Effect of Heat Input on the Tensile Strength and Hardness of Weld Metal Using ER410H as Filler Metal Without Heat Treatment

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Abstract. In the oil and gas exploration industry, martensitic stainless-steel (MSS) pipes are commonly employed for its corrosion and abrasion resistance. Binding materials with a thickness of less than 6 mm is typically accomplished using a TIG welding procedure with ER410H as the filler material. It is believed that the effect of heat on the mechanical properties of weld metal is proportional to the amount of heat input applied. To the best of our knowledge, no research has been conducted on the extent of change in the mechanical properties of weld metal when ER410H is used as a filler material. Therefore, the purpose of this research is to assess the effect of heat input on the mechanical properties of weld metal employing ER410H as a filler material. TIG welding was employed as the welding procedure. Variation of heat input was carried out by varying the welding current. The specimen is weld metal measures 300 mm in length and 6 mm in thickness. The welding process is carried out conventionally, that is, without prior or subsequent heat treatment. Tensile and hardness tests were then carried out on the specimens. According to the test results, the maximum average hardness was 389.8 HV at the average heat input, current, and voltage were 2.1 kJ/min, 110 A, and 15.5 Volt, respectively. Meanwhile, the lowest average hardness was 370.5 HV at the average heat input, current, and voltage were 1.9 kJ/min, 90 A, and 13.3 Volts, respectively. The highest average tensile strength was 90.9 kgf/mm^2 at the average heat input, current, voltage were 2.1 kJ/mm, 110 A, and 15.5 Volt, respectively. Meanwhile, the lowest average tensile strength was 79.0 kgf/mm^2 at the average heat input, current, and voltage were 1.9 kJ/mm, 90 A, 13.3 Volt, respectively. It was concluded that the greater the heat input, the higher the tensile strength and the hardness of weld metal. The increase is caused by the fact that the martensitic material relatively cools down quickly, so it is easier to produce a martensite phase during welding.

Keywords: weldmetal; TIG; GTAW; martensitic; heat input; tensile, hardness

I. INTRODUCTION

Because of its great corrosion and abrasion resistance, martensitic stainless-steel (MSS) pipes are frequently employed in the oil and gas exploration industry [1]. There are many grades of MSS. TP410 is one of the martensitic material grades. To

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bind these materials together with thicknesses less than 6 mm, a Tungsten Inert Gas (TIG) welding procedure, with ER410H as the filler metal, is typically used.

Filler metal, that is melted together with base metal to form weld metal after the welding process, greatly influences the mechanical properties of a welded joint. The filler metal used for welding martensitic materials must also be martensitic. In general, the properties of the filler metal are dictated by the properties of the base metal to be welded.

According to the electrode data sheet, filler metal 410H has a maximum hardness of 207 HB (201 HV) [2] and a tensile strength of 530 MPa (54 kgf/mm^2) [3]. The heat input applied during the welding process will have an impact on the filler metal's tensile strength and hardness [4].

Several studies on martensitic material 410 have been carried out by some expert researchers. Among others, the study conducted by Hejripour et al. [5]who caried out research on the welding consumable selection process for dissimilar metals welding between stainless steel 410 and inconel 718 using TIG welding. This result shows that consumable 82-410 has better mechanical properties than 718-410.

Furthermore, Jiajia Shen, et al. [6], have conducted research on the microstructure and mechanical properties of GMAW welding for CoCrFeMnNi material with 410 stainless steels as filler material. The results of this research show that with filler material 410 there is no increase in hardness in the fusion area. However, it increases the tensile strength of the welded joint compared to without using 410 filler material.

To the best of our knowledge, of all the researches that have been carried out by the experts, the studies were more focused on the case of dissimilar materials welding by studying the mechanical properties of welded joints. And, we have not found specific studies regarding the mechanical properties of weld metal.

Therefore, this research was conducted to determine the mechanical properties of weld metal as an effect of welding heat input. TIG welding procedure using filler material ER410H was used. Meanwhile, the heat input variations were carried out by varying the welding current.

II. MATERIALS AND METHODS

As previously stated, the welding procedure used for specimen preparation was TIG welding. TIG welding is often referred to as Gas Tungsten Arc Welding (GTAW). GTAW is an arc welding technique that utilizes an arc between a non-consumable tungsten electrode and a base metal involving shielding gas to protect the weld bead from atmosphere [7]–[9].

Migatronic PI 250 was used as the TIG welding machine. Because heat input is related to welding current proportionally, this investigation was carried out by varying the welding current into four stages, namely 90, 100, and 110 A. The welding heat currents applied remained within the range chosen by Kumar et al. [10] in their TIG Welding research, ranging from 20 to 120 A.

Using a current clamp, the current variation employed and its concomitant voltage were observed while welding. The travel speeds were determined by timing how long it took the welder to complete the welding of the specimen. The heat inputs were then estimated again using (1) and tabulated in **TABLE 1**.

$$Heat\ input = \frac{Current\ .Voltage}{Travel\ speed} \quad (1)$$

TABLE 1. WELDING PARAMETERS

Specimen Number	**Time (min)**	**Travel Speed (mm/min)**	**Heat Input (kJ/mm)**
Sp-1 (90A,13.3V)	7.6	39.5	1.82
Sp-2 (90A,13.3V)	7.9	37.9	1.90
Sp-3 (90A,13.3V)	7.7	39.2	1.83
Sp-4 (90A,13.3V)	7.5	40.0	1.80
Average		39.1	1.84
Sp-1 (100A,14.6V)	6.1	49.2	1.78
Sp-2 (100A,14.6V)	6.3	47.7	1.84
Sp-3 (100A,14.6V)	6.8	44.0	1.99
Sp-4 (100A,14.6V)	6.3	47.6	1.84
Average		47.1	1.86
Sp-1 (110A,15.5V)	5.7	52.4	1.95
Sp-2 (110A,15.5V)	6.4	47.2	2.17
Sp-3 (110A,15.5V)	6.4	46.9	2.18
Sp-4 (110A,15.5V)	6.3	47.3	2.16
Average		48.5	2.11

The welding consumables are then chosen in accordance with the TIG Welding regulations. The electrode selected was EWTH-2 ANSI/AWS A5.12-80 with a size of 1.6 mm x 175 mm manufactured by Weldcraft. Meanwhile, the filler metal was ER410H with the diameter of 2.4 mm. The gas flow rate was 10 L/min. The gas flow rate chosen is consistent with Chen et al.[11] research, which used gas flow rate variations ranging from 5, 10, 15, and 20 L/min.

Welding position is thought to be important because it influences weld pool convective flow, weld bead morphology, thermal cycle, and cooling rate in the specimen [12]. Therefore, with several considerations, the specimen was welded in the flat welding position (1G).

It should be noted that this research focuses on tensile strength and hardness of weld metal. Since the weld metal is the metal that has been molten during welding and then solidified [13], the specimen was created by trimming the welding joint around the weld metal.

This research went through various steps as depicted in the research flowchart in Fig. 1. This research begins with preparation of the equipment, tools, and welding consumables. The welding specimen was then created by welding MMS using the filler metal ER410H and with current variations aforementioned. The welding results are subsequently cut away, leaving simply the weld metal with the thickness of 6 mm, length of 300 mm, and width of 10 mm. The welding is carried out without heat treatment. There are four specimens for each current variation, as depicted in Fig. 2.

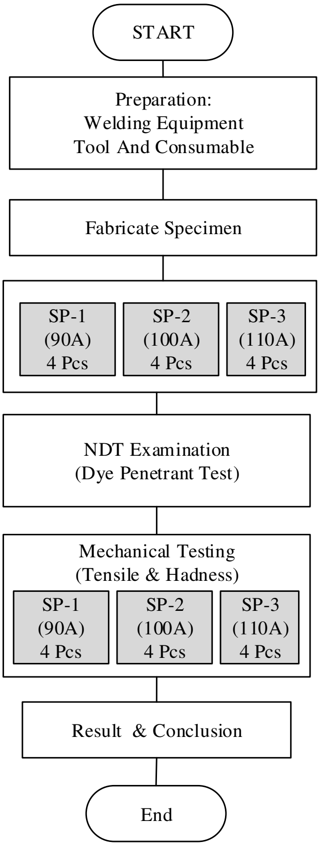

Fig. 1. Research flowchart

The specimens were then evaluated with a non-destructive test (NDT) utilizing the dye penetrant test method. The liquid penetrant testing in ASME standards refers to the ASME Code Section V Article 6. The NTD is a testing procedure that does not damage the material [14]. The testing is to detect gap that cause weld discontinuities [15]. The discontinuity is an imperfection in the welding joint material due to a lack of homogeneity in the mechanical or metallurgical or physical properties [16]. There were three samples of weld materials have been taken for NDT testing, and the result showed that none of them experienced defects in the form of discontinuities.

Afterward, the weld metal was mechanically tested to establish its mechanical properties. In this investigation, two types of testing were used: hardness testing and tensile testing. Micro Hardness Tester, FM800, Future Tech Corp, Japan was used for the hardness test refers to ISO 9015-1. Meanwhile, the tensile test was carried out on the Cesare Galdabini Gallarate, Italy /1987/32557 Machine, which has a maximum load of 100 kN. Tensile testing is referred to the AWS D1.1 standard.

(a) Specimen SP-1, 2, 3, and 4 of weld metal with the current of 90 A

(b) Specimen SP-1, 2, 3, and 4 of weld metal with the current of 100 A

(c) Specimen SP-1, 2, 3, and 4 of weld metal with the current of 110 A

Fig. 2. The specimens with every current variation.

III. RESULTS AND DISCUSSIONS

The specimens following the tensile test are shown in **Fig. 3**. From the figure, it can be seen that each specimen broke off at a different location. Meanwhile, the mechanical properties of the weld metal specimens are listed in **Error! Reference source not found.**.

(a) Specimen SP-1/2/3/4 (90A/13.3V) with heat input of 1.84 kJ/mm

(b) Specimen SP-1/2/3/4 (100A/14.6V) with heat input of 1.86 kJ/mm

(c) Specimen SP-1/2/3/4 (110A/15.5V) with heat Input of 2.11 kJ/mm

Fig. 3. The specimen's breaking condition following the tensile test.

TABLE 2. MECHANICAL PROPERTIES OF THE WELD METAL.

Specimen Number	**Heat Input (kJ/mm)**	**Hardness (HV)**	**Tensile (Kgf/mm^2)**
Sp-1(90A/13.3V)	1.82	369.8	85.2
Sp-2(90A/13.3V)	1.90	364.6	84.6
Sp-3(90A/13.3V)	1.83	360.2	80.1
Sp-4(90A/13.3V)	1.80	387.4	88.8

Average	1.84	370.5	84.7
Sp-1(100A/14.6V)	1.78	383.0	93.8
Sp-2(100A/14.6V)	1.84	369.6	80.3
Sp-3(100A/14.6V)	1.99	412.0	60.7
Sp-4(100A/14.6V)	1.84	375.0	81.5
Average	1.86	384.9	79.0
Sp-1(110A/15.5V)	1.95	387.8	84.7
Sp-2(110A/15.5V)	2.17	424.7	98.1
Sp-3(110A/15.5V)	2.18	391.7	97.9
Sp-4(110A/15.5V)	2.16	355.1	82.8
Average	2.11	389.8	90.9

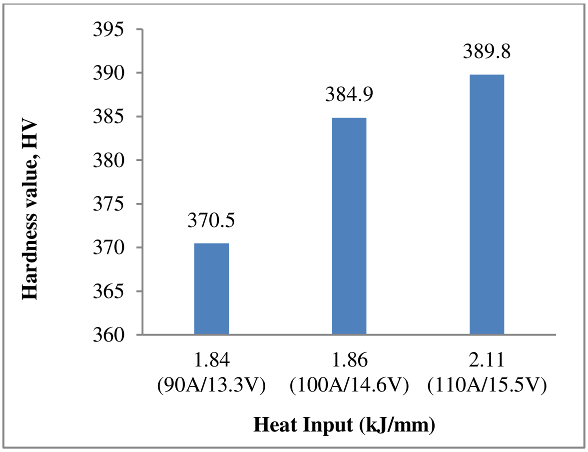

Fig. 4. The effect of heat input on the hardness value of weld metal.

Fig. 4 indicates that increasing the welding heat input causes an increase in weld metal hardness. The maximum hardness measured was 389.8 HV with a heat input, current, and voltage of 2.11 kJ/mm, 110 A, and 14.6 Volt, respectively. Meanwhile, the lowest hardness was 370.5 HV at heat input, current, and voltage of 1.84 kJ/mm, 90A, and 13.3 Volt, respectively. When compared to the hardness of the filler material prior to welding, 202 HV, there is a very considerable increase in hardness due to the welding process effect. This is the property of the filler metal, which cools quickly after welding and creates a martensitic phase with a hard and brittle properties. It is a fact that the hardness of the weld metal will increase dramatically if heat treatment is not performed before and after welding. Fig. 5 depicts the proportion of weld metal hardness increase after welding based on heat input.

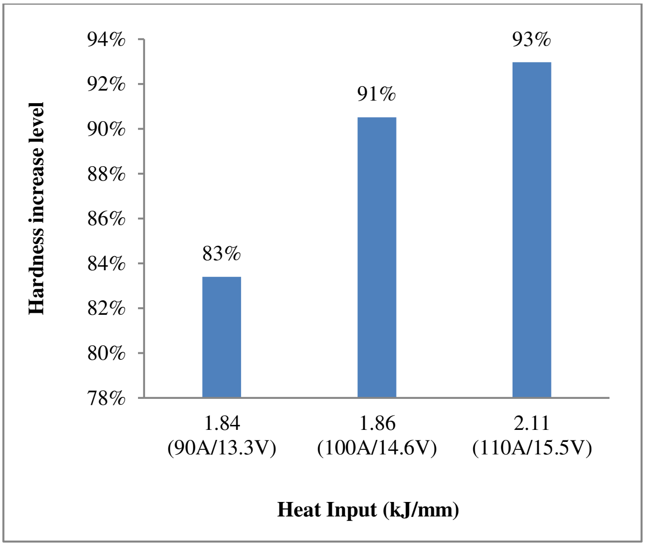

Fig. 5. The increase level of the weld metal hardness in percentage.

From the data in tabulated **Error! Reference source not found.** above, it can be explained that the welding heat input affects the tensile strength of the weld metal as shown in **Fig. 6**.

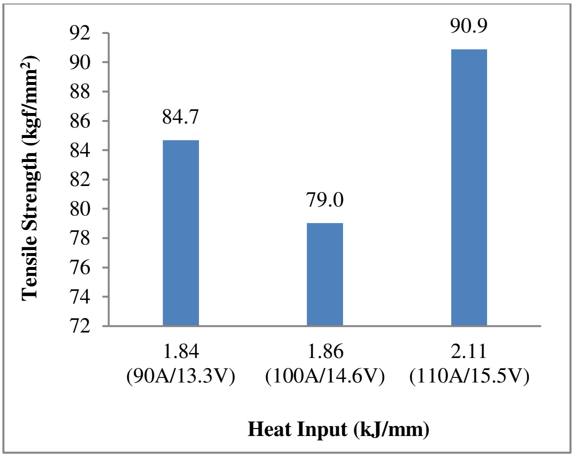

Fig. 6. Tensile strength of the weld metal.

According to **Fig. 6**, the highest tensile strength is 90.9 kgf/mm^2 for a heat input, current, and voltage of 2.11 kJ/mm, 110 A, and 15.5 Volt, respectively, while the lowest tensile strength is 84.7 kgf/mm^2 for a heat input, current, and voltage of 1.84 kJ/mm, 100 A, and 14.6 Volt, respectively. In general, increasing the heat input increases the tensile strength of the weld metal. Because the raw material data indicates that the filler material ER401H has a minimum strength of 54 kgf/mm^2 before welding, the welding effect results in a significant increase in tensile strength. This is due to the filler material's tendency to generate a hard martensite phase, which boosts the weld metal's tensile strength. **Fig. 7** depicts the growing amount of tensile strength after welding effect dependent on heat input.

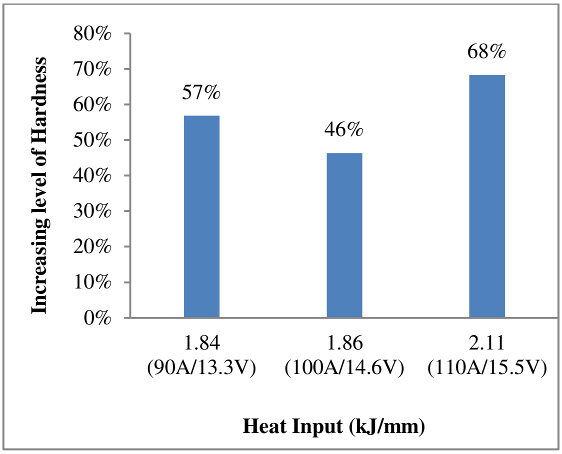

Fig. 7. The effect of heat input on the increase level of tensile strength of ER4110H.

IV. CONCLUSIONS

According to the research conducted, the heat input affects the hardness and tensile strength of ER410H weld metal. For three different variations of heat input, namely 1.84, 1.86, and 2.11 kJ/mm^2, the hardness of the weld metal is 370.5, 384.9, and 389.8 HV, respectively, and the tensile strength increases by 84.7, 79.0, and 90.9 kgf/mm^2.

When compared to the raw material data of ER410H filler material, there was a very considerable increase in hardness and tensile strength. The hardness increase ranges from 83% to 93%, while the tensile strength increases ranges from 46% to 68%. The increase in hardness and tensile strength of weld metal is caused by non-heat-treated welding.

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