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X-RAY RADIOGRAPHIC ANALYSIS OF AISI 304 STEEL STEEL JOINTS RESULTS ON TUNGSTEN INERT GAS WELDING WITH CURRENT 40 – 60 AMPERES

Engineering

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ABSTRACT

X-Ray Radiographic Analysis of Aisi 304 Stainless Steel Plate Joints From Inert Gas Tungsten Welding Results with 40 – 60 Ampere Current. Metal welding process is one of the main processes in machine construction. The quality of welded joints determines the strength and toughness of a machine construction. The quality of welded joints of installed construction can be determined by the non-destructive test method using X-ray radiography equipment. This study aims to obtain a butt joint obtained from TIG welding of AISI 304 stainless steel plate with a current of 40 - 60 A, identification of defects in the 1G butt joint, and analysis of the quality of the weld joint. The research method used is testing of welded joints using X-ray radiography which refers to the ASME V article II standard and the connection quality refers to ASME section IX. The results showed that TIG welding with a current of 60 Ampere produced a butt joint butt joint that was penetrated and there was no gap between the plates, whereas with a current of 40 A and 50 A the weld joint was not see-through but there was still a gap between the plates. Incomplete penetration weld defects were found in the welded SS 304 plate joints with a current of 40 A. Welded porosity defects were found in the welded SS 304 plate joints with a current of 50 A. Weld defects were not found in the SS 304 plate joints with a current of 60 A. Butt joint connections TIG welded SS 304 plate with the best current of 60 A compared to the current of 40 A and 50 A.

KEYWORDS

X-ray radiography, SS 304, TIG, butt joint, weld defects.

Preliminary

In the industrial era 4.0 in the construction sector, it is marked by the use of information technology in every aspect of work, including in the machinery construction sector, making it imperative for construction human resources to adapt. The three main players in the 4.0 construction industry, namely technology providers, digital infrastructure providers, and users of industry 4.0 technology and infrastructure, with their respective responsibilities and authorities. The application of information technology (internet) from planning, design, implementation, maintenance, to rebuilding is a system that is included in the construction industry 4.0, it is expected to create project management that is cost effective, timely and quality appropriate [1]. In connection with the development of the era, mastery of metal joining technology with welding techniques in the field of machine construction must be mastered properly.

Welding is the process of joining metals into a single unit due to heat with or without the influence of pressure or which produces metallurgical bonds caused by attractive forces between atoms. Welding is the joining of two or more metal parts, either similar or dissimilar by heating to the melting temperature using a filler or without a filler [2]. Welding techniques are widely used in the construction sector, including shipping, bridges, steel frames, pressure vessels, pipelines, vehicles, rails, and so on. Technically, to produce welded joints with good quality, additional materials (filler metal) are needed so that the weld metal deposit is formed properly. Welding electrodes (welding rods) on the market consist of many different sizes, types, and brands. Selection of the appropriate electrode can improve the results of welding with good quality[2,3]. The suitability between the properties of the weld in the welding process, namely the strength of the welded joint, must be considered so that the results of the welding are as expected. The type of electrode is selected according to the type of parent metal material. In addition, the voltage, current and speed when doing welding are also very influential on the results of the weld [4]. In this regard, the welding design and welding method must pay attention to the suitability between the properties of the weld and the use of the construction and environmental conditions.

Stainless steel is one of the materials that is widely used in industry, such as pressure vessels, radioactive waste containers and other manufacturing industries. Stainless steel has advantages over other metals including good corrosion resistance and good weldability, thus providing easy welding to produce good quality welded metal joints [2].

Stainless steel can be welded by electric welding, which is often used in Indonesia today is Gas Tungsten Arc Welding (GTAW) or better known as Tungsten Inert Gas (TIG). Heat input in TIG welding is one of the important factors to produce a good welded joint. The heat input can be controlled by adjusting the current, voltage, and welding speed. In addition to heat input, the type of electrode used in welding also affects stainless steel welding results [2].

Ardiyansah (2017) conducted research on the analysis of weld defects in butt joint welding with variations in welding current and position. At 80 A, there are 2 (two) types of welding defects, namely incomplete fusion and slag. In the 100 A current there are 2 (two) types of welding defects, namely slag and incomplete fusion, while at the 120 A current there is 1 (one) type of welding defect, namely cracks. In this study, three (3) types of welding defects were found, namely incomplete fusion, crack and slag [5].

Endramawan (2017) conducted a study on the application of Non Destructive Test Penetrant Testing (NDT-PT) for the analysis of 3G butt joint Shielded Metal Arc Welding (SMAW) welding results. Endramawan got some porosity in metal welded joints but still within the accepted criteria [6].

Setiawan and Imran (2019) conducted research on welding defects in SMAW butt joint welding with current variations of 70 A, 90 A and 110 A. They found that the butt joint from the penetrant test results revealed that there were welding defects in the form of spatter, lack of fuss, undercut and cluster porosity, while the results of the ultrasonic test revealed that there were weld defects, namely cracks and lack of fusion. At a current of 70 A, a weld with many weld defects was produced, while a current of 90 A and 110 A produced a good weld at a welding position of 1G with a steel plate thickness of 6 mm [7].

Cahya and Ichwan (2013) conducted research on welded joints on SS 316 material with TIG and MIG welding methods and the thickness of the test object is 2-3 mm. They found that the welded joints obtained by the MIG method had better hardness, tensile strength and impact strength values than the TIG method [8].

Metal welded joints have an important function in a construction because the connection will receive the same load if the workpiece being assembled receives an external load. Because the size is smaller than the workpiece, the external stress it receives will be concentrated in the weld joint, so that if it gets a large load, it is likely that the first fracture will occur in the welded joint. Welding defects will affect the strength of welded joints of a steel construction, Welded joints must not have weld defects exceeding the acceptance criteria required by the American Welding Society (AWS). The research carried out in this final project has the aim of obtaining a welded connection of the AISI 304 stainless steel plate butt joint. 2. Identification of defects in the 1G butt joint connection of AISI 304 stainless steel plate. 3. Quality analysis of the 1G butt joint connection of AISI 304 stainless steel plate. The methods used in this study are:

1. The butt joint welded on the AISI 304 stainless steel plate is carried out by the TIG welding method.
2. Testing of welded joints on AISI 304 stainless steel plates using X-ray radiography equipment.
3. Analysis of weld defects using standard ASME section V article II and ASME Section IX.

Literature Review

Stainless Steel

Stainless steel or better known as stainless steel is an alloy of iron (Fe), carbon (C) and about 10% chromium (Cr) as the main alloying element. The presence of Cr is intended to prevent metal corrosion processes. The ability to resist rust is obtained from the formation of a chromium oxide layer which blocks the oxidation process of iron on the surface of stainless steel. There are many types of stainless steel on the market, such as SS 201, SS 304, SS 316, SS 316 L and others, where the higher the series, the better the stainless steel and corrosion resistance. Stainless steel is very easy to care for unlike steel which has to be painted or chromed[4]. Stainless steel only needs to be wiped down to restore its like-new luster. But if there is a scratch on the stainless steel, it needs to be polished so that it returns to its original shine.

The classification of stainless steels is based on the chromium (Cr) content, but other alloying elements are added to improve the behavior of stainless steels according to the application. The classification of stainless steels is based on their metallurgical structure, namely Austenitic, Ferritic, Martensitic, Duplex, and Precipitation Hardening stainless steels.[4]

Austenitic Stainless Steel

Austenitic stainless steels contain a minimum of 16% by weight of chromium and 6% by weight of nickel (standard grade for 304), up to super austenitic stainless steel grades such as 904L (with higher levels of hhrom and nickel and additional elements Mo up to 6% by weight). Molybdenum (Mo), Titanium (Ti) or Copper (Co) serves to increase resistance to temperature and corrosion. Austenitic stainless steels are suitable for low temperature applications because the element Ni makes stainless steels less brittle at low temperatures. Austenitic stainless steel is widely used as raw material for computer floppy disk lighting, computer keyboard lock springs, kitchen sinks, food processing equipment, architectural applications, chemical equipment, and others.[4]

The basic properties of austenitic stainless steels are

A. Excellent Corrosion Resistance In Organic Acid, Industrial And Marine Environments.
B. Excellent Welding Ability.
C. Excellent Formability, Buildability And Ductility.
D. The Properties At High Temperatures Are Good And At Low Temperatures Very Good.
E. Does Not Contain Magnets When Stainless Steel Is Strengthened.
F. It Can Be Hardened Only By Forming A Metal Profile At Cold Temperatures.

Ferritic Stainless Steel.

Ferritic stainless steels generally contain 10.5 – 18% by weight of chromium such as grades 430 and 409. Ferritic stainless steels are slightly less resilient than austenitic stainless steels. Its corrosion resistance is not very good and it is relatively more difficult to fabricate. However, the shortcomings of ferritic stainless steels have been corrected at grades 434 and 444 and in particular at grade 3Cr12. Ferritic stainless steel is used as a raw material for the centerpiece of computer floppy disks, automotive trim, automotive steam exhaust, hot water tanks, and others.

The basic properties of ferritic stainless steels are[4]:

A. Sufficient For Good Corrosion Resistance Enhancement With Chromium Content
B. It Cannot Be Hardened By Heat Treatment And Is Always Used In Reinforced Magnets.
C. Weldability Is Low.
D. Its Shaping Ability Is Not As Good As Austenitic.

Martensitic Stainless Steel

Martensitic stainless steels have a main element of chromium (lower than ferritic stainless steels) and a relatively high carbon content (0.1 – 1.2%), eg grades 410 and 416. Grade 431 stainless steels have chromium up to 16% by weight. but the microstructure is still martensitic because the Ni content is only 2%. Ferritic stainless steel is used as a material for cutlery, blades, surgical instruments, rods, coils, safety pins, etc.

The basic properties of martensitic stainless steel are[4]:

A. Medium Corrosion Resistance.
B. It Can Be Hardened By Heat Treatment And Hence The Degree Of Hardness.
C. Weldability Is Less.
D. Magnetic.

Characteristics of AISI 304 . Stainless Steel

AISI 304 stainless steel is one type of austenitic stainless steel with the main alloying element content consisting of 0.08% carbon, 18% Cr and 8% Ni. There are several types of 304 stainless steel, namely 304 (S30400), 304L (S30403), and 304H (S30409). AISI 304 stainless steel is very susceptible to Stress Corrosion Cracking (SCC) in the presence of chloride ions as the destroyer of the passive layer, and high temperature corrosion, such as oxidation, carburizing, nitriding, sulphizing, and others. [5]

AISI 304 stainless steel is the most commonly used steel in the nuclear industry because of its high corrosion resistance, good formability, high temperature resistance and easily available materials in the market. Nuclear properties of austenitic stainless steels, such as the area of neutron absorption, absorption and fast or thermal scattering, are highly dependent on the composition of the combining elements. reactor coolant pipe because it is resistant to high pressure and temperature.[5]

Welding

Based on the definition of the Deutche Industrie Normen (DIN), welding is a metallurgical bond at a metal or alloy metal joint which is carried out in a melted or liquid state. This definition can also be interpreted further that welding is a local connection of several metals using heat energy. Welding is a way of joining two solid objects through melting and fusion using heat. Based on this terminology, 2 (two) decisive conditions apply in welding, namely: the materials to be joined must be able to melt by heat, the materials to be joined must be compatible with each other.[2]

Welding is a metal joining process in which metals become one due to heat with or without the influence of pressure. Welding is also defined as a metallurgical bond caused by attractive forces between atoms.[2]

Some of the advantages of using welded joints are as follows:

A. Welding Produces A Permanent Joint.
B. Welded Joints Can Be Stronger Than The Starting Material If The Filler Metal Is Used And Proper Welding Techniques Are Used.

Generally welding is the most economical joining process in terms of material use and fabrication costs Welding is not only limited to the environment. Based on the main heat input given to the base metal, the welding process can be divided into 2 (two) ways, namely[2] :

1. Welding using heat energy that comes from fusion (welding flame), for example: arc welding, gas welding, electron discharge welding, and others.
2. Welding using heat energy that does not come from a welding flame (non-fusion), for example: friction stir welding (welding process with friction), forging welding, and others

RESEARCH METHODOLOGY

Research Flowchart

The stages in the research on X-ray radiographic analysis of the connection of AISI 304 stainless steel plates are shown in Figure 1 as follows:

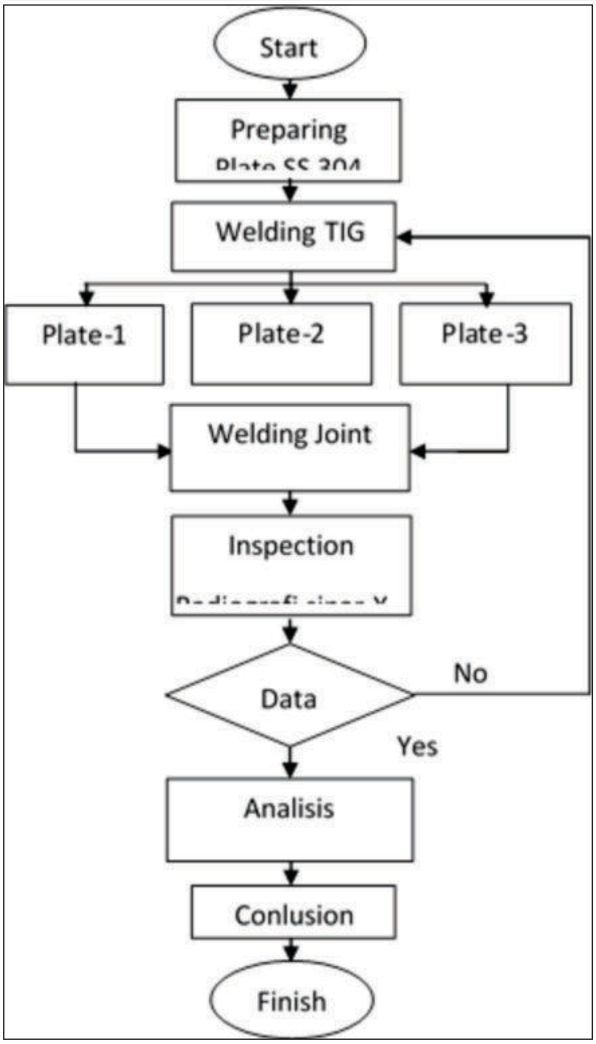


Figure 1: Flowchart X-ray Radiographic Analysis Of The Joints Of AISI 304 Stainless Steel Plates With Currents Of 40 A, 50 A, 60 A

RESULTS AND DISCUSSION

Welded Connection

The process of joining 2 (two) AISI 304 stainless steel plates is carried out by welding using the TIG method. The welding process uses 3 (three) current variations, namely 40 A, 50 A, and 60 A. The type of welding connection used is a butt joint with 2 (two) passes:

A. Number Plate Connection 1

In plate number 1 connection, the welding position 1G is the welding position under the hand (down hand) with the workpiece horizontal position. In this welding, the position of the electrode forms an angle of 60° to the workpiece and the current used is 40 A. The electrode used is an AWS A5.12-80 type electrode. The resulting welded joints on AISI 304 stainless steel plates are:

Pass 1	Pass 2
Curent:40A	Curent:40 A
Volt:9.5V	Volt:10,7 V
Timer:2 minute 25 detik	Timer:2 minute 10 detik

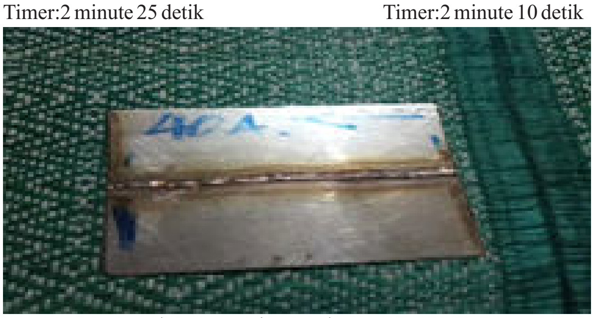


Figure 2. SS 304 plate connection number 1

In pass 1 welding, a plate connection with a weld length of 17 cm is produced with a welding speed of 0.1172 cm/second. (= 7.034 cm/minute). The resulting weld joint is not perfect, it is characterized by the weld metal not penetrating to the bottom so that the connection between the two plates is not closed. This is because the current used in welding the plate is too low. Therefore, pass 2 welding was carried out, with a weld length of 17 cm and a welding speed of 0.1307 cm/second (= 7.846 cm/minute). In pass 2 welding, a welded joint is produced that has covered the gap between 2 (two) plates.

B. Number Plate Connection 2

At the connection plate number 2, the welding position is 1G. In this welding, the position of the electrode forms an angle of 60° to the workpiece and the current used is 50 A. The electrode used is an AWS A5.12-80 type electrode. The resulting welded joints on AISI 304 stainless steel plates are:

Pass 1	Pass 2
Curent:50A	Curent:50 A
Volt:10,2 V	Volt:9,5 V
Timer:1 minute 50 detik	Timer:2 minute 33 detik

Figure 3 SS 304 Plate Connection Number 2

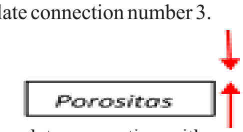
In pass 1 welding, a plate connection with a weld length of 17 cm is produced with a welding speed of 0.1545 cm/second. (= 9.27 cm/minute). The resulting weld joint is not perfect even though the weld metal has penetrated the bottom of the plate but the connection between the two plates is still a gap. This is because the current used in plate welding is still low. Therefore, pass 2 welding was carried out, with a weld length of 17 cm and a welding speed of 0.111cm/second (= 6.67 cm/minute). In pass 2 welding, a welded joint is formed that has clearly covered between 2 (two) plates.

C. Number Plate Connection 3

At the plate number 3 joint, the welding position is 1G. In this welding, the position of the electrode forms an angle of 60° to the workpiece and the current used is 60 A. The electrode used is an AWS A5.12-80 type electrode. The resulting welded joints on AISI 304 stainless steel plates are:

Pass 1	Pass 2
Curent:60 A	Curent:60 A
Volt:12,2V	Volt:10,5 V
Timer:1 minute 30 detik	Timer:2 minute 10 detik

Figure 4. SS 304 plate connection number 3.



In pass 1 welding, a plate connection with a weld length of 17 cm is produced with a welding speed of 0.188 cm/second. (= 11.33 cm/min). The resulting welded joint is good with no gaps but the weld metal does not penetrate the bottom of the plate. In pass 2 welding, with a weld

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length of 17 cm and a welding speed of 0.130 cm/second (= 7.8 cm/min) which results in a perfect weld joint between 2 (two) plates. Thus, welding the connection of 2 (two) SS 304 plates using a current of 60 A produces the best welded connection compared to a current of 40 A and 50 A.

Weld Defect Identification

The quality of welded joints on AISI 304 stainless steel plates can be determined by testing these joints with X-ray radiography equipment. The parameters used to identify possible weld joint defects are as follows:

Voltage (Voltage): 150 kV
Strong Current (Current): 2 mA
Time (Time): 1 Min
(a) SS 304 Plate Connection Number 1
Current 40 A
IQI : ASTM-1A
Welding Density: 1.9 (blackish weld)
Welding Defect Result: Incomplete Penetration

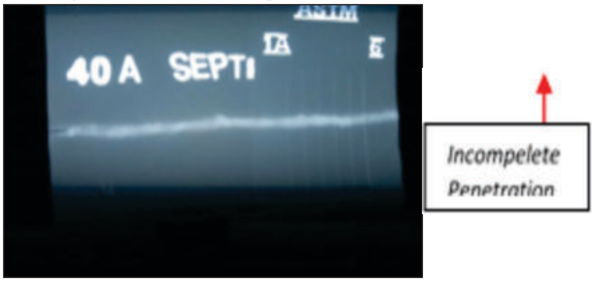

Figure 5. Welded joints of SS 304 plate number 1.

The SS 304 number 1 plate welded joint resulting from TIG welding with a current of 40 A (Figure 4.4) has a weld density of 1.9. In plate weld joint number 1, an incomplete penetration type weld defect was identified. Incomplete penetration type is a defect that occurs in the root area or the root of the weld does not penetrate, with straight black lines on the radiographic film because the welding amperage is too low, the welding speed is too fast and the welding arc is too high.

(a) SS 304 Plate Connection Number 2
Current 50 A
IQI: ASTM -1A
Weld Density: 2.5 (blackish weld)
Weld Defect Results: Porosity (porosity)

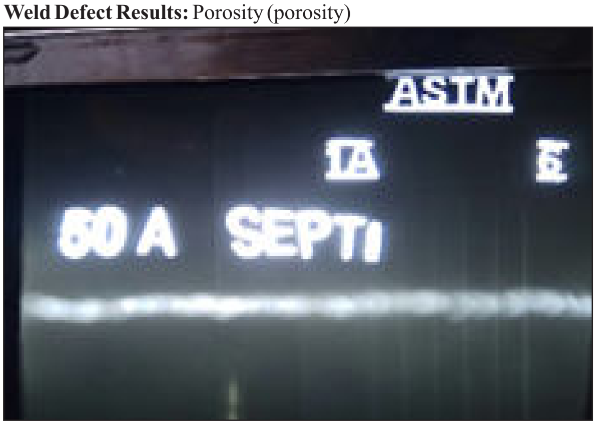

Figure 6. SS 304 Plate Welding Connection Number 2

The SS 304 number 2 plate welded joint resulting from TIG welding with a current of 50 A (Figure 4.5) has a weld density of 2.5. At plate number 2 welded joints identified the presence of porosity type weld defects. Weld porosity defects are a group of gas bubbles trapped in the weld, porosity in the form of small spherical cavities. The radiographic film shows a small black hole, because the welding speed is too fast, the amperage is too high and the workpiece is dirty.

(a) SS 304 Plate Connection Number 3
Current 60 A
IQI : ASTM-1A
Weld Density: 1.9 (Blackish Weld)
Results of Welding Defects: No Defect (without defects)

Figure 7. SS 304 plate welding connection number 3.

The SS 304 number 3 plate welded joint resulting from TIG welding with a current of 60 A (Figure 4.6) has a weld density of 1.9. In plate number 3 welding joints, no weld defects were identified. At the connection plate number 3, no defects were found because the compact welded joint covered all parts of the two plates that were joined. This means that welding parameters with a current of 60 Ampere can produce a perfect butt joint.

According to ASME Section IX, the permissible limits for weld defects in a welded joint are:

1. Incomplete penetration is not permitted regardless of the amount contained in the weld joint.

1. Porosity, allowable limit:
   a. Maximum total porosity size of 20% of material thickness in every 6 inches of weld length,
   b. Maximum total porosity size 1/8 Inch in every 6 Inch weld length.

Based on the ASME Section IX, the plate weld joint number 1 does not meet the requirements because it has an incomplete penetration defect. At the number 2 plate joint because the maximum total porosity size is less than 20% of the thickness of the SS 304 plate in every 6 inches of welding length.The plate number 3 welded joint meets the requirements because there are no weld defects found, and this connection is of the best quality compared to the number 1 plate connection and number 2 plate connection.

CONCLUSION

Based on the results of the analysis that has been carried out, the following conclusions are obtained:

1. TIG welding with a current of 60 Ampere produces a butt joint that is welded through and there is no gap between the plates, while with a current of 40 A and 50 A it produces a connection that does not penetrate and there is still a gap between the plates.
2. Incomplete penetration weld defects were found at the joints of the SS 304 plate welded with a current of 40 A.
3. Welding porosity defects were found in the welded SS 304 plate joint with a current of 50 A.
4. Welding defects were not found in the SS 304 plate joint with a current of 60 A.
5. The welded connection for plate number 2 and welded joint for plate number 3 meet the requirements, while the connection plate number 1 does not meet the quality requirements according to ASME section IX.
6. The TIG welded SS 304 butt joint plate with a current of 60 A has the best quality compared to a connection with a current of 40 A and 50 A.

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