http://jurnal.unmer.ac.id/index.php/jtmt
TRANSMISI
ISSN (print): 9-772580-228020
ISSN (online): 2580-2283

Analisa Kegagalan Pipa Jenis *Galvanized Iron* di Perumda Tirta Kanjuruhan

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ARTICLE INFORMATION

Received: 23 February 2023
Revised: 15 March 2023
Accepted: 20 April 2023
Published: 1 September 2023

DOI: 10.26905/jtmt.v19i2.12015

ABSTRACT

The most commonly used type of water pipe is iron pipe commonly called Galvanized Iron pipe. The disadvantage of GI pipe is that it rusts easily. So it can result in degradation, decreased efficiency and construction, poor water quality, and higher maintenance costs. Water channeled through rusty pipes will pollute the water and adversely affect the health of those who consume it. This study aims to determine the factors causing failures of GI pipes in the distribution pipeline that have failed due to corrosion. The tested pipe is a 1/2" sized, 5-year-old corroded pipe whose distribution uses a gravity system and a pumping system. To support this analysis, operational data on fluid and environmental conditions around the pipeline are needed, as observations on macro and microstructures, and hardness testing. The corrosion rate is calculated through the thickness loss method and the corrosion rate in the gravity system is 0.153 mm/year higher than the pipe in the pumping system. Microstructure observations support the characterization of the material that this pipe is mild steel, where this type of steel has a high Fe content so it is vulnerable to corrosion attacks. Rockwell hardness testing showed that the corrosion rate is directly proportional to the hardness value of the pipeline. The results of the analysis show that the environment around the pipe which has low soil resistivity and high humidity levels is the main factor in the occurrence of uniform corrosion of the pipe. The selection of inappropriate materials is also supportive as the cause of corrosion occurring.

Keywords: failure analysis, corrosion, galvanized iron, Rockwell hardness, microstructure

1. Introduction

A Regional Owned Enterprise (BUMD) in Malang Regency, Regional Public Company (Perumda) Tirta Kanjuruhan provides drinking water services as the organizer of the Drinking Water Supply System (SPAM). Pipes as the main component in distributing clean water have criteria that are generally based on several factors . Much of the world's need for clean water is of the same nature, such as the need for safe, durable pipes in waterways to keep them free of contaminants. The topography and contour of the land traversed also influence the selection of suitable pipes, which requires the use of strong, high-quality products [1].

The most common type of water pipe is an iron pipe or what is usually called a GI pipe. The disadvantage of iron pipes is that they rust easily. This can result in degradation, reduced efficiency and construction, poor water quality, and higher maintenance costs. Furthermore, the substances produced by corrosion can contaminate the water that is distributed, causing disease in humans who consume it regularly, such as lung disease, digestive tract disorders, and damage to other body tissues [2].

Therefore, in this research, failure tests will be carried out on clean water distribution pipes distributed to houses in one of the Perumda Tirta Kanjuruhan service areas. Some of the tests carried out include hardness testing, as well as analysis of the results of macrostructure photos and microscopic photos. So that the results of the research that has been carried out can provide benefits and prevention in determining the type of pipe used, analyzing pipe failures, and being able to determine the causes and impacts of corrosion [3].

2. Methodology of Research

The variables used in this research include pipe material, namely Low Carbon Steel with Zinc Coating, pipe size, and pipe age as fixed variables. Meanwhile, the independent variables in this research are the distribution system in the pipe being tested and the environment around the pipe. The research was carried out at the Material Testing Laboratory, Department of Mechanical Engineering, Faculty of Engineering of Universitas Merdeka Malang in January 2023.

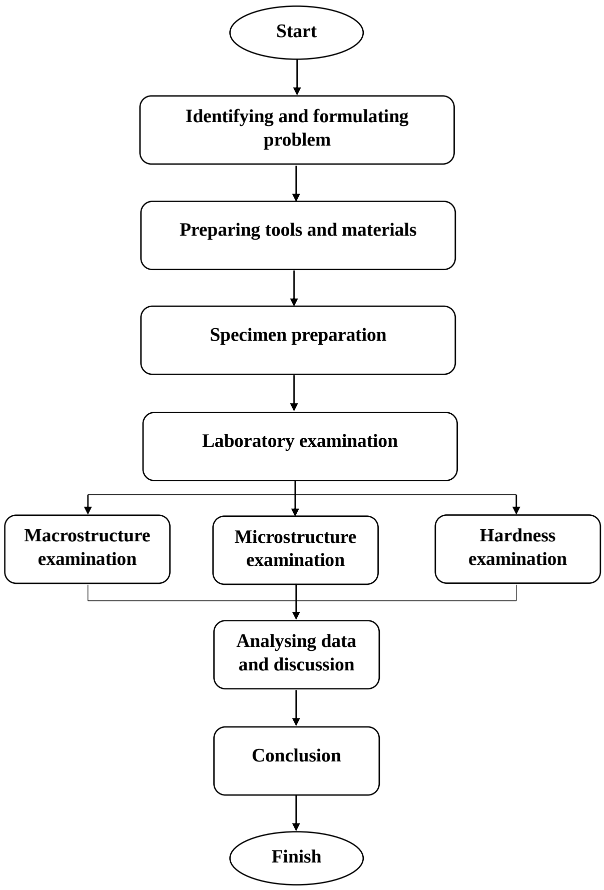

Figure 1. Research flowchart

The tools and materials needed for this research are as follows:

- Digital camera
- Cutter
- Sandpaper grade 500 to 3,000
- Metal Polish
- Duster
- Etching Solution (95% Ethyl Methyl Alcohol and 5% nital solution or HNO3)
- Small Plastic Containers
- Stopwatch
- Aquadest
- Large Plastic Containers
- Liquid soap
- Cotton
- Hair Dryer
- Metallurgical Microscope
- Dyno-Eye
- Laptops
- Rockwell Hardness Tester

2.1 Observation of macrostructure

Macro testing is one of the metallographic testing methods, where the test results can be the basis for determining the mechanical properties of the material. Macro testing can be done with the naked eye. Macro testing is a test to see the structure of the material using a magnification below 50x. Macro testing displays images of the surface of the specimen without any treatment. Macro testing can determine the structural properties, defects, and segregation of mixed elements with the naked eye or minimal magnification of a microscope. In this modern era, macro testing can also be captured using a sophisticated SLR camera or smartphone camera.

2.2 Specimen preparation

Before proceeding to the main test, it is necessary to cut the specimen as in Figure 2. The tubular pipe is cut 1 cm long and transversely for the hardness test.

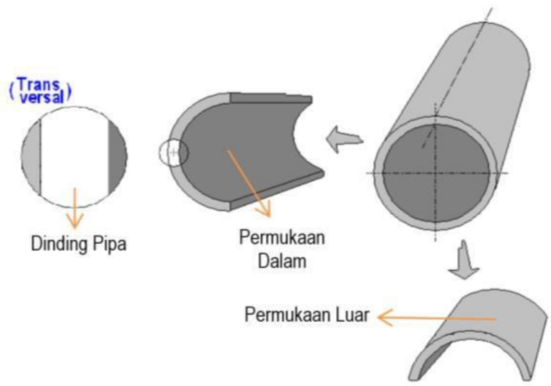

Figure 2. Specimen cutting

There are 3 specimens for hardness testing. The first specimen is to test the pipe wall, the second specimen is to test the outer surface of the pipe, and the third specimen is to test the inner surface of the pipe. Meanwhile, for microstructure testing, polishing and etching need to be carried out first. The top and bottom planes of the test object must be flat and parallel. The specimen must be smooth and free of scratches. The following are the steps for preparing microstructure testing specimens to obtain quality microstructure image results:

a) Grinding and sanding
   This process uses graded sandpaper from coarse to fine sandpaper.
b) Polishing
   The test specimens were polished using a metallographic polishing machine. This machine consists of a rotating disc with velvet cloth. The polishing method is that the test object is placed on a rotating disk, and a small amount of lubricating paste is applied to the polishing cloth. If the sanding lines are still visible, continue polishing. When it is flat and shiny, the specimen is cleaned and continued with etching.

Figure 3. Polished specimen

2.3 Observation of microstructure

The analysis used to determine grain diameter is the planimetry method (Jefferies). This method uses the help of a circle. The grain size is determined from the magnification used which refers to the Jefferies multiplier factor.

$$Na = f(n_1 + 0.5n_2)$$
$$G = [3.32\log(Na) - 2.95]$$

Where:

G	=	Item size is referred to in the table ASTM E-112 (µm)
Na	=	Number of items
n_1	=	Number of items in the circle
n_2	=	Number of items that intersect the circle
F	=	Multiplier factors in the Jefferies table

Figure 4. Observation of microstructure using a metallurgical microscope

2.4 Rockwell hardness test

The hardness test in this research is the Rockwell Hardness Test because the process is simple, efficient, and does not require a microscope to measure traces. The Rockwell Hardness Test uses an indenter to press the plane of the specimen. The pressure from the indenter is a minor load. Next, the major load is added which is the main load. The indenter used during testing depends on the type of material being tested.

2.5 Corrosion rate analysis

Corrosion rate is the speed of propagation or the rate at which the quality of the material decreases over time. Determination of the corrosion rate can be calculated using the lost pipe thickness, using the following formula:

$$Corrosion\ Rate\ (CR) = \frac{t_{nominal} - t_{actual}}{time\ (year)}$$

Where:

$t_{nominal}$	=	Initial design pipe thickness (mm)
t_{actual}	=	Pipe thickness at the time of current inspection (mm)
Pipe life	=	Time from installation to inspection (years)

Actual pipe thickness measurements are carried out at different points to get accurate results.

3. Result and Discussion

3.1. Fluid operational data

In this research, failure analysis was carried out on the Gi pipe in the gravity system and pumping system. The gravity system utilizes differences in height to distribute fluid, while the pumping system utilizes pump pressure.

Table 1. Operational data

No	Description	Operational Data	
		Gravity System Pipe	Pumping System Pipe
1	Fluid pressure	0.9 bar	1.1 bar
2	Fluid temperature	25.5℃	26.7℃
3	The outside diameter of the pipe	21.3 mm	21.3 mm
4	Pipe inner diameter	15 mm	15 mm
5	Thickness	2.6 mm	2.6 mm

Based on the table above, it is known that the fluid pressure is still considered a very small pressure, considering that based on the GI pipe specifications, the hydrostatic test results are 50 kgf/cm^2 or 49 bar. So it can be said to meet the standards.

The fluid temperature obtained is also normal at room temperature. At this temperature, it will not affect changing the physical properties of the pipe. Meanwhile, the results of the fluid quality inspection obtained (table 2) have met the requirements for drinking water quality based on the Regulation of the Minister of Health of the Republic of Indonesia Number: 492/Menkes/Per/IV/2010. So that the quality of the fluid that flows through the pipe is of good quality and does not cause corrosion or have a bad impact on the health of those who consume it.

Table 2. Fluid Quality Data

No	**Parameters checked**	**Unit**	**Drinking Water Requirement Limits**	**Result**	
				Gravity System	**Pumping System**
A.	**PHYSICS**				
1	Amount of dissolved solids (TDS)	Mg/L	≤ 500	248	172
2	Turbidity	NTU	≤ 5	0.23	0.74
3	Smell	-	Odorless	-	-
4	Flavor	-	Tasteless	-	-
5	Color	TCU	≤ 15	0	0
6	Electrical conductivity (DHL)	Ms/cm	-	0.255	0.325
B.	**CHEMISTRY**				
1	Aluminum	Mg/L	≤ 0.2	0.002	0.03
2	Iron	Mg/L	≤ 0.3	0.2	0
3	Quantity hardness	Mg/L	≤ 500	196	178
4	Chloride	Mg/L	≤ 250	28.5	29.5
5	Mangan	Mg/L	≤ 0.4	0.2	0.2
6	Acidity (pH)	-	6.5 – 8.5	7.2	7.6
7	Sulfate	Mg/L	≤ 250	11	0
8	Copper	Mg/L	≤ 2	0	0
9	Nitrate	Mg/L	≤ 50	2.4	14.9
10	Nitrite	Mg/L	≤ 30	0	2
11	Cyanide	Mg/L	≤ 0.07	0.01	0.006
12	Calcium	Mg/L	≤ 200	119.4	14
13	Magnesium	Mg/L	≤ 150	76.6	74
14	Detergent	Mg/L	0.005	0.01	0.02
15	Total Chromium	Mg/L	0.05	0	0
16	Zinc	Mg/L	3	0.15	0

3.2. Corrosion rate analysis

Through the technical specifications for medium class GI pipe SNI 0039:2013, the thickness and diameter of the pipe can be determined. Where the thickness of the pipe in new condition is 2.6 mm. Measurement of the actual thickness of each pipe variable is carried out at three different points, to get accurate results. Thus, it will get an average corrosion rate on gravity system pipes of 0.153 mm/year and an average corrosion rate on pumping system pipes of 0.053 mm/year. This is consistent with a higher thickness reduction in gravity system pipes because the corrosion rate is proportional to the reduction in pipe thickness that occurs due to corrosion [3].

Table 3. Corrosion Rate Analysis Results

Variable	T actual at the point (mm)			Pipe life (years)	Corrosion rate at point - (mm/year)			Average corrosion rate
	1	2	3		1	2	3	
Gravity System Pipe	1.5	2	1	5	0.22	0.12	0.12	0.153
Pump System Pipe	2.5	2	2.5	5	0.02	0.12	0.02	0.053

3.3. The influence of the pipe's external environment on corrosion

One of the things that dominates as a cause of corrosion is environmental factors. The installation location of each pipe is known. The gravity system pipe is installed through a rocky riverbank with brownish water. Meanwhile, the pumping system pipes are installed underground through the irrigation land in the rice fields [4].

According to Muhammad, R. P. & Nurdin Ali, S. H., soil resistivity values influence the potential for corrosion in underground pipelines. Resistivity is a quantity that shows the level of resistance to electric current in a material. High resistivity can be said to slow down corrosion. The majority of soil in rice fields is clay, peat, or wet soil. This type of soil has the lowest resistivity compared to other types of soil, such as soil on roadsides or residential areas, so it has an extreme level of corrosiveness.

Figure 4. The installation environment for the pumping system pipe is in rice fields

In theory, the land planted in rice fields must have sufficient moisture for good growth of rice or other plants. So apart from soil resistivity, soil moisture also has an influence on corrosion that occurs. Moreover, at the location where the pipe is installed, flooding often occurs during the rainy season, which will increase soil moisture.

The corrosion rate of gravity system pipes located on river banks has a higher corrosion rate. It can be seen that in the photo of the environment, the river is around the residents' fields. So, it can be assumed that the type of soil around the river is more or less the same as the type of soil in the rice field environment. However, this gravity system pipe is not planted in the ground but is located on a riverbank, which means the pipe is submerged in river water. So the environment outside the pipe can be considered to have a very high humidity level and is higher than in the rice field environment. The higher the humidity level, the higher the corrosion rate [1].

Figure 5. The Pumping System Pipe Installation Environment is on the River Bank

Apart from that, if you look at the brownish color of the river water, it can be assumed that the water is murky and does not meet standards. Water turbidity can occur due to the presence of dissolved substances or Total dissolved solids (TDS) which is quite high. TDS, which can be categorized as an impurity substance, can cause additional reduction reactions on the metal surface. Undesirable reduction reactions can cause many metal atoms to lose electrons, causing oxidation and causing corrosion.

3.4. Results of macrostructure observations

The gravity system pipe from which the sample was taken, measuring 15 cm, can be seen to have experienced higher corrosion in the middle to the left. This corrosion is characterized by the pipe surface being worn and peeling and having a reddish-brown hue. Meanwhile, the pump system pipe has fewer reddish-brown spots. If we compare the results of observing the macrostructure of the inner surface of the pipe, it can also be seen that the rust deposits on the gravity system pipe are more prominent and numerous. This supports the fact that the corrosion rate in gravity system pipes is indeed higher.

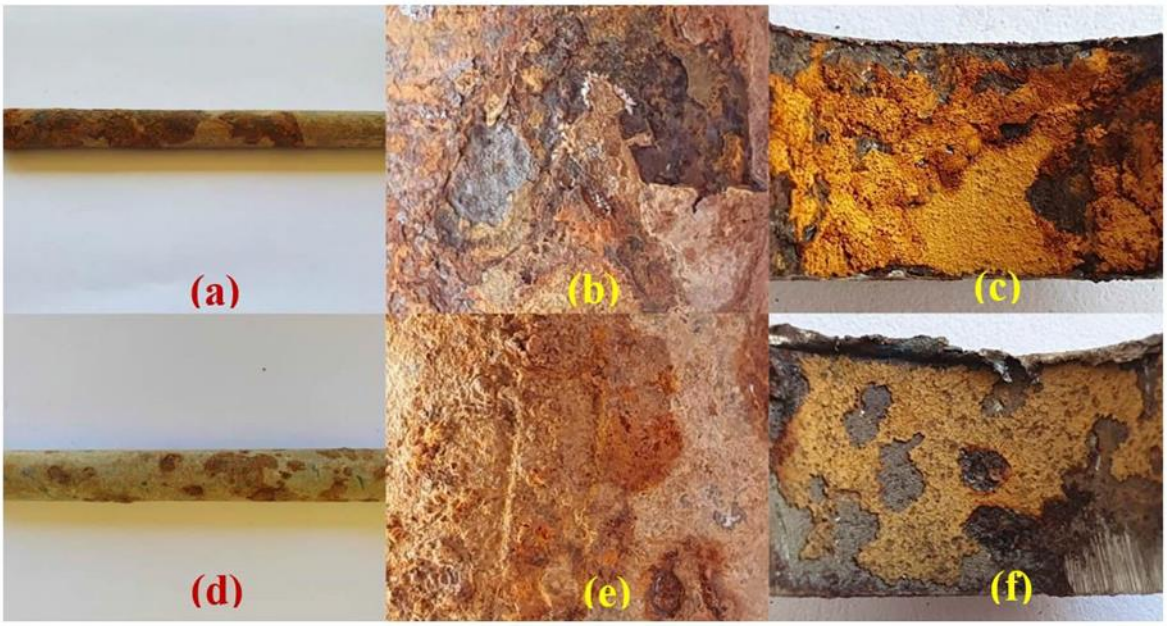

Figure 6. Macro Structure Photo Results

By observing the macrostructure, it can be seen that the corrosion that occurs is uniform. According to NACE, uniform corrosion causes a decrease in the overall thickness of the material, which can be identified by the corrosion of the surface and the presence of rust products. This rust product is a reddish brown product as can be seen in the macro photos.

3.5. Results of microstructure observations

The results of the grain size analysis showed that the value was not too far between the new pipe and the corroded pipe. Then the number of grains will be known, and then the grain size will be found. Referring to Table ASTM-112 [5], from the grain size, the grain diameter can be determined. It was found that the grain diameter of the new pipe, gravity system pipe, and pumping system pipe was 46.67 µm respectively; 47.22 µm; and 46.70 µm.

From these results, it is known that the grain diameter of new pipes and corroded pipes does not have a significant difference. So it can be said that the grain diameter of the three pipes is almost the same. The microstructure of metals can change if plastic deformation occurs and heat treatment occurs. Corroded pipes do not undergo permanent changes in shape or heat treatment. The ambient temperature and fluid temperature are normal temperatures that will not change the microstructure of carbon steel. So there is no significant change in the grain size of the corroded pipe [6].

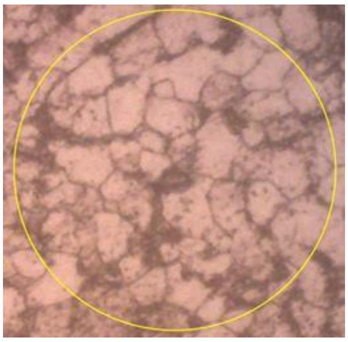

Figure 7. Photo Results of the Microstructure of the Outer Surface of the New Pipe

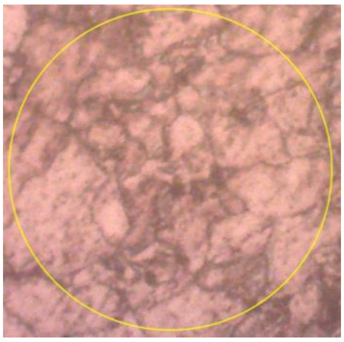

Figure 8. Photo Results of the Microstructure of the Outer Surface of the Gravity System Pipe

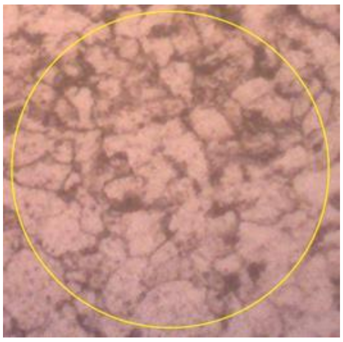

Figure 9. Photo Results of the Microstructure of the Outer Surface of Piping System Pipes

3.6. Rockwell hardness test results

The final test is the Rockwell hardness test, where on new pipes the test is carried out on 3 sides, namely the pipe wall (transverse side), the outer surface, and the inner surface of the pipe. The material tested was low carbon steel, so the major load used was 100 kg and a 1/16" ball indenter was used [7].

Table 4. Rockwell Hardness Test Results

No	Variables	Pipe Side	Hardness Value at point (HRB)					Average (HRB)
			1	2	3	4	5	
1	New pipes	Pipe wall	75	67.5	68	64	73	69.5
		Outer surface	82	88	88	87	86	86.2
		Inner surface	104	95	101	98	95	98.6
2	Gravity System Pipe	Outer surface	75.5	71	74	71	78	73.9
		Inner surface	82	85	74	86	86	82.6
3	Pumping System Pipe	Outer surface	80	84	85	83	75	81.4
		Inner surface	87	84	88	87	90	87.2

It was found that the hardness value on the walls of the new pipe was 69.5 HRB, on the outer surface of the new pipe it was 86.2 HRB, and on the inner surface of the new pipe, it was 98.6 HRB. The inner surface of the pipe has the highest hardness. Meanwhile, the corroded pipe cannot be tested on the walls because the walls of the corroded pipe are too thin, causing errors and the needle on the hardness scale rotating more than 3 times [8].

The hardness value of the corroded pipe on the outer surface is close to the hardness value on the pipe wall. This happens because corroded pipes experience material degradation. Likewise, the inner surface of the pipe experiences a decrease in hardness value. So it can be assumed that corrosion occurs evenly on the outer surface and inner surface of the pipe.

The hardness value is inversely proportional to the grain diameter value. Even though the grain diameter does not have a significant difference in value, if we sort them from the largest diameter, they are gravity system pipes, pump system pipes, and new system pipes. Hall-Petch Equation.

$$\sigma yield = \sigma_0 + k_y . d^{-1/2}$$

where σ is the average diameter of the crystal grains, indicating that the yield strength of a metal (σyield) will increase if the grain size decreases? The strength of a metal is directly proportional to its hardness (HR), so the larger the grain size, the smaller the hardness.

These failures can provide lessons and solutions for the future. installation of distribution piping system lines, making it possible to pass through various terrains and types of soil. Starting from passing through riverbanks, mountains, rice fields, plantations, asphalt roads, gravel land, and so on. This requires replacing pipe materials that can be used in various fields and are resistant to corrosion.

HDPE pipes are better used in environments with high humidity because they are made from polyethylene (high-density plastic) which is resistant to corrosion. This type of pipe is considered stronger and will not experience corrosion is suitable for the distribution of clean water and is drinking water certified according to Minister of Health Regulation

492, so it is safe for distributing clean water. Its flexible and flexible nature makes the installation process for water distribution in this pipe easier compared to other material water pipes. When compared to GI pipes, HDPE pipes are lighter. Thus, the installation process is much easier and also cheaper in terms of handling and transportation.

4. Conclusion

Based on the research results, it can be seen that the factors that cause failure are the choice of material in the form of low carbon steel which has a high Fe composition, causing pipes with this material to be susceptible to corrosion. So, HDPE pipes will be better used in environments with high humidity, because they are made from a type of plastic that is resistant to corrosion. The external environment of the pipe has low soil resistivity values and high levels of humidity, causing the metal to easily oxidize, forming rust and causing widespread corrosion.

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