In-service operating conditions affecting on weld HAZ hardness for API5L Gr.B pipe steel maintenance.

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Abstract. This study aims to investigate the influences of in-service welding conditions on maximum HAZ hardness, namely heat input, pipe wall thickness, and medium flow rate. The research consists of two parts; computationally thermal analysis and actual welding experiments. In conclusion, it suggested that increasing heat input resulted in decreasing maximum HAZ hardness, as well as, the range of run pipe thickness in the experiment was insignificantly influenced on HAZ hardness. Additionally, the higher flow rate induced more HAZ hardness with a certain flow rate level. HAZ hardness between the sleeve plate and the run pipe was insignificantly different. Nevertheless, it indicated that HAZ hardness prediction via computational analysis was more conservative than experiments.

1 Introduction

The In-service welding is widely accepted solution for pipeline repairing that can be applied onto pressurized pipeline and non-stopping natural gas transportation. Especially, when the system cannot be isolated or shut down. However, welding onto lived pipeline can cause Hydrogen Induced Cracking (HIC)[1-3] due to the flowing fluid within the system. In practice, avoiding hydrogen induced cracking is undertake through reducing HAZ hardness. However, there is unclear main effect of individual welding conditions on HAZ hardness. The limited welding parameters are capable to select to meet the desire conditions.

As relevant studies [3-9] have reported involving thermal analysis models and welding procedure qualifications. Fischer[3] developed a calculation method using finite difference to determine the heat transfer coefficient in In-service welding this model can use to calibrate the medium conditions which are used during welding. Nolan[4] developed two hardness prediction models for using to select welding parameters to achieve a satisfied hardness level to avoid the risk of cracking in In-service welding. One of factors is considered as an indicator to evaluate the susceptibility of Hydrogen Induce Cracking is HAZ hardness[1]. Bailey[5] investigated HAZ cracking by the use of SMAW wires with different hydrogen level. The result showed that the cracking did not occur when the critical hardness was not more than 350 HVN. Gravell[6] advices 350 is a conservative hardness limit for using to asses HIC in In-service welding. Cassie[7] studied the effect of material composition on weld hardness In-service welding with CE varied from 0.25 to 0.48. Cassie found that the material composition is directly related to weld hardness. Weld hardness raised with increasing carbon equivalent. DeHertogh[8] conducted welding with artificial flow to study effect of preheat temperature on hardness by simulating four different preheat levels and found that the size of HAZ decreased as decreasing preheat temperature. However, these studies are unclear regarding the effects of in-service welding conditions, especially in API5L Gr.B pipe steel applications.

Therefore, in order to find out properly welding procedures based on severely in-service operating conditions, this research is aimed to investigate the influence of three (3) welding parameters on the maximum HAZ hardness on API 5L GR. B pipe steel, namely welding heat input, run pipe thickness, and medium flow rate. These operating conditions needs to appropriate parameters for in-service piping welding in the future.

2 Experimental Procedure

In this study, operating conditions during in-service pipeline welding were investigated in order to determine maximum HAZ hardness. There are three (3) factors were studied, namely welding heat input, run pipe thickness, and medium flow rate.

2.1 Tested Materials

Pipe steel API5L Gr.B standard was used as tested material. Pipe size of 219.8 mm in diameter and 8.18 mm thick was employed. Chemical compositions of tested material was examined with optical emission

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spectrometer (OES) as shown in Table 1. Carbon equivalent (CE_{IIW}) was calculated as 0.37.

Table 1. Chemical compositions of tested materials (wt%)

C	Mn	Cu	Ni	Cr	Mo	V
0.134	0.969	0.181	0.099	0.223	0.049	0.003

Note. $CE_{IIW} = C + Mn/6 + (Cu+Ni)/15 + (Cr+Mo+V)/5$

GTAW process was performed with a filler metal of ER70S-G according to AWS A5.18 standard, as well as, EWTH-2 ttungsten electrode of 2.4 mm in diameter. Argon shielding gas of 99.9% was used as flow rate of 15 L/min. DCEN current polarity was given.

2.2 Methods

This work was divided into two parts. Firstly, computational simulation, commercial PRCI program (Thermal analysis model for hot tap welding V4.2) was applied. In-service operating conditions during GTAW were considered for calculation, namely welding heat input, chemical compositions of tested material, run pipe thickness, and amount of medium flow rate. Such thermal analysis program was beneficial to estimate maximum HAZ hardness value depending on in-service operating conditions. PRCI program computed thermally based on finite element method (FEM) and HAZ hardness prediction by means of Yurioka's Model[9]. Schematic of PRCI-Thermal analysis during welding is illustrated as Fig.1. Utilized parameters for simulations and experiments were given as Table 2 respectively.

Secondly, actual experiments were carried out as in-service operating conditions which were suggested through PRCI thermal analysis. The experimental set up as shown in Figure 2 was accomplished according to API 1104 Annex B. This means that a sleeve plate is attached to a main run pipe to form a fillet weld lap joint. The welding was performed with GTAW(KEPPI MasterTIG) in 5G uphill position. In this experiment, water was circulated instead of methane as the medium for safety reason. The water flow rate during welding was calculated in order to obtain the convective heat transfer be equivalent to in-service natural gas (Methane) pipelines[10]. Water flow rate were measured and monitored with ultrasonic flow meter (LONGRUN LRF-200 series). In order to regulate the certain experiment conditions, at both inlet and outlet of the main run pipe, temperature gauges were installed for monitoring difference between the outlet and the inlet. And also a pressure gauge was set to measure inline pressure during welding.

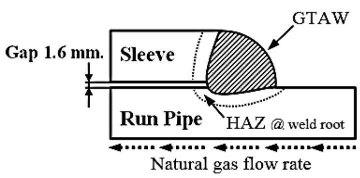
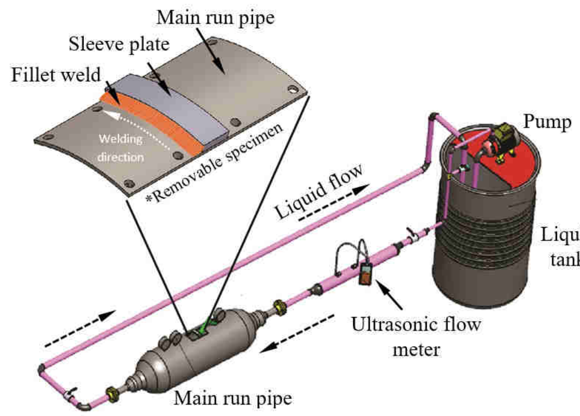


Fig. 1. Schematic of PRCI-Thermal analysis during welding

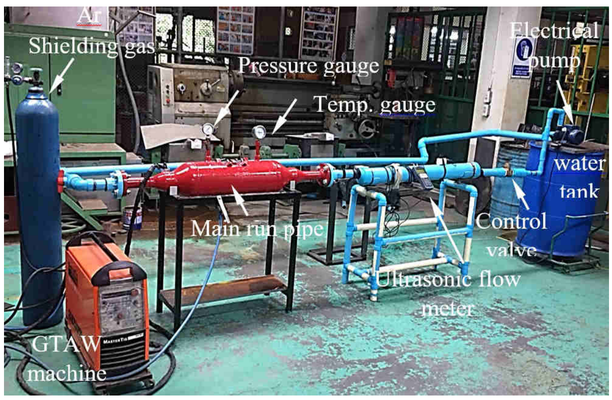
Table 2. Utilized parameters for experiments

Case	Heat Input (HI) kJ/mm (kJ/inch)	Pipe Thickness (mm)	PRCI (Methane) Flow rate (mmscfd)	Experiment (Water) Flow rate (m^3/hr.)
A	1.2(30)	8	42	19.1
B	2.0(50)	8	42	19.1
C	2.8(70)	8	42	19.1
D	2.8(70)	4	37	16.9
E	2.8(70)	6	37	16.9
F	2.8(70)	8	37	16.9
G	2.8(70)	8	0	0
H	2.8(70)	8	44	19.7

Note. mmscfd: Million standard cubic feet per day



(a) Schematic of in-service pipeline welding



(b) Experimental setup of in-service pipeline welding

Fig. 2. Experimental Set Up

Generally, the weld root has the potential for hydrogen induced cracking because of the stress concentration due to the gap between sleeve and pipe. Then, each welded specimen was cut into 3 test pieces. Later on, those test pieces were grinded, polished and etched with 2% Nital acid. Optical microscopic (Leica DM-2500M) was used so as to examine a sound weld. In addition, maximum hardness in the HAZ area of coarse-grained region at the root weld pass was averagely measured with micro-vickers hardness tester (Matsuzawa MMT-X3). Measuring procedure was operated in accordance with ASTM E384-11 as shown in Fig 3. That is measuring point interval was given as 0.2 mm from a fusion line, an indent spacing of 0.5 mm with applied load of 500 gram, as well as hold time of 10 seconds. The hardness value for evaluation was obtained from average maximum hardness of 3 specimens.

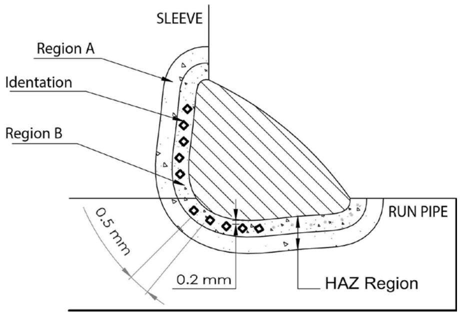


Figure 3. HAZ Hardness Measuring Procedure

3 Results and discussion

3.1 Effect of welding heat input

As completed welding experiments, Figure 3 shows the cross sectional area of the welded specimen in different heat inputs. The weld profile of entire specimens welded with GTAW were concave shape. The HAZ dimension in the pipe was wider than in the sleeve. As the results, heat input of 1.2, 2.0, and 2.8 kJ/mm revealed that the depth of penetration was not different, but the HAZ of the run pipe was wider than the sleeve. On the top of that as shown in Fig. 4, the PRCI result indicated that reducing maximum HAZ hardness at the weld root was influenced with increasing heat input. Similarly to the hardness of run pipe, HAZ hardness reduce significantly after increasing heat input. On the other hand, the hardness of sleeve did not change although heat input increased.

3.2 Effect of run pipe thickness

In this case, the run pipe thickness of 4, 6, and 8 mm was studied. Figure 5 shows the weld cross sections of different run pipe thickness. From the results, PRCI calculations exhibited that maximum HAZ hardness was almost unchanged when increasing the pipe thickness. In addition to PRCI calculations, experimental results were slightly difference and not agree to computational prediction as presented in Figure 6.Comparing HAZ hardness between run pipe and sleeve, the HAZ hardness of the run pipe and the sleeve of 4 and 6 mm were insignificantly difference. But the HAZ hardness is different when the run pipe thickness reach 8 mm. It may affect from the different gap between the run pipe and sleeve.

Welding Heat Input

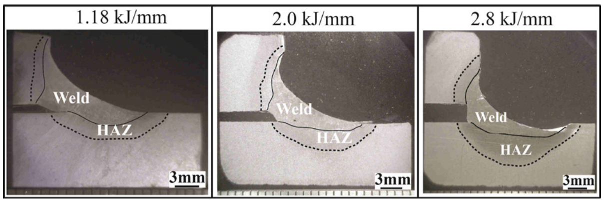


Fig. 3. The weld cross sections due to heat input
(the main pipe of 8 mm thick, flow rate of 42 mmscfd)

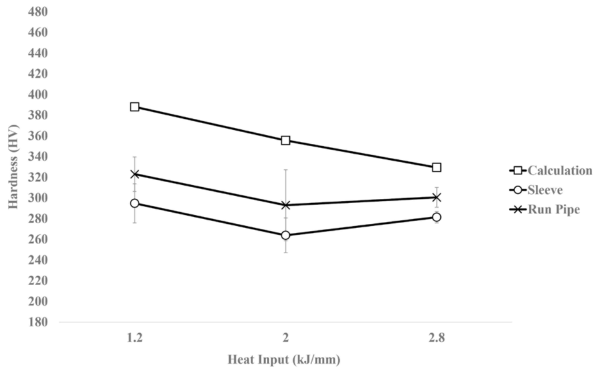


Fig. 4. Max. HAZ hardness and Heat Inputs
(the main pipe of 8 mm thick, flow rate of 42 mmscfd)

Run Pipe Thickness

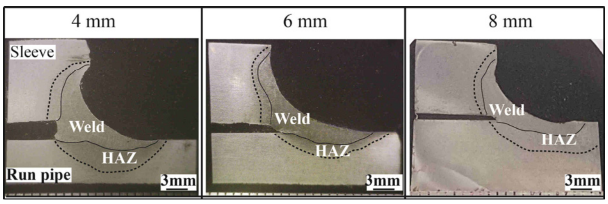


Fig. 5. The weld cross sections due to different pipe thickness
(heat input of 2.8 kJ/mm, flow rate of 37 mmscfd)

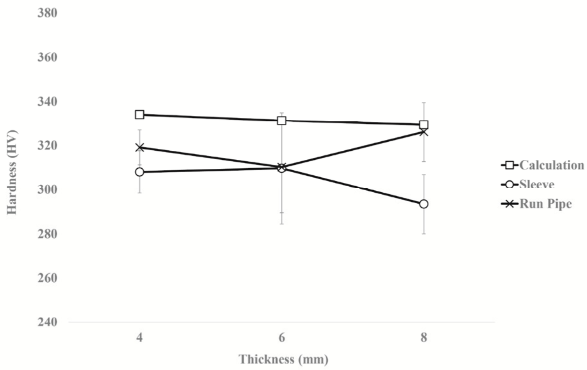


Fig. 6. Max. HAZ hardness and the run pipe thickness
(heat input of 2.8 kJ/mm, flow rate of 37 mmscfd)

3.3 Effect of medium flow rate

The influence of flow rates on maximum HAZ hardness is presented in Fig.7 and 8. Both the results of the experiments and the PRCI calculations indicated that when the flow rate increased from 0 to 37 mmscfd, maximum HAZ Hardness raised up accordingly. However, when the flow rate was at the range of flow rate between 37 and 44 mmscfd, the maximum HAZ hardness was constantly remained. This is mean that, increasing flow rate has a tendency to promote higher maximum HAZ hardness but there is reaching a certain level.

Volumetric Flow Rate

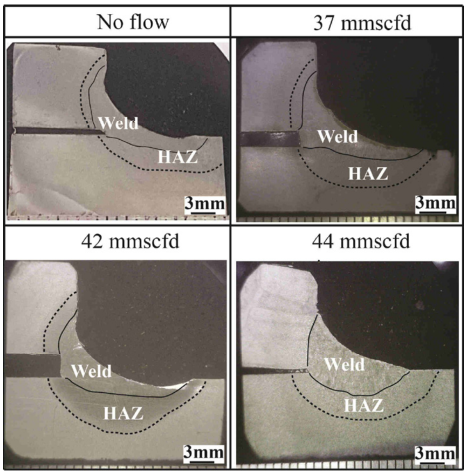


Fig. 7. The weld cross sections due to different flow rate (heat input of 2.76 kJ/mm, run pipe thickness of 8 mm)

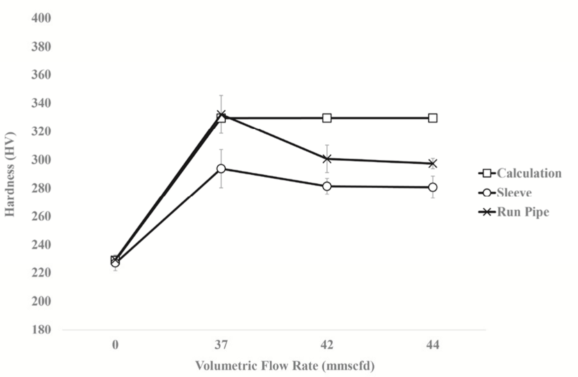


Fig. 8. Max. HAZ hardness and the medium flow rate (heat input of 2.76 kJ/mm, run pipe thickness of 8 mm)

5. Conclusions

This research investigated the influences of the in-service operating conditions on HAZ hardness, namely welding heat input, run pipe thickness, and medium flow rate. The results can be concluded that;

1) Welding heat input was significant effect on maximum HAZ hardness at the weld root. That is an increasing heat input resulting in decreasing maximum HAZ hardness.
2) In this case, HAZ hardness was insignificantly influenced on the range of run pipe thickness from 4 to 8 mm. This was suggested through PRCI calculations and the actual experiments.
3) As for medium flow rate, maximum HAZ hardness increased with rising up the flow rate. However, when increasing the flow rate to reach a certain level, the hardness was no longer changed significantly.
4) From the results, HAZ hardness prediction using PRCI thermal analysis was significantly higher than experiments indicating more conservative. Whilst HAZ hardness between the sleeve plate and the run pipe was slightly different.

Acknowledgments

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