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Testing of Carbon Steel Pipe and Stainless-steel Duplex Pipes of Welding Joints: A Cost and Time Perspective

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Abstract

In the welding process, it is not uncommon for a defect or discontinuity to occur in the welding results. Common defects on the surface are undercut, concavity, incomplete penetration, spatter, burn-through, and mismatch. While defects in internal welds that are often found during testing are porosity, worm holes, slag inclusions, incomplete fusion, and cracks, To obtain pipeline results that comply with the specifications set by the welding engineer and ASME or ASTM standards, it is necessary to test surface cracks and inside cracks using the non-destructive test (NDT) method, namely the dye penetrant test and radiography test, to determine the results of welding at pipe joints. In addition, it is also necessary to know the time and cost required for each method in the testing process. The results of the radiography test and penetrant test on carbon steel pipe welding joints showed porosity welding defects 1 mm long. Weld defects in duplex stainless-steel pipes were not found. Then the results of the total testing time using the radiography test take 18% longer than testing using the penetrant test. Furthermore, the total costs that need to be incurred during the test are found to be 2~3 times more expensive than the cost of the penetrant test.

Keywords: NDT; welding joints; Carbon Steel; duplex stainless-steel; pipelines; costs; work time; defects

1. Introduction

In the oil and gas processing industry, a piping system is used to distribute fluids such as oil, fuel oil, utility water, cooling water, and other liquid fluids. Gas fluids in the form of fuel gas, natural gas, steam, instrument water, utility water, plant water, and other liquid gases Piping installations take the form of stretches of pipelines consisting of pipe bars that are connected to each other and function to flow fluids, both liquid and gas, from one location to another or from one process equipment to another process equipment in an integrated refinery process. The existence of piping installations in the industrial environment of oil and gas processing refineries is important; even piping installations occupy 30–35% of all equipment components in refineries. Therefore, the existence of a piping installation must be endeavored to always be in good condition and ready for use [1].

In the oil and gas production process, it is distributed from upstream to downstream using very long pipelines, and one type of pipe used is stainless-steel and carbon steel pipe. Which is where the material has different levels of content and will experience a change in properties after welding. Most of these pipelines are products that are connected using welding techniques. The strength of the welded joint is influenced by several factors, including welding procedures, materials, electrodes, and the type of seam used [2]. In the welding process, it is also not uncommon for a defect or discontinuity to occur in the welding results. Types of defects in welding itself can be divided into three types: surface cracks, subsurface cracks, and inside cracks. Defects that occur on the surface of the weld can usually be proven by a visual check and also by the penetrant test method. Meanwhile, defects that are below the surface (subsurface cracks) can be proven by the magnetic particle inspection method. And the type of defect that is inside the surface (an inside crack) can be proven by the radiography test and ultrasonic test methods. Common defects on the surface are undercut, concavity, incomplete penetration, spatter, burn-through, and mismatch. While defects on the inside (internal) of the weld that are often found during testing are porosity, worm holes, slag inclusion, incomplete fusion, and cracks, Much research has been done on welded joints for each construction object [3][4][5].

To obtain pipeline results that comply with the specifications set by the welding engineer and welding inspector, a method is needed to monitor quality at each level of manufacture and use [6]. Because oil and gas companies use a lot of pipelines that are always flowed by fluid, it is necessary to do surface crack and inside crack tests with the penetrant test and radiography methods in order to determine the condition of the welded parts of the pipeline. Duplex stainless-steel material and carbon steel material are used. From the aspect of their forming material, pipelines can be made of steel, stainless-steel, duplex, or polymer materials such as polyethylene and polypropylene, which have started to be used in some low-pressure gas pipelines. And in terms of the network system, pipelines can be grouped into wellhead lines and transmission lines [7].

Basically, duplex stainless-steel material can be welded because duplex stainless-steel material consists of balanced ferrite and austenite phases, each of which is 50%. This is what causes duplex stainless-steel material to be more difficult to weld because the heat of welding will greatly affect the balance between the ferrite or austenite. The heat of welding will cause the austenite (weldable, tough) phase to be more dominant (> 50%) than the ferrite phase, which results in a slow cooling rate and a decrease in the tensile strength of the material. On the other hand, if the duplex stainless-steel material is affected by less heat, the cooling speed of the material will be relatively faster. As a consequence, the ferrite (strong) phase is more dominant (> 50%) than the austenite phase [8].

2. Materials and Methods

In this study, the object of research was carbon steel pipes and stainless-steel duplex pipes, which were then analyzed for their welding results by using the penetrant test and radiography test methods, as well as the time of testing and economic analysis. The type of data used in this research is secondary data, such as field data, books, reports, journals, and others related to the problem to be studied. The data in this study included carbon steel pipe material data, stainless-steel duplex pipe material data, radiography test results data, penetration test results data, test time data, and test cost data.

The material analyzed is a welded joint of ASME SA 106 carbon steel pipe and ASTM A790 stainless-steel duplex pipe, where ASME SA 106 carbon steel pipe material is a standard specification for seamless carbon steel pipes for high temperature service [6]. Some are commonly used in power plants, boilers, petrochemical plants, oil and gas refineries, and ships where pipes must convey liquids and gases that are transported at high temperatures and pressures. ASME SA 106 carbon steel has a chemical composition of 0.30 carbon, 0.39-1.06 manganese, 0.035 sulfur, 0.035 silicon, 0.40 chromium, and 0.40 copper. While the duplex stainless-steel material used is ASTM A790, this material includes seamless and straight-seam ferritic and austenitic steel pipes intended for general corrosive service, with particular emphasis on resistance to stress corrosion cracking. These steels are prone to embrittlement if used for a long time at high temperatures. The use of steel varies based on the content of the alloying element carbon [9].

In this study, testing used the non-destructive test (NDT), where NDT is a physical test of a material or test object to look for defects in the object without damaging or destroying the test object. The purpose of NDT testing is to detect defects with a certain procedure on an object by an operator. Non-destructive testing (NDT) has many methods for the testing process, among them visual inspection, liquid penetrant, magnetic particles, ultrasonic, eddy current, and radiography. However, this study will only use two test methods, namely liquid penetrant to determine surface cracks and radiography to determine inside cracks [10].

Liquid penetrant tests are the simplest NDT method. This method is used to find defects in the exposed surface of solid components, both metal and non-metal, such as ceramics and plastic fibers. Through this method, defects in the material will be seen more clearly [10]. Meanwhile, radiographic testing is part of radiology. Radiology is a general term given to a material testing method based on differences in radiation absorption by the workpiece or test object being examined. The radiographic test aims to see defects in the weld metal that cannot be seen with a visual check. Radiography testing involves basically irradiating the test object with high-powered rays such as X-rays and gamma rays [11].

3. Results

3.1 Radiographic Test Results

Radiography testing was carried out using a sentinel gamma camera. The 880 Delta Radiograph was loaded with an Iridium 192 source with an activity of 53 Ci. The shooting technique used is the DWSI (Double Wall Single Image) method and the penny/IQI used is ATM 1B. Then the following results are obtained:

3.1.1 Radiographic Testing on Carbon Steel Pipes

Radiographic testing was carried out on 10 (ten) sections of ASME SA 106 Carbon Steel pipe material with a diameter of 8 inches with a thickness of 20.6 mm, so one of the welded surfaces is shown in Figure 1 below:

Figure 1 Surface results of welding sections 5-10 inches

Welding uses the GTAW-SMAW welding method. The test results and radiographic film observations showed that there were no weld defects in that part. This 5-10 inch section is marked with film code 2 (two)/sheet 2 (two), the film tested is shown in Figure 2 below:

Figure 2. Film test results on welding sections of 5-10 inches

Of the total welding parts that have been tested, then observations are made on all radiographic films assisted by a ragiography expert (AR), so that the results are shown in Table 1 below:

Table 1 Results of radiographic film observations of carbon steel pipes

No.Film (Sheets)	Film Density	Types of Weld Defects	Information
1	3.0/3.5	Not found	Accepted
2	3.0/3.5	Not found	Accepted
3	3.0/3.5	Not found	Accepted
4	3.0/3.3	porosity(1mm)	Accepted
5	2.8/3.2	Not found	Accepted
6	3.0/3.5	Not found	Accepted
7	3,2/3,4	Not found	Accepted
8	3.0/3.5	Not found	Accepted
9	3.0/3.5	Not found	Accepted
10	3.0/3.5	Not found	Accepted

The results of the table show that there is one welding result that has a weld defect in the form of porosity along 1 mm at the weld joint as shown by Radiographic film no.4 (four), but the weld defect is still acceptable based on the ASME B31 standard.

3.1.2 Radiographic Testing on Duplex Stainless-steel Pipes

Radiographic testing was carried out on 10 (ten) sections of ASTM A790 Duplex Stainless-steel pipe material with a diameter of 8 inches with a thickness of 12.7 mm, then one of the welded surfaces is shown in Figure 3 below:

Figure 3 Surface results of welding sections 0-5 inch

Welding uses the GTAW-SMAW welding method. The test results and radiographic film observations showed that there were no weld defects in that part. This 0-5 inch section is marked with film code 1 (one)/sheet 1 (one), the film test results are shown in Figure 4 below:

Figure 4. Film test results on welding sections 0-5 inches

Of the total welding parts that have been tested, then observations are made on all radiographic films assisted by a ragiography expert (AR), so that the results are shown in Table 2 below:

Table 2. Results of radiographic film observations of stainless-steel duplex pipes

No. (Sheets)	Movies	Film Density	Types of Weld Defects	Information
1		3.0/3.2	Not found	Accepted
2		3,2/3,4	Not found	Accepted
3		3.0/3.2	Not found	Accepted
4		3.0/3.2	Not found	Accepted
5		3.0/3.2	Not found	Accepted
6		3.0/3.2	Not found	Accepted
7		3.0/3.2	Not found	Accepted
8		3.0/3.2	Not found	Accepted
9		3.0/3.3	Not found	Accepted
10		2.9/3.3	Not found	Accepted

Table From the table of radiographic film observations, it shows that there are no weld defects in all the Duplex Stainless-steel pipes tested, so that all pipe materials can be used.

3.2 Penetrant Test Results

Penetrant tests have been carried out using SKL-SP1 penetrant fluid, SKD-S2 developer fluid, and SKC-S cleaner fluid. Using the visible penetrant test technique, the following results are obtained:

3.2.1 Penetrant Test on Carbon Steel Pipes

*Penetrant Test*carried out on 6 (six) sections of ASME SA 106 Carbon Steel pipe material with a diameter of 6 inches with a thickness of 14.27 mm, then one of the welded surfaces before being cleaned by a cleaner is shown in Figure 5 below:

Figure 5 Surface results of side 1 CS welding

Welding uses the GTAW-SMAW welding method. This Carbon Steel pipe is then cleaned using SKC-S cleaner fluid and the help of a rag tool. Furthermore, the surface is sprayed with penetrant liquid as shown in Figure 6 below:

Figure 6 Application of penetrant liquid on side 1 CS

All welded surfaces are treated with SKL-SP1 penetrant liquid and the dwell time is waited for 5 minutes until it is felt that the liquid has entered the surface weld defect gap. After that, the penetrant liquid is cleaned with running water or cleaner fluid and rags. Then the welding surface is sprayed with developer liquid as shown in Figure 7 below:

Figure 7 Application of liquid developer on side 1 CS

The welding surface is sprayed with SKD-S2 developer liquid and the interpretation time is waited for 10 minutes, so that if there are defects on the surface of the object, spots of penetrant liquid will appear on the surface of the welding result. In this test there is a weld defect in the form of porosity along 1 mm. This surface is marked with the name side 1.

From the results of observations of all weld surfaces that have been carried out by the Penetrant Test assisted by a level II Penetrant Test inspector, the results are shown in Table 3 below:

Table 3 Penetrant Test Results for carbon steel pipes

No. Side Section	Types of Weld Defects	Information	Dwell Time
1	porosity(1mm)	Accepted	5 minutes
2	Not found	Accepted	5 minutes
3	Not found	Accepted	5 minutes
4	Not found	Accepted	5 minutes
5	Not found	Accepted	5 minutes
6	Not found	Accepted	5 minutes

3.2.2 Penetrant Test on Duplex Stainless-steel Pipes

*Penetrant Test*carried out on 10 (ten) sections of ASTM A790 Duplex Stainless-steel pipe material with a diameter of 8 inches with a thickness of 12.7 mm, then one of the welded surfaces before being cleaned by a cleaner is shown in Figure 8 below:

Figure 8 Surface results of side 6 DSS welding

Welding uses the GTAW-SMAW welding method. This Duplex Stainless-steel pipe is then cleaned using SKC-S cleaner liquid and the help of a garbage tool. Furthermore, the surface is sprayed with penetrant liquid as shown in Figure 9 below:

Figure 9 Application of penetrant liquid on the 6 side of the DSS

All welded surfaces were given SKL-SP1 penetrant liquid and waited for a dwell time of 10 minutes until it was felt that the liquid had entered the surface weld defect gap. After that, the penetrant liquid is cleaned with running water or cleaner fluid and rags. Then the welding surface is sprayed with developer liquid as shown in Figure 10 below:

Figure 10 Application of liquid developer on the 6 side of the DSS

The welding surface is sprayed with SKD-S2 developer liquid and the interpretation time is waited for 10 minutes, so that if there are defects on the surface of the object, spots of penetrant liquid will appear on the surface of the welding result. In this test there is no indication of defects on the surface of the welding results. This surface is marked with the name side 6.

From the results of observing all weld surfaces that have been carried out by the Penetrant Test assisted by a level II Penetrant Test inspector, the results are shown in Table 4 below:

Table 4 Penetrant Test Results for Stainless-steel Duplex Pipes

No. Side Section	Types of Weld Defects	Information	Dwell Time
1	Not found	Accepted	10 minutes
2	Not found	Accepted	10 minutes
3	Not found	Accepted	10 minutes
4	Not found	Accepted	10 minutes
5	Not found	Accepted	10 minutes

No. Side Section	Types of Weld Defects	Information	Dwell Time
6	Not found	Accepted	10 minutes
7	Not found	Accepted	10 minutes
8	Not found	Accepted	10 minutes
9	Not found	Accepted	10 minutes
10	Not found	Accepted	10 minutes

3.3 Time Analysis

After the Radiography and Penetrant Tests have been carried out, an analysis of the total time spent during the tests is obtained as follows:

3.3.1 Time Analysis of the Radiography Test

This test was carried out on a total of 20 radiographic shootings and the time required during the test was obtained as shown in Table 5 below:

Table 5 Analysis of the time of the Radiography Test

No.	Pipe material name	Initial Install Time	*Exposure Time*	Pause Time	Uninstall time	Total Time
1	*Carbon Steel A1*	5 min	3 Minutes (x5)	30seconds(x5)	3 minutes	25 Minutes
2	*Carbon Steel A2*	5 min	5 Minutes (x5)	30seconds(x5)	3 minutes	35 Minutes
3	*Duplex Stainless-steel 1*	5 min	2 Minutes (x5)	30seconds(x5)	3 minutes	20 minutes
4	*Duplex Stainless-steel 1*	5 min	2 Minutes (x5)	30seconds(x5)	3 minutes	20 minutes
					Total Time	1 Hour 40 Minutes

During testing, time is spent on several activities during shooting such as the initial install time where all radiographic equipment is prepared and installed according to the shooting procedure, then exposure time is the irradiation time during which the source emits radiation until it is recorded on radiographic film according to exposure time calculations, then the delay time is the time when the source is moved and the radiographic film is replaced due to a change in the shooting side, the last is the uninstall time when all the pipe material has been tested, the equipment needs to be removed and tidied up again according to the radiographic testing procedure.

3.3.2 Penetrant Test Time Analysis

This test was carried out with a total of 16 sides that were tested for Penetrant and the time required during the test was obtained as shown in Table 6 below:

Table 6 Analysis of Penetrant Test time

No.	Pipe material name	Cleaning Time	*Dwell Time*	*Interpretation Time*	Total Time
1	Carbon Steel B1	3 minutes	5 minutes	10 minutes	18 Minutes
2	Carbon Steel B2	3 minutes	5 minutes	10 minutes	18 Minutes
3	Duplex Stainless-steel 1	3 minutes	10 minutes	10 minutes	23 Minutes
4	Duplex Stainless-steel 1	3 minutes	10 minutes	10 minutes	23 Minutes
				Total Time	1 Hour 22 Minutes

During testing, time is spent on several activities during the penetrant test such as cleaning time where the entire surface to be tested is cleaned using a liquid cleaner, then dwell time is the waiting time given for the penetrant fluid to enter the defective surface, the last is the interpretation time is the time wait if there is a defect on the surface, the penetrant liquid will rise to the surface and can be identified as a welding defect.

3.4. Economic Analysis

After conducting radiographic testing and Penetrant testing, an economic analysis is carried out and the costs that must be incurred during the testing are as follows:

3.4.1 Economic Analysis of the Radiography Test

This test was carried out at the PT. XYZ company by requiring 3 company workers including OR, AR, and PPR. then obtained data on testing fees and costs based on Government Regulation no.47 of 2011 Ministry of Industry which is shown in Table 7 below:

Table 7 Analysis of the price of a Radiography Test [12]

no.	Type of service / services	Testing Fee	PP-47-2011 (Ministry of Industry)
1	Radiography Film (size 4x10)	IDR 40,000/sheet	IDR 40,000/sheet
2	Radiography Film (size 4x15)	IDR 50,000/sheet	IDR 50,000/sheet
3	level 1 Radiography Operator (OR)	IDR 150,000/day	IDR 200,000/day
4	level 2 Radiologist (AR)	IDR 350,000/day	IDR 400,000/day
5	Radiation Protection Workers (PPR)	IDR 350,000/day	IDR 400,000/day

From the results of observing the data above, the total costs incurred during the radiographic testing are obtained as shown in Table 8 below:

Table 8 Analysis of the cost of the Radiography Test

No.	Type of service / services	Testing Fee	Amount	Total
1	Radiographic Film (size 4x10) (carbon steel)	IDR 40,000/sheet	10 sheets	IDR 400,000
2	Radiographic Film (size 4x10) (Duplex SS)	IDR 40,000/sheet	10 sheets	IDR 400,000
3	level 1 Radiographic Operator (OR)	IDR 150,000/day	1 day	IDR 150,000
4	level 2 Radiologist (AR)	IDR 350,000/day	1 day	IDR 350,000
5	Radiation Protection Workers (PPR)	IDR 350,000/day	1 day	IDR 350,000
			Total :	IDR 1,650,000

3.4.2 Penetrant Test Economic Analysis

This Penetrant Test is supervised and assisted by a Level 2 Penetrant Test inspector at the company PT. XYZ, so the test cost data and cost comparison are obtained based on Government Regulation no. 47 of 2011 Ministry of Industry which is shown in Table 9 below:

Table 9 Penetrant Test price analysis [12]

No.	Type of service / services	Testing Fee	PP-47-2011 (Ministry of Industry)
1	Dye Penetrant	IDR 90,000/meter	IDR 90,000/meter
2	Level 2 Penetrant Test (PT)	IDR 300,000/day	IDR 400,000/day

From the results of observing the data above, the total costs incurred during Penetrant testing are obtained as shown in Table 10 below:

Table 10 Penetrant Test cost analysis

No.	Type of service / services	Testing Fee	Amount	Total
1	Dye Penetrant	IDR 90,000/meter	4 meters	IDR 360,000
2	Level 2 Penetrant Test (PT)	IDR 300,000/day	1 day	IDR 300,000
			Total :	IDR 660,000

4. Discussions

The results of this study indicate a significant difference between the 2 NDT tests in terms of economy and quality of the test results. But in terms of processing time is relatively not much different. The two NDT tests used in pipe welding joints for several types of materials are commonly used depending on the needs in the field. Likewise the findings of the desired defects. Research also needs to be complemented by several other NDT tests such as MPI, UT, ET and others. This is a form of validation of the findings of defects in welded joints to make them more comprehensive. Although from an implementation perspective it depends on the need for NDT tests where not everything has to be done. Several studies have also shown the same results in detecting surface and internal weld defects [13][14][15][16][17]. This research is more focused on processing time and cost without neglecting the results of welding defects detected by the 2 tests. Few studies have discussed the cost and processing time perspectives. Most focus on the test method and the significance of the weld defects found.

5. Conclusions

Based on the results of the Non-Destructive Test, the Radiography Test method on Carbon Steel type pipes showed that the results on the welded joint contained only one film/sheet which had a weld defect in it, namely film/sheet at number 4 with 1 mm porosity welding defects. Then the results of testing the Duplex Stainless type pipe showed that there were no weld defects in all the pipe joints tested. Next is the Penetrant Test result on the Carbon Steel type pipe showing the results on the welded joint there is only one side that has a weld defect in it, namely the side at number 1 with a 1 mm porosity welding defect. Then the results of the Duplex Stainless-steel type pipe test showed that there were no weld defects in all the pipe joints tested. All NDT test results indicate that all welded joints are acceptable according to ASME and ASTM standards so that the pipes can be used for the needs of the oil and gas industry. The results of the analysis of the non-destructive testing time of the Radiography Test method with a total of 20 sheets of material firing showed that the results of all Radiography tests obtained a total testing time of 1 hour 40 minutes. Then the results of the Penetrant Test time analysis with a total of 16 sides of material testing obtained a total testing time of 1 hour 22 minutes. From the results of all NDT tests, the total testing time was 3 hours 2 minutes. Next is the economic analysis of the Radiography Test and Penetrant Test, so the cost that needs to be spent during the Radiography Test is IDR 1,650,000. and the Penetrant Test fee is IDR 660,000. So that from all the NDT tests, the total cost that needs to be spent is IDR 2,310,000.

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