: 100 V	RECT: FULL
Angle: 71,0°	DAMP: 50 Ω	Thick: 10,00 mm
	Pulser: SQUARE	
Screen Type: Standard		

Gate	Start	Width	Level	Alarm	Status	Leg	
1	19,87	43,05	20 %	OFF		L2	

Fig. 14: Ultrasonic testing results of the Butt joint welded at 128 A

Table 3 presents a summary of six welding lines corresponding to three different welding positions. Each welding position suitable for the

Table 3: Summarized results correspond to each welding current

Weld Sample	Actual Welding Current (Itt)	Quality Result
Welded T-joint	95A	Lack of fusion at the root
	133A	Acceptable
Welded Lap joint	110A	Lack of fusion at the root
	128A	Acceptable
Welded Butt joint	116A	Porosity and slag inclusions
	152A	Crack

weld line is measured during the welding process and the results are checked by ultrasonic method for the weld line.

Welding current value Itt < 128 A, ultrasonic results have many bad habits like: Lack of fusion at the root, porosity, and slag inclusions;

Welding current value Itt = (128 – 133) A, ultrasonic results meet weld quality requirements;

Welding current value Itt > 133 A, ultrasonic results produce many defects such as cracks and destruction.

IV. CONCLUSION

This study meticulously explores the critical relationship between welding current and the quality of welds in manual arc welding machines, utilizing ultrasonic testing to evaluate the integrity of welds. The research findings reveal a profound influence of welding current on the occurrence of defects such as lack-of-fusion and porosity, which significantly impact the structural integrity and reliability of welded joints. The understanding of the dynamics between welding parameters and weld quality is enriched, offering a scientific basis for developing better welding practices that ensure higher quality, reliability, and efficiency in welded fabrications. Future studies could expand on this by exploring the interplay of other variables such as electrode type and welding speed, further contributing to the body of knowledge in welding technology.

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