Effect of Heat Input in Dissimilar Welding on SS304H and T22 to Hardness Distribution and Delta Ferrite Content with GTAW Process

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Abstract. In this paper, a study was carried out on the effect of various heat input on the hardness distribution and delta ferrite content in dissimilar welding on T22 and SS304H tube boilers in power plants using Gas Tungsten Arc Welding (GTAW). The heat input used in this study is 2.9 KJ / mm, 3.1 KJ / mm and 3.6 KJ / mm. Controlling the heat input parameter is one method to reduce problems in dissimilar welding. The general problem occurs in dissimilar welding is the failure on the weldment to occur due to differences in chemical composition, mechanical properties and thermal coefficients of the two materials where it makes degradation in the microstructure in the fusion zone and creating residual stress than susceptibility to fatigue in material or cracks. All variation of heat input in this study is safe to operate in the welding process and low tendency to hot cracking. Using the lowest variation of heat input 2.9 KJ/mm has the highest value of hardness distribution and lowest FN value.

1. Introduction
Welding joint which has two types of metal is generally used in power plants. Dissimilar metal welding is a method for connecting different metals, for example connecting stainless steel with a low alloy steel tube in the boiler. The different metal used because the tube in the boiler works at different temperatures and pressures. In the boiler parts with high temperatures made of austenite stainless steel which has excellent stainless steel properties at high temperatures and pressures, and in parts with lower temperatures using alloy steel due to the economic value of the material. In this study, the material used is SS304H and T22 alloy steel.

In DMW (Dissimilar Metal Welding), where differences in chemical composition between the two materials in the fusion line, differences in the microstructure make mechanical properties also different. That's all difference makes the welding joint susceptible to failure. Further difference in the thermal coefficient of each material also makes degradation in the microstructure in the fusion zone, thus creating the residual stress and fatigue in material or crack. [5] [6] [7].
Step to reduce all problems in DMW is predicted the chemical composition of weld metal, buttering the base metal which has a different thermal coefficient, controlling the heat input, and reducing the residual stress on the welding by heat treatment. [9] [10]

A lot of case dissimilar welding in tube boiler is concern welding procedure must be specified for reduce the failure. In this study variation of heat input will observe to obtain effect of hardness distribution and FN value.

2. Research Method.
Study literature and observations used to find information related to the problem to be examined. Thermo ARL Spectrometer used for the tested chemical composition to determine the chemical composition contained in the material to be welded. The results of chemical composition will be used to determine the welding procedures specification with study literature. The chemical composition of the material and its mechanical properties are shown in table 1.

Macroscopic observations using the professional camera were carried out in welded specimens with variations of heat input. The material was cut using a saw shown in figure 3. This observation obtains the information condition of the welding joint in a macro. Then for metallographic testing and micro-hardness provided grinding, polishing, and etching [5]. Metallographic testing is carried out to determine the micro conditions in the material.

Hardness test using Micro Vickers Hardness method with a load of 0.5 kgf [5] [14] carried out to determine the value of the hardness of the weld area SS304H and T22 in base metal, HAZ each material, and weld metal. Figure 2 shown position testing is on root weld, layer I, and layer II.

Delta ferrite content using a ferrite-scope which results is in ferrite number value (FN). FN value used to determine material in safe limits corrosion resistance and avoidance of hot crack.

![Figure 1. Groove](image)

Table 1. Chemical Composition of Material

| Percentage of Chemical Composition | C   | Cr  | Ni  | Mn  | Si  | P    | Mo  |
|-----------------------------------|-----|-----|-----|-----|-----|------|-----|
| SS304H                            | 0.0067 | 18.38 | 7.62 | 1.14 | 0.41 | 0.02 | 0.45 |
| T22                               | 0.110 | 2.02 | 0.04 | 0.43 | 0.202 | 0.005 | 0.899 |
| ER309                             | 0.15 | 22-25 | 12-14 | 0.5-2.5 | 0.04 | 0.03 | 0.75 |
Table 2. Welding Procedure Specification

| Base Metal Specification |
|--------------------------|
| Base Metal 1             | T22          |
| Base Metal 2             | SS304H       |
| Length                   | 150 mm       |
| Diameter                 | 63.5 mm      |
| Thickness                | 5 mm         |

| Joint Design             |
|--------------------------|
| Welding Joint            | Butt Joint   |
| Groove Angle             | 60°          |
| Length                   | 150 mm       |
| Total Pass               | Multiple Pass|

| Filler Metal             |
|--------------------------|
| AWS NO                   | ER309        |
| Diameter                 | 2.4 mm       |

| Welding Characteristic   |
|--------------------------|
| Position                 | 1G/2G        |
| Polarity                 | DCEN         |
| Current                  | 70A;90A;110A |
| Voltage                  | 10V          |
| Welding Speed            | 54 mm/min    |

| Treatment                |
|--------------------------|
| Preheat                  | NA           |
| PWHT                     | NA           |

Figure 2. Spot Location Hardness Test
3. Result and Discussion

3.1. Welding Data

### Table 3. Weld Metal Dimension

|               | 70A  | 90A  | 110A |
|---------------|------|------|------|
| $\eta$       | 3.14 |      |      |
| d (mm)       |      | 63.5 |      |
| Circumference (mm) |      | 199.39 |      |
| t (second)   |      | 1478 | 1008 |
| w (mm)       | 5    |      |      |
| Efficiency GTAW |      | 0.7  |      |

### Table 4. Welding Speed and Heat Input

| E (Volt) | I (Ampere) | P (Watt) | V (mm/s) | Heat Input (KJ/mm) |
|----------|------------|----------|----------|--------------------|
| 10       | 70         | 700      | 0.1349   | 3.6                |
| 10       | 90         | 900      | 0.1978   | 3.1                |
| 10       | 110        | 1100     | 0.2620   | 2.9                |

### Table 5. Weld Metal Dilution

| Heat Input  | T22 | SS304H |
|-------------|-----|--------|
| 3.6 KJ/mm   | 25  | 30     |
| 3.1 KJ/mm   | 30  | 40     |
| 2.9 KJ/mm   | 35  | 50     |

The welding parameter in data table 3 used to obtained data in table 4. Heat input is inversely proportional to a large current. Table 5 shows the dilution is inversely proportional to the heat input.
because when using low heat input will obtain a high ampere. It causes an increase in the dilution because the bow is stiffer and hotter [5].

3.2. Microstructure Examination

![Figure 4. Macro Photography](image)

Figure 4 shown macro observations welding filling pattern of weld metal and base metal.
Figure 5. Microstructure of weld metal welds by GTAW WM, FL and HAZ regions SS304H and T22 magnification 100x; (a) (b) 3.6 J / mm; (c) (d) 3.1 J / mm; (e) (f) 2.9 J / mm (etching kalling’s reagent [4] [16])

Figure 5 shown the microstructure of weld metal, fusion line, and HAZ for SS304H and T22. As we know, to determine the difference of microstructure in this study using the basic theory of metallurgy which material SS304 is austenitic stainless steel has microstructure grains austenite and T22 is carbon steel so the microstructure is base on ferrite and pearlite. Weld metal has structure micro like cast iron because the peak temperature achieved in the weld metal reached the melting point material.

Figure 6. Base Metal 500X (a) SS304H (b) T22
Figure 6 shown the microstructure of base metal unaffected by heating in the welding process. Figure 6b microstructure of T22 consists of perlite and ferrite. Figure 6a shows the SS304H base metal structure consisting of grains austenite.

Figure 7. Microstructure Carbide Precipitate 500x Magnification (a) 3.6 J/mm; (b) 3.1 J/mm; (c) 2.9 J/mm (etching electrolysis) [16].

Figure 7 shown HAZ in material SS304H found carbide precipitate in area distance from the fusion limit. The width of the precipitation area is 3.6 J/mm wider than the precipitation area at a heat input of 2.9 J/mm.

Figure 8 shown the transition microstructure after cooling in the T22 weld metal. The transition before the base metal is coarse grains and fine grains in base metal [2] [3]. Coarse grain width formed on a heat input 3.6 J/mm wider than coarse grain at heat input 2.9 J/mm. Figure 8d seen base metal and HAZ transitions on SS304H. The difference in austenite large grain which after cooling HAZ area grains becomes larger than the base metal.
Figure 8. Microstructure HAZ T22 500X Magnification (3.6 KJ / mm; (b) 3.1 KJ / mm; (c) 2.9 KJ / mm (etching kalling reagent); (d) HAZ SS304H 500X (electrolysis etching [4] [16])

3.3. Hardness Testing

Figure 9. Distribution of Hardness 3.6 KJ / mm
Figures 9, 10, and 11 show the distribution hardness in variation heat input 3.6 KJ/mm, 3.1 KJ/mm, and 2.9 KJ/mm. HAZ in SS304H is fluctuating because of the hardness value affected by precipitation carbides. The hardness value in T22 is slightly higher than the base metal because affected by heat input and cooling time. Hardness value with heat input is 3.6 KJ/mm lower than the hardness value at the heat input 2.9 KJ/mm. It confirms with theory multi-layer welding where hardness value due to post heat pre-heat causes differences hardness distribution. In layer I the hardness value is lower than layer II and root because in during welding in layer I occur post pre-heat [1]

### 3.4. Delta Ferrite Content

| No | 3.6 KJ/mm | 3.1 KJ/mm | 2.9KJ/mm |
|----|-----------|-----------|----------|
| 1  | 6.2       | 5.2       | 3.1      |
| 2  | 7.2       | 5.7       | 3.2      |
| 3  | 6.3       | 5.3       | 3.2      |
| Average | 6.5   | 5.4       | 3.1      |
Figure 6 shows the results of the FN test on the weld metal. The heat input of 3.6 KJ/mm value of FN content is 6.2 - 7.2. The heat input of 3.1 KJ/mm value of FN content is 2 - 5.7. Heat input 2.9 KJ/mm value of FN content is 3.1 - 3.2. The higher heat input the FN value also rises. A lower ferrite value, means better the corrosion resistance of stainless steel [6]. ER309 filler specifications, the value of FN is resistant to hot cracks and does not reduce resistance to material corrosion. After testing with ferrite-scope method, the presence δ-ferrite in weld metal with heat inputs of 3.6 KJ/mm, 3.1 KJ/mm and 2.9 KJ/mm is safe in limitation standard, where test specimens not a tendency to hot cracks. The best corrosion resistance based on FN values is found in materials with 2.9 KJ/mm heat input followed by 3.1 KJ/mm and 2.9 KJ/mm.

4. Conclusion
1. The highest hardness value is in layers II and root, because of the multilayer welding effect. Layer I applied post heat and pre-heat at the same time while the root and layer II on the welding process.
2. The highest hardness value is 310 HVN on HAZ SS304H in 2.9KJ/mm heat input. Chromium carbide precipitation rise the hardness value. Higher heat input will decrease hardness value because the material is due to the slower cooling.
3. Heat input of 3.9 KJ / mm has the lowest FN value with an average of 3.1 FN. The value of FN is directly proportional to the heat input. Based on the literature that weld metal which is resistant to hot cracks and without reducing corrosion resistance maximum value is 8 FN. Stated in the δ-ferrite content in the weld metal, this method is a safe and low tendency to hot crack. Stated in the δ-ferrite content in weld metal, this method is safe and low tendency to hot crack.

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Reference
[1] William D, Callister, Fundamental of Materials Science and Engineering. John Wiley and Sons, 2001
[2] Ceepls, Kay, Metallography and materialographic specimen preparation, light microscopy image analysis and hardness testing, ASTM International 2012
[3] Jeffus, Larry, Welding Principles and Application, Delmar Cengage Learning, USA, 2012

[4] Guohong Chem, Qi Zhang, Junjian Liu, Jiaqing Wang, Xinhai Yu, Jian Hua, et al, 2012 ‘Microstructure and mechanical properties of T92/Super 304H dissimilar steel weld joints after high-temperature ageing’, School of Materials Science and Engineering Hafei University of Technology, Hefei 230009, China.

[5] Dinesh W. Rathod, Sunil Pandley, PK. Singh, Rajesh Prasad, 2015 ‘Experimental Analysis of Dissimilar Metal Weld Joint: Ferritic to Austenitic Stainless Steel’, Department of Mechanical Engineering, Indian Institute of Technology Delhi, New Delho 110016, India

[6] Vukić Lazića, Dušan Arsića, Ružica R. Nikolića, Dragan Rakíc, 2016 ‘Selection and analysis of material for boiler ipes in a steam plant’, Faculty of Engineering University of Kragujevac., Sestre Janjić 6, 34000 Kragujevac, Serbia

[7] Sukhdeep Singh, Kjell Hurtig, Joel Anderson, 2018 ‘Investigation on effect of welding parameters on solidification cracking of austenitic stainless steel 314’, Department of Industrial and Material Science, Chalmers University of Technology, Gothenburg SE-41296, Sweden

[8] Wei Wang, Xue Wang, Wanli Zhong, 2014 ‘Failure analysis of dissimilar steel welded joints in a 303t/h USC’, Electric Power Research Institute of Guangdong Power Grid Corporation, Guangzhou 510080, China

[9] Dilip Kumar Singh, Vikram Sharma, Ritwik Basu, Mostafa Eskandari, 2019 ‘Understanding the effect of weld parameters on the microstructures and mechanical properties in dissimilar steels weld’, Department of Mechanical and Manufacturing Engineering, MIT, Manipal Academy of Higher Education (MAHE), Manipal-576104, India

[10] Wichan Chuaiphan, LoeshpahnSrijaroenpramong, 2020 ‘Evaluation of microstructure, mechanical properties, and pitting corrosion in dissimilar of alternative low cost stainless steel grade 204Cu and 304 by GTA welding joint’, Department of Mechanical and Industrial Engineering, Rajamangala University of Technology Krungthep, 2 Nanglinchee Road, Tungmahamek, Sathorn, Bangkok, 10120, Thailand