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Defect analysis of butt joint type SMAW welding connection of SS400 steel material using liquid penetrant and ultrasonic test methods

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Abstract

SMAW welding is a type of electric arc welding where the electrode is melted by the heat generated from the electric arc between the electrode tip and the workpiece. The working principle of SMAW welding is to use heat from an electric arc to melt the base metal and the tip of the electrode coated with flux, which also functions as a filler material in the metal joining process. The purpose of this study is to determine the effect of variations in current strength and electrode type on the type of weld defects in SS400 steel material welding joints. In this study, weld defects identified from liquid penetrant testing showed six types of defects, namely crack, porosity, incomplete fusion, slag inclusion, over spatter, and undercut, while ultrasonic testing found four types of defects, namely crack, incomplete penetration, incomplete fusion, and slag inclusion. Liquid penetrant and ultrasonic testing data show that the welding process using currents of 120 A and 110 A with E7016 electrodes has the most defects, meanwhile, at a current of 100 A with E7018 electrodes, it is a welding parameter with weld results that are protected from welding defects. Based on the test data, it can be concluded that variations in current and electrode type affect the number and type of weld defects that appear, which are influenced by the welding process, the amount of current, the diameter and type of electrode, electrical polarity, and penetration rate. These parameters in SMAW welding determine the efficiency and quality of metal joining results.

1. Introduction

SS400 low carbon alloy steel material is a low carbon steel that, according to JIS (Japanese Industrial Standards) standards is widely used for general construction. The SS in SS400 plate stands for “Steel Structure” and indicates that this plate is specifically designed for steel structures. The number 400 in the name of this board indicates the minimum tensile strength which is approximately 400 [1]. SS400 steel's characteristics of high strength and durability make it a top choice in many construction projects, especially in the bus body manufacturing process at the body shop. However, although this material has good mechanical qualities such as high tensile strength and hardness, improper welding processes and parameters can cause defects in the joints.

Parameters that affect welding using Shielded Metal Arc Welding (SMAW) include current strength, electrode type, electrical polarity and penetration rate [2]. These parameters make the basis for proper selection in order to obtain the quality or quality of welding joints that avoid weld defects.

Based on the definition of DIN (Deutch Industrie Normen) Welding is a local process that creates a metallurgical bond between alloy metals that are joined in a liquid state through a heating process. In other words, welding is the joining of two metals by heating or melting, where the ends of the metals to be joined are melted by heat generated by combustion or electric arc (fuel gas). The principle of the welding process is to connect two or more components, more precisely assemble several components into a machine [3].

Shield Metal Arc Welding (SMAW) is a type of arc welding in which the electrode is melted by the heat generated from the electric arc between the electrode tip and the welded material. The principle of SMAW welding is to use arc heat to melt the base metal and closed electrode tip which can be used as a filler material in the metal joining process [4]. This type of welding uses a type of flux-coated electrode that protects the welding process from the oxidizing influence of outside air by coating the electrode metal with flux.

The amperage used for welding depends on several factors, including the material and size of the weld joint, the position of the weld, the type of electrode, and the diameter of the electrode core [5]. The welded area has a large heat capacity, so a high current is required. The wrong current selection can result in welding defects such as undercut, porosity, and crack. the current strength used can be determined based on the electrode specifications recommended by the electrode manufacturer.

Electrodes are conductors that conduct electricity, and when they come into contact with parts welded to the base metal, another current flows generating heat and melting the electrode as an adhesive between dissimilar metals [6]. Electrodes can be in the form of rods or wires. The type of electrode has a significant effect on the strength of the current used. It depends on the rate of melting or deposition and the depth of penetration.

Current strength and electrode type affect the quality of the weld. Too low a current causes insufficient penetration, while too high a current can increase the brittleness of the weld. The electrodes used in SMAW welding have different flux and core wire compositions. Improper selection of electrodes will result in brittle welds, lack of strength, and lack of penetration in the weld metal.

Inspection of metal structures such as steel is essential to understand the condition of the material and take preventive measures before equipment failure due to cracking, corrosion, and joints due to long-term use. Material testing is a method of measuring and determining the suitability of materials for use in components [7]. This makes it possible to determine the strength of the material when used and ensure that no damage occurs because the material does not meet the specified requirements to withstand the load. There are many methods of testing and inspection, be it destructive testing (DT), or non-destructive testing (NDT) [8], [9], [10],

According to [11], the types of welding defects in welding consist of two types, namely internal welding defects (inside the weld) and visual welding defects (on the surface). This study aims to analyze the effect of variations in current strength and electrode type in the SMAW welding process on SS400 steel plate joints on the types of defects detected through liquid penetrant and ultrasonic testing. Along with the development of technology in the field of Non-Destructive Testing (NDT), observation of weld defects can be done both visually and internally, through liquid penetrant and ultrasonic test methods [12], [13], [14], [15].

2. Research Methods

The process of making test objects in the process of making test objects aims to determine the size of objects to be tested, in this study the objects to be tested used SS400 steel plate test material by making 2 types of specimens, namely specimens for ultrasonic tests with dimensions of 120 mm long x 80 mm wide x 6 mm thick and liquid penetrant testing with dimensions of 120 mm long x 40 mm wide x 6 mm thick. SS400 carbon steel is a JIS G 3101 structural steel, and is a common type of steel (low carbon steel) whose chemical composition is carbon (C), manganese (Mn), silicon (Si), sulfur (S), and phosphorus (P) and has a tensile strength of about 400-510 Mpa [16].

This welding position used is horizontal and horizontal direction. In this welding step, the position used is the 1G position with the Butt joint type in SMAW welding, the electrodes used are type E7016 and E7018 Size 3.2 mm. The E7016 electrode has a low hydrogen potassium coating which produces a more stable arc and medium to deep penetration so that it is more suitable for welding with DC + polarity (DCEP), while the E7018 electrode has a low hydrogen potassium coating with additional iron powder which increases melting efficiency and produces stronger welds and smoother weld surfaces. These electrodes are treated with a preheat process before being used for welding to reduce the moisture content of the flux layer. The electrodes are preheated at a temperature of about 100°C-150°C for 1-2 hours, then stored in an electrode storage oven to keep them dry before being used in the welding process.

Welding was carried out with 3 different variations of electric current, namely 100 A, 110 A, and 120 A. The polarity used was DCEP (Direct Current Electrode Positive), with a voltage of 25 volts and welding speed ranging from 3-5 mm/second. Welding was performed in the 1G (flat) position. The liquid penetrant and ultrasonic testing specimens are shown in Figs. 1 and 2.

After welding treatment of SS400 carbon steel butt joint with E7016 and E7018 electrodes using currents of 100 A, 110 A, and 120 A, then research data collection was carried out through liquid penetrant testing and ultrasonic testing.

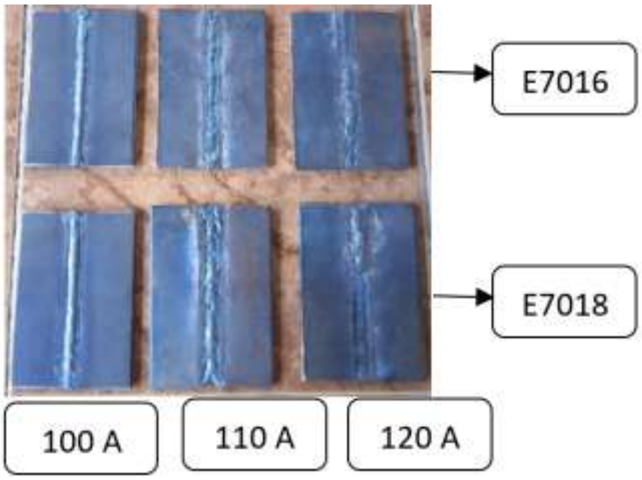


Fig. 1. Liquid Penetrant Test Specimen with E7016 electrode

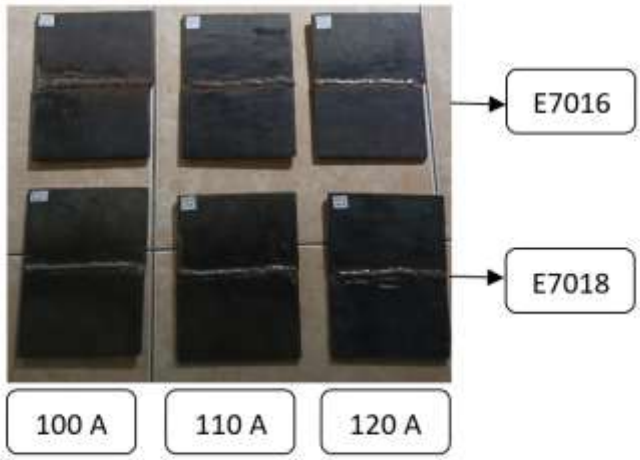


Fig. 2 Ultrasonic Test Specimen

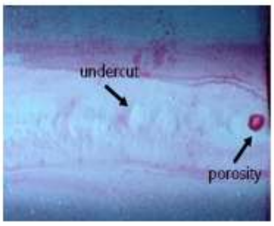
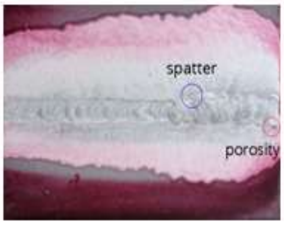
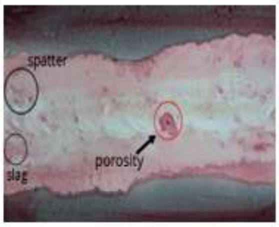
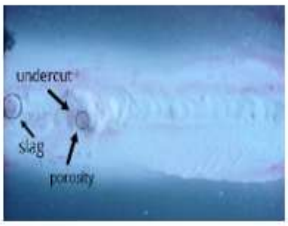
3. Result and Discussion

3.1 Liquid Penetrant Testing

Liquid penetrant testing aims to determine the number and type of visual defects. From the results of liquid penetrant testing carried out on each specimen with a total of 6 specimens that have been treated with welding with different current strengths and electrode types, there are indications of various welding defects.

Images of liquid penetrant test results on butt joint welding joints with E7016 and E7018 electrodes and current variations of 100 A, 110 A, and 120 A will be presented in Table 1. Based on the results of liquid penetrant testing, shown in Table 1, using electrodes E7016 and E7018 with a current strength of 100 A, there are almost no red spots and red lines from defects in the welding results. This indicates that at a current of 100 A, the melting process of the electrode and base metal occurs stably, penetration is sufficient, and the resulting weld spatter is optimal.

Table 1. Images of liquid penetrant test results

Arus	E7016	E7018
100 A		
110 A		
120 A		

At electrode E7016 current 110 A there are 3 indications of defects, namely porosity with a defect length of 7 mm, 5 mm in undercut defects and slag inclusion there are 2 defect points with the longest size of 2.5 mm. While at E7018 electrode current 110 A there are 2 indications of porosity defects with a defect length of 2 mm and over spatter there are 4 defect points with the longest size of 2 mm. shows that high current strength can occur defects as evidenced by the number of holes and red lines, namely the type of Incomplete fussion defect caused by lack of penetration in the weld joint and the welding speed is too fast, defects in the form of over sparter, namely defects in the form of weld spatter found on the edge of the weld, sparter defects occur due to the condition of the electrode that is too far away and the amperage is too high, and slag inclusion defects cause this defect because the slag cleaning process is lacking so that it is accumulated by the weld results.

At a current of 120 A, defects that appear more and more, on the E7016 electrode there are 3 indications of defects, namely porosity with a defect length of 8 mm, slag inclusion there are 2 defect points with the longest size of 2 mm. and over spatter there are 4 defect points with the longest size of 2 mm. While at the E7018 electrode current of 120 A there are 3 indications of porosity with a defect length of 3 mm, 4 mm in undercut defects and slag inclusion there are 2 defect points with the longest size of 2 mm. Overall, increasing the current tends to increase the number and size of defects. shows that using high current strength can cause many defects as evidenced by the number of holes, red lines, and red spots in the welding results.

3.2 Ultrasonic Test

Ultrasonic testing aims to determine the depth of defects and the type of internal defects. From the results of ultrasonic testing carried out on each specimen with a total of 6 specimens that have been treated with welding with different current strengths and electrode types, there are indications of various welding defects. This test uses the Sonatest ultrasonic flaw detector and Kuplan Sonagel, which serves to facilitate the propagation of ultrasonic waves from the probe to the test object. The following are the results of testing with the Ultrasonic Test method on welds using electrodes E7016 and E7018 with current strengths of 100 A, 110 A, and 120 A. The results of testing with the ultrasonic test method on butt joint welds using electrode E7016 with current strengths of 100 A, 110 A, and 120 A are shown in Figs 3-5.

Fig. 3. Ultrasonic test results at 100 A current

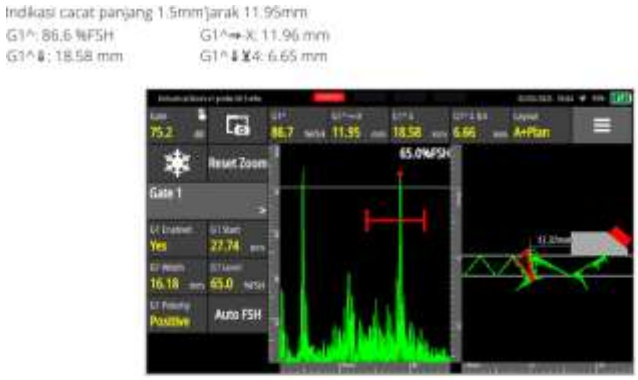


Fig. 4. Ultrasonic test results at 110 A current

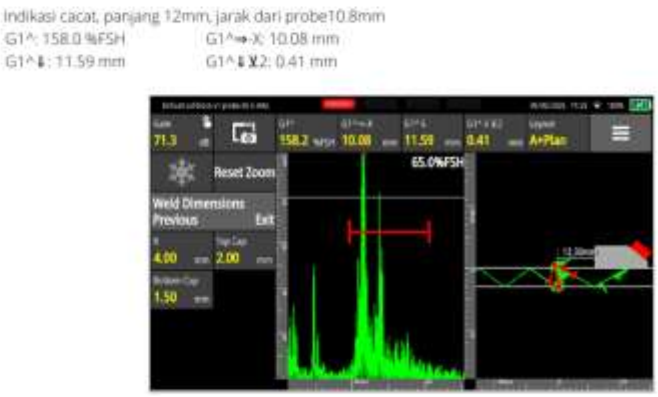


Fig. 5. Ultrasonic test results at 120 A current

Ultrasonic test data using E7016 electrodes can be seen in Table 2.

Table 2. Ultrasonic test data using E7016 electrode.

E7016	Testing Specimen			
	type of weld defect	length defect	distance defect	depth defect
100 A	1. crack	2 mm	14,59 mm	2,19 mm
110 A	1. incomplete penetration	1,5 mm	11,95 mm	6,66 mm
	2. crack	7 mm	13,54 mm	2,41 mm
	3.slag inclusion	2 mm	12,39 mm	3,08 mm
120 A	1. crack	12 mm	10,08 mm	0,41 mm
	2. incomplete penetration	5 mm	16,55 mm	3,10 mm
	3. incomplate penetration	1,5 mm	12,45 mm	2,31 mm
	4. crack	2 mm	11,57 mm	0,45 mm

The most common defect in materials subjected to ultrasonic testing using the E7016 electrode is the Incomplete Penetration defect, which is a defect that occurs due to the lack of penetration of the weld metal into the joint or weld root, so that the two base metals that are joined are not formed completely. Incomplete Penetration can occur due to electrode spacing that is too high and welding speeds that are too high during the welding process.

The test results using the ultrasonic test method on butt joint welds using E7018 electrodes with current strengths of 100 A, 110 A, and 120 A are shown in Fig.s 6-8.

Fig. 6. Ultrasonic test results at 100 A current

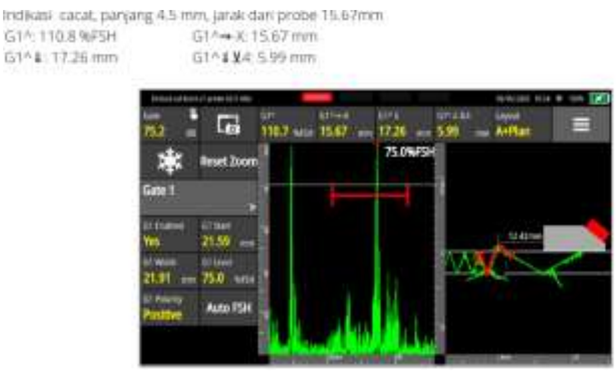


Fig. 7. Ultrasonic test results at 110 A current

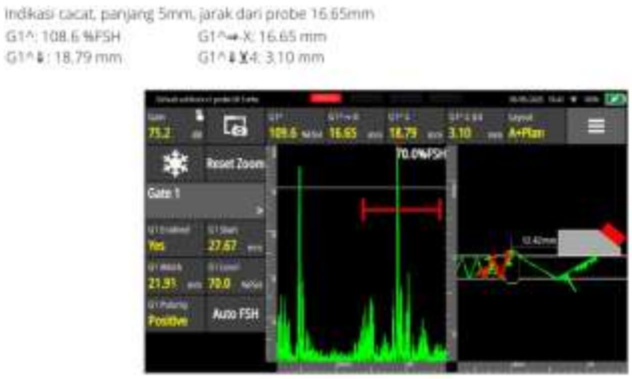


Fig. 8. Ultrasonic test results at 120 A current

Ultrasonic test data using electrode E7018 in Table 3.

Table 3. Ultrasonic test data using electrode E7016.

E7018	Testing Specimen			
	type of weld defect	length defect	distance defect	depth defect
100 A	1.slag inclusion	2 mm	12,62 mm	2,94 mm
110 A	1. crack	4,5 mm	15,67 mm	5,99 mm
	2. incomplete penetration	7 mm	12,29 mm	1,09 mm
120 A	1. crack	5 mm	16,55 mm	3,10 mm
	2. incomplate penetration	6 mm	12,92 mm	5,33 mm
	3. crack	3 mm	12,29 mm	3,13 mm

Based on the results of ultrasonic testing, the E7018 electrode shows better welding results with fewer defects in number and length than the E7016 electrode. Shown in table 3.4 data results of E7018 electrodes with current variations of 100 A, 11 0 A, 120 A, a current of 100 A found only 1 indication of defects with a length of 2 mm at a depth of 2.94 mm, the type of defect identified is slag inclusion. 110 A current found 2 indications of defects with a length of 4.5 mm at a depth of 5.99 mm, the type of defect identified is incomplate penetration defects, while the other type of defect is crack detected with a defect length of 7 mm at a depth of 1.09 mm. At a current of 120 A, 3 indications of defects were detected, namely 2 crack defects with lengths of 5 mm and 3 mm at a depth of 3.10 mm and 3.13 mm, while another type of defect, incomplate penetration, was found with a defect length of 6 mm at a depth of 5.33 mm.

These results show that the most common defects found in ultrasonic tested materials are incomplete penetration and cracks, which are types of defects in the form of cracks in the weld and incomplete penetration is a defect that occurs due to the lack of penetration of weld metal into the joint or weld root, so that the two base metals that are joined are not formed completely. Cracks and incomplete penetration can occur due to unstable stresses during the material shrinkage process and welding speeds that are too high.

The most common defect in materials tested using the E7018 electrode is a crack. Crack defects are formed because the gap distance or root opening is too wide, the electrode distance or welding arc is too high, and the travel speed is too high which causes the weld metal to be unable to fill the gap completely and cools too quickly, causing excessive tensile stress which triggers the formation of cracks.

4 Conclusion

The characteristics of weld defects identified from liquid penetrant testing show six types of defects, namely crack, porosity, incomplete fusion, slag inclusion, over spatter, and undercut, while ultrasonic testing found four types of defects, namely crack, incomplete penetration, incomplete fusion, and slag inclusion. Based on liquid penetrant and ultrasonic testing on butt joint welding joints with E7016 electrodes, the most defects are found at currents of 110 A and 120 A. Meanwhile, the use of E7018 electrodes at a current of 100 A is the optimal welding parameter or weld result that avoids weld defects because it produces the least number of weld defects in the SMAW welding process.

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