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FAILURE ANALYSIS OF BOILER SUPERHEATER PIPE BY MECHANICAL PROPERTIES TESTING AND CORROSION RATE TESTING

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ABSTRACT

Superheater is a subcritical boiler component that functions to reheat saturated steam at constant working pressure so that it becomes saturated steam. This study aims to (1) analyze failures in superheaters, (2) test mechanical properties of superheater pipe materials, (3) calculate corrosion rates in superheater pipes with weight loss methods, (4) provide preventive maintenance solutions to minimize superheater pipe damage.
The method used in this study is a qualitative approach with the type of experimental study. The method of failure analysis in this superheater pipe is by testing mechanical properties, calculating the corrosion rate of the superheater pipe and providing maintenance solutions. The results of this study are (1) the failure that occurs in this superheater pipe is the occurrence of corrosion and leakage, (2) after heat treatment with a temperature of 8500C on the superheater pipe material, the hardness value increases to 148 BHN, the impact value also increases to 43.26 joules and the phase that occurs in this material is ferrite and pearlite which shows the specimen is increasingly tenacious, (3) the corrosion rate that occurs in the superheater pipe is 0.0489 mmpy, (4) the workable maintenance solution is hardening to increase the durability and service life of the superheater pipe.
Keywords: Superheater, Noise, Mechanical Properties, Heat treatment.

ABSTRAK

Superheater adalah sebuah komponen boiler subcritical yang berfungsi untuk memanaskan Kembali uap saturated pada tekanan kerja konstan sehingga menjadi uap saturated. Penelitian ini bertujuan untuk (1) menganalisa kegagalan pada superheater, (2) melakukan pengujian sifat mekanik terhadap material pipa superheater, (3) menghitung laju korosi pada pipa superheater dengan metode weight loss, (4) memberikan solusi pemeliharaan pencegahan atau preventive maintenance untuk meminimalkan kerusakan pipa superheater.
Metode yang digunakan pada penelitian ini adalah pendekatan kualitatif dengan jenis study eksperimental. Metode Analisa kegagalan pada pipa superheater ini adalah dengan cara pengujian sifat mekanik, menghitung laju korosi pada pipa superheater dan memberikan solusi pemeliharaan.
Hasil dari penelitian ini adalah (1) kegagalan yang terjadi pada pipa superheater ini adalah terjadinya korosi dan kebocoran, (2) setelah dilakukan heat treatment dengan suhu 8500C pada material pipa superheater maka nilai kekerasanya meningkat menjadi 148 BHN, nilai impak juga meningkat menjadi 43,26 joule dan fasa yang terjadi pada material ini adalah ferrite dan pearlite yang menunjukkan spesimen semakin ulet, (3) laju korosi yang terjadi pada pipa superheater adalah 0,0489 mmpy, (4) solusi pemeliharaan yang bisa diterapkan adalah hardening untuk meningkatkan ketahanan dan umur pakai pipa superheater
Kata kunci : Superheater, Kegalalan, Sifat Mekanik, Heat treatment.

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1. Introduction

A steam boiler, also known as a boiler, is a pressurized steam vessel that heats water to produce steam. A turbine converts this steam into electrical energy, and the residual steam from the turbine is passed to several production process stations, such as digesters, refiners, sterilizers, and boilers. Boilers are essential for palm oil mills because they produce energy [1]. Any disruption or damage to the boiler will lead to the failure of the palm oil mill.

Superheater is a subcritical boiler pipe section that serves to reheat saturated steam with constant working pressure so that it becomes superheated steam [2]. The pipe converts water into steam which is then distributed to turbines and to other machines that require high-pressure hot steam. Superheater pipes often experience various problems, such as leakage and rust on the pipe surface. This is very disadvantageous because the palm oil processing production process is completely stopped due to this damage..

Aluminum is a non-ferrous metal with several advantages and is widely used in various fields. There are in research lusiana.et al 2019. Is to analyze the failure analysis method by means of several destructive examinations and tests to determine the cause of failure, such as making visual observations, conducting chemical composition examinations using spectroscopy, conducting hardness testing using a micro vickers tester, and observing the microstructure observed using optical microscopy and scanning electron microscopy (SEM). The grain boundaries of the ferrite phase in the microstructure were thinned with enlarged grain size as a result of sperodization and decarburization as well as pitting corrosion from SEM examination of the corrosion product crust..

Based on previous research, it shows that this study conducted several tests such as micro vikers tester, and observation of microstructure using optical microscopy and scanning microscopy (SEM). Moving from that, the author will try to make research by adding hardness testing with a Brinel hardness tester, impact testing with the charphy method, comparing mechanical properties before heat treatment and after heat treatment (heat treatment) and testing the corrosion rate using the weight loss method.

Based on the previous background, the problem that will be solved by the author through this Final Project research is to calculate and minimize the corrosion rate that occurs in the boiler superheater pipe of PT. PN IV Adolina.

The objectives of this study are:

1. Analyzed the failure of the superheater pipe.
2. Conduct mechanical properties testing which includes: hardness testing, metallographic testing before and after heat treatment.
3. Calculating the corrosion rate of the superheater pipe with the weight loss method.
4. Provide preventive maintenance solutions to minimize superheater pipe damage.

2. Method

2.1 Watertube Boiler Specifications

The specifications of PT Perkebunan Nusantara IV Adolina watertube boiler are as follows :

a.	Merk	: Takuma
b.	Tipe	: Boiler Watertube
c.	Model	: N-600
d.	Capacity	: 30 ton/jam
e.	Minimum vapor temperature	: 220^0C
f.	Maximum vapor temperature	: 280^0C
g.	Maximum Pressure	: 20 kg/cm^2
h.	Superheater Pipe Materia	: ASTM A213 T12
i.	Flow velocity	: 0.1200 m^3/Kg

Chemical Composition of Superheater Pipe

The superheater pipe material is ASTM A213 T12 steel which is classified as low steel with carbon 0.05, this steel can be used at a maximum temperature of 560^0C.

Table 1. ASTM A213 T12 steel chemical composition

Composition	C	Si	Mn	P	S	Cr	Mo
ASTM A213 T12	0.05-0.15	Maks 0.5	0.30-0.61	0.025	0.025	0.80-1.25	0.44-0.65

The following are the mechanical properties of ASTM A213 T12 steel:

Table 2. Mechanical properties of ASTM A213 T12 steel

Properties	Value	Units
Brinell hardness	160	BHN
Vickers hardness	170	HV
Rockwell Hardness	85	HRB
Tensile Stress	415	MPa
Yield Strength	220	MPa
Elongation	30	%

2.2 Research Procedures

The research work steps used in the boiler superheater pipe failure analysis are as follows :

1. Visual Observation on Superheater Failure
   Visual observations were made with the aim of determining which section of pipe had failed and to identify the type of failure that may have occurred in the pipe, while taking samples of new and failed pipes for further analysis.
2. Forming of Superheater Pipe Specimen (ASTM A213 T12 Steel)
   Before testing in this failure analysis, the superheater pipe material must first be formed using grinding and scraping machines, the superheater pipe was formed into a plate of the appropriate size for each test.
3. Hardness Testing Process
   In this study, hardness testing was carried out to determine the level of hardness in the superheater pipe so that we can know how much maximum pressure the superheater pipe can receive when operating.
   The results of the brinel hardness test are obtained using the formula :

$$BHN = \frac{2P}{\pi D[D-\sqrt{(D^2-d^2)}]} \quad (1)$$

Description:

BHN = Brinell Hardness Number
P = Pressing Load (kg or kgf)
d = diameter of the indentation mark (mm)
D = indenter diameter (mm)

   1. Proses Perlakuan Panas (Heat Treatment)
      The heat treatment of this study aims to change the mechanical properties of the superheater pipe material and the author intends to carry out a hardening process to obtain an increased hardness value.
   2. Hardness testing process after heat treatment
   3. Microstructure Process

   This test aims to determine the grain size and phase contained in the superheater pipe material.

4. Corrosion Rate Testing Process
   This corrosion rate test uses a weight loss technique, which compares the weight of the corroded specimen before and after immersion. Then from the reduced weight we know how much corrosion rate occurs in the material.

To calculate how much weight is lost due to corrosion, the following formula is used :

$$CR = \frac{(\omega_0 - \omega_1) \times 87.6}{a.t.d} \quad (2)$$

Where :

CR = Corrosion rate (mm/year)

ω_0 = initial mass of the sample (g)

ω_1 = mass of sample after corrosion (g)

a = Area (cm^2)

t = time (h)

d = Density of metal or polymer (g/cm^3)

The following figure shows the research flow chart:

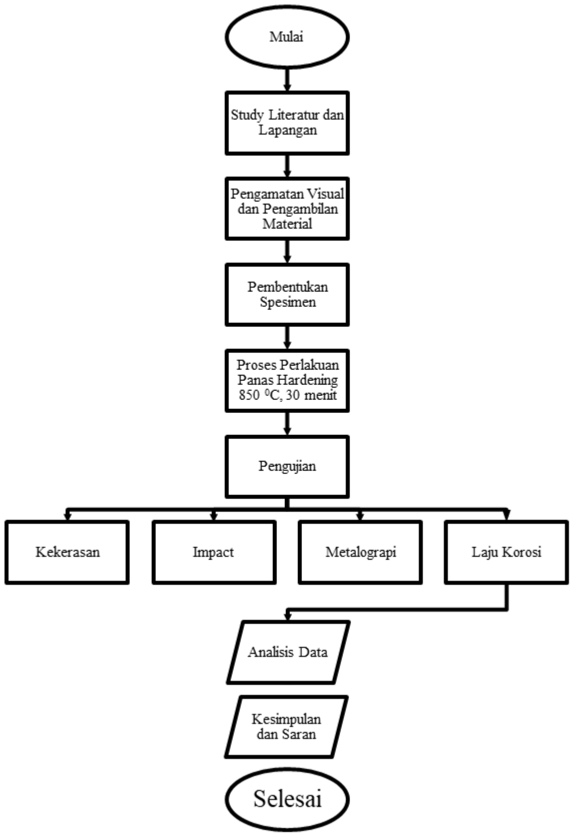

Figure 1. Research Flowchart

3. Result and Discussion

3.1 Visual Observation

In failure analysis, visual observation is the first step to determining damage. This is done because by looking at the shape of the damage, an initial hypothesis can be made as a basis for determining the next step.

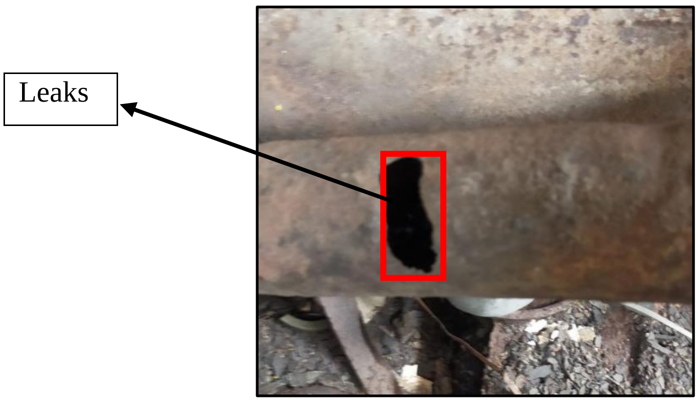

Figure 2 Visual observation of failed pipes

Figure 2 shows the visual observation of the failed superheater pipe. According to the visual observation, the corrosion and leakage of the superheater pipeline caused the steam to flow out. Age of use and high pressure are the causes of pipe damage.

3.2 Results of the Specimen Making Process

The superheater pipe material will be formed into 2 forms of specimens totaling 6 specimens, namely for hardness, impact, metallography and heat treatment tests. The specimens are formed using grinding and scraping machines.

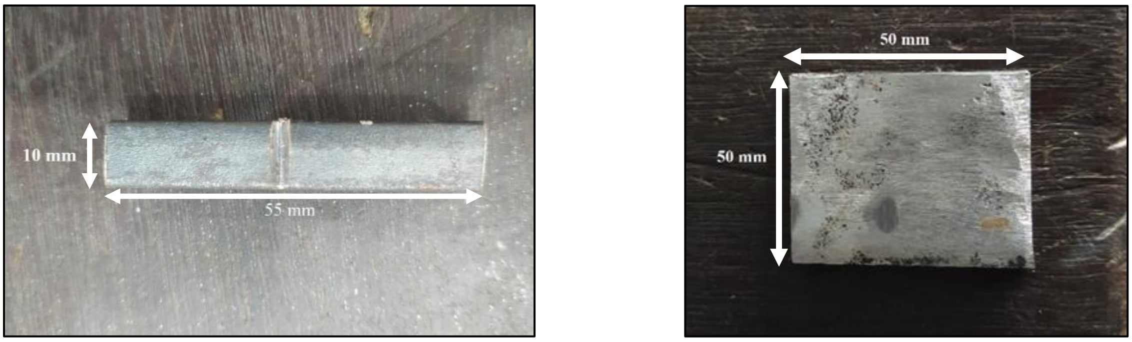

Figure 3 Specimen

3.3 Results of Hardness Testing

This hardness test was conducted to determine the hardness of the superheater pipe material (ASTM A213 T12 steel). In this brinel test a load of 1500 kg was used and held for 15 seconds, with ASTM type E-10 standards.

3.3.1 New Pipe Specimen

After testing the Brinell method, the Brinell Hardness Number (BHN) of each specimen is shown in table 3.

Table 3 Brinell Hardness Number Specimen Material before heat treatment

Point	Indentation Diameter (mm)		Load (Kg)	Violence Rate (BHN)	Average (BHN)
	D	d			
1	10	3.8		127	
2	10	3.9	1500	121	127.66
3	10	3.7		135	

The following is an example of a calculation to find the hardness value of a specimen using the Brinel method :

$$BHN = \frac{2P}{\pi D[D-\sqrt{(D^2-d^2)}]}$$

$$= \frac{2 \times 1500}{3.14 \times 10[10-\sqrt{(10^2-3{,}8^2)}]}$$

$$=127 \text{ BHN}$$

3.3.2 Hardness Testing Results of Superheater Pipe After Corrosion

Table 4. Brinell Hardness Number Spesimen Korosi

Point	Indentation Diameter (mm)		Load (Kg)	Violence Rate (BHN)	Average (BHN)
	D	d			
1	10	4,1		109	
2	10	4,0	1500	114	110.66
3	10	4,1		109	

The following is an example of a calculation to find the hardness value of a specimen that has been corroded by the brinel method :

$$BHN = \frac{2P}{\pi D[D-\sqrt{D^2-d^2})]}$$

$$= \frac{2\times1500}{3,14\times10[10-\sqrt{10^2-4,1^2})]}$$

$$=109 \text{ BHN}$$

3.3.3 Pipe Specimen After Heat Treatment

Table 5. Brinell Hardness Number Spesimen heat treatment

Point	Indentation Diameter (mm)		Load (Kg)	Violence Rate (BHN)	Average (BHN)
	D	d			
1	10	3.5		151	
2	10	3.6	1500	142	148
3	10	3.5		151	

The following is an example of calculations to find the hardness value of specimens that have been heat treated with the brinel method :

$$BHN = \frac{2P}{\pi D[D-\sqrt{D^2-d^2})]}$$

$$= \frac{2\times1500}{3,14\times10[10-\sqrt{10^2-3,5^2})]}$$

$$=151 \text{ BHN}$$

After obtaining the hardness or BHN value of ASTM A 213 T12 steel with various conditions, a comparison of the hardness test results will be made through a graph and to make it easier for readers to read the comparison of the results of this hardness test.

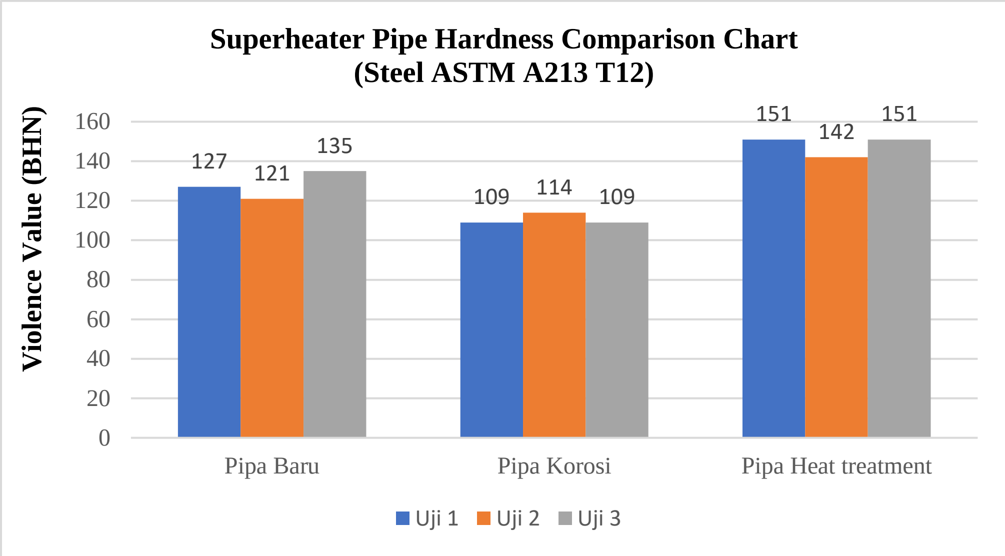

Figure 4. Graph Hardness Comparison Chart

From the graph, it can be seen that the results of the brinel hardness test on ASTM A213 T12 steel from each specimen, obtained in specimens that have experienced corrosion, the hardness is lower than the hardness of the material specimen before heat treatment, and after heat treatment of the material before heat treatment, the hardness increases.

3.3.4 ASTM A335 P91 Steel Material Specimen

After testing the hardness of the superheater pipe ASTM A213 T12 steel material, then the researcher will make a comparison with hardness testing also on the material that the author wants to try, namely ASTM A335 P91 Steel material.

Table 6. Brinell hardness number baja ASTM A335 P91

Point	Indentation Diameter (mm)		Load (Kg)	Violence Rate (BHN)	Average (BHN)
	D	d			
1	10	3,0		207	
2	10	3,1	1500	194	198
3	10	3,1		194	

The average hardness value of the steel from these test results is 198 BHN and is similar to the hardness value in the mechanical properties which is 200 BHN. Below will be shown a comparison table of the hardness test results on ASTM A213 T12 steel material and on ASTM A335 P91 steel.

Table 7. Comparison of hardness values

Name	Load (Kg)	Hardness Value (BHN)
Baja ASTM A213 T12	1500	127,66
Baja ASTM A335 P91	1500	198

From the table above, the author will make a graph to make it easier for readers to compare the kekerasanya value shown in the graph below :

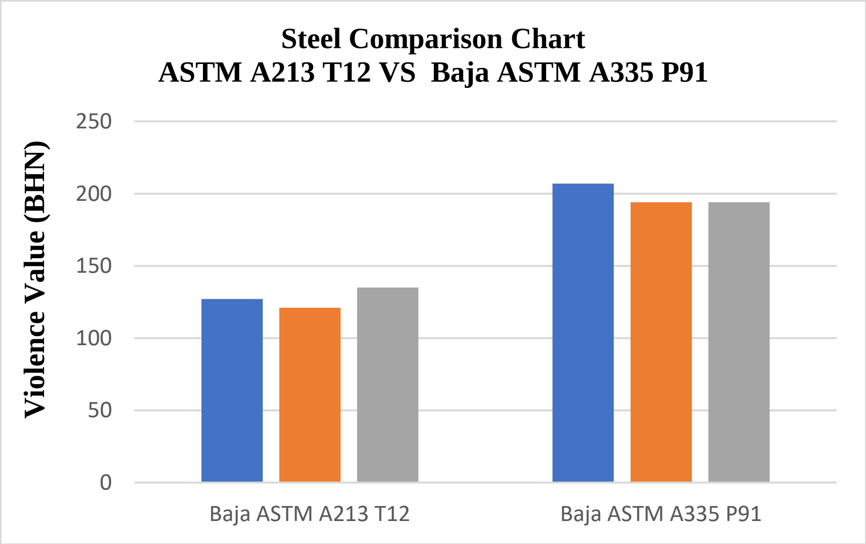

Figure 5. Graph Comparison of Hardness

From the graph above, it is found that the average hardness value of ASTM A213 T12 steel is 127.66 BHN and the average hardness value of ASTM A335 P91 steel is 198 BHN, which is higher than the previous pipe material.

3.4 Microstructure Testing Results

3.4.1 Microstructure Testing Results Before Heat Treatment

The results of microstructure testing before heat treatment with 200x magnification are shown in Figure.

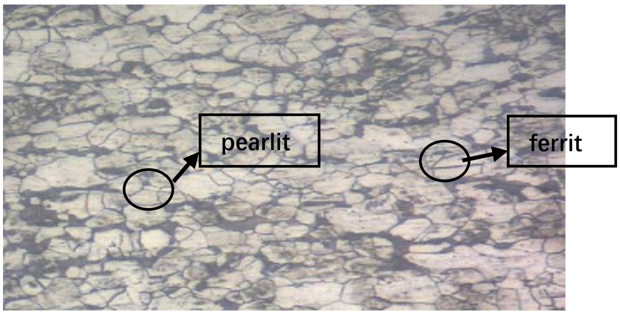

Figure 6. Material specimen before heat treatment

The image above shows the microstructure of the pure specimen (material before heat treatment). You can see pearlite in the black or dark structure and ferrite in the light structure. This shows that this specimen is pristine. These ferrite and pearlite phases show that ASTM A213 T12 steel is classified as steel with ductile properties. ASTM A213 T12 steel is classified as low carbon steel which has 0.05% C carbon which affects the hardness of the material.

3.4.2 Microstructure Testing Results After Heat Treatment

The results of microstructure testing before heat treatment with 100x and 200x perbesaraan can be seen in Figure 7.

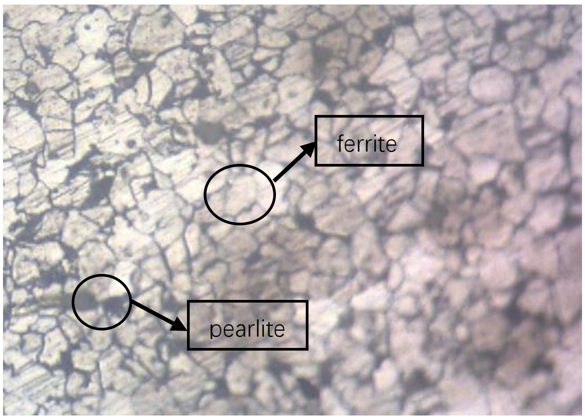

Figure 7. Spesiment After Heat Treatment

The picture above shows a photo of the specimen structure after heat treatment, the phase obtained is as above where the phase still has ferrite and pearlite but the structure is getting bigger. This shows that the specimen is more resilient, which is supported by the data from the impact test results.

3.5 Corrosion Rate Test Results

After conducting corrosion testing on ASTM A213 T12 Steel superheater pipe material, the results of the corrosion rate are obtained as in the table below.

Table 8. Corrosion rate test results

Material	Starting Weight (g)	Final Weight (g)	Wide (mm^2)	Soaking Time	Corrosion Rate Mm/year
Baja ASTM A213 T12	77.8145	77.7933	2892.75	7 hari	0.0489

The formula used to calculate this method is as follows:

$$CR=\frac{(\omega_0-\omega_1)\times 87.6}{a.t.d}$$

$$=\frac{(77.8145-77.7933)\times 87.6\times 8.46\times 10^4}{2892.75\times 168\times 9.7}$$

$$= 0.0489 \text{ mmpy}$$

The results of testing the corrosion rate with the weight loss method or the so-called weight loss method show that the corrosion rate that occurs in this superheater pipe is 0.0489 mmpy, which means that in one year the corrosion that occurs is 0.0489 mm.

4. Conclusion

Based on the results of research and data analysis that has been carried out on superheater pipes or ASTM A213 T12 steel, conclusions are obtained, including :

1. After visual observation of the boiler superheater pipe, it is known that the failure that occurs in the superheater pipe is corrosion and leakage in the superheater pipe.
2. The following are the results of the mechanical properties testing:
   a. The hardness test results show that the superheater pipe specimen that has undergone corrosion is 110.66 BHN has the lowest hardness value, while the hardness value of the pipe material before heat treatment is 127.66 BHN, and after heat treatment with a temperature of 850 ^{0}C the hardness value increases to 148 BHN.

b. The results of metalogaphy testing show that the material specimens before heat treatment have ferrite and pearlite phases, after heat treatment with a temperature of 850 ^{0}C and the phases contained are still ferrite and pearlite but the structure is getting bigger which shows the specimen is more ductile.

3. After testing the corrosion rate with the weight loss method on pipe specimens that have been corroded, the corrosion rate that occurs in this superheater is 0.0489 mmpy.
4. After conducting this research, the maintenance solution used as a maintenance solution is hardening to increase the durability and service life of the superheater pipe.

5. Acknowledgements

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6. Conflict of Interest

The author declares no conflict of interest related to data, support financial, and personal relationships in this paper.

References

[1]. Sugiharto, A. (2016). Tinjauan Teknis Pengoperasian Dan Pemeliharaan Boiler. Forum Teknologi, 56-68.
[2]. Lukito, Niko Adi, Mas Irfan P. Hidayat, and Haniffudin Nurdiansah. 2016. “Analisa Kegagalan Pipa Desuperheater Spray Pada Pembangkit Listrik Tenaga Uap Unit 4 PT. PJB UP. Gresik.” Jurnal Teknik ITS 5(2).
[3]. Lusiana, Lusiana, Fatayalkadri Citrawati, Erie Martides, and Gugum Gumilar. 2019. “Analisis Kegagalan Pipa Boiler Superheater Pada Pabrik Kelapa Sawit.” DIAMIKA : Jurnal Ilmiah Teknik Mesin 11(1): 26
[4]. Nugroho, Sri, and Azis Purwanto. 2011. “Analisis Kegagalan Piston Sepeda Motor Bensin 110 Cc.” Prosiding Seminar Nasional Sains dan Teknologi ke-2: 118–23.
[5]. Panjaitan, A. S. (2018). Metode Overallequipment Effectivenee (OEE), Failure Modes And Effect Analysis (FMEA), Reliability Block Diagram (RBD) Untuk Memetakan Efektivitas Produksi Di PT. Perkebunan Nusantara IV - Adolina . Skripsi.
[6]. Saefuloh, Iman, Haryadi, Abdurrofi Zahrawani, and Bintang Adjiantoro. 2018. “Pengaruh Proses Heat treatment Dan Tempering Terhadap Sifat Mekanik Dan Struktur Mikro Baja Karbon Rendah Dengan Paduan Laterit.” Jurnal Teknik Mesin 4(1): 56–64.
[7]. Arisandi, Duddy. 2015. Baca "Analisis Kegagalan Blok Rem Metalik Kereta Api (Shoe Train Brake Failure Analysis)".
[8]. Collins, Jack A., pada tahun 1993. Trouble with Materials in Mechanical Design: Analysis, Prediction, Prevention, WILEY, 2nd Edition.
[9]. Esemka, Abstrak Engine. 2013. “Program Studi Teknik Mesin , Universitas Islam 45 Bekasi Email : Handoyoyopi@yahoo.Com.” 1(1): 17–25.
[10]Muhammad Yusuf R Siahaan, Rakhmad Arief Siregar, and Faisal Amri Tanjung, Optimized Flexural Strength of Aluminium Honeycomb Sandwiches Using Fuzzy Logic Method for Load Bearing Application, International Journal of Intelligent Systems and Applications in Engineering, Volume 11 (4s), Pp. 466-472, 2023.
[11]V. Cohal, Spot Welding of Honeycomb Structures, IOP Conference Series: Materials Science and Engineering, No. 227, Pp. 1-6, 2017.
[12]M. Yusuf Rahmansyah Siahaan, dkk, Analisis Karakteristik Bahan Tembaga Akibat Pengaruh Proses Penempaan Terhadap Kekuatan Impak, Jurnal Rekayasa Material, Manufaktur dan Energi, Volume. 6, No.1, Hal. 99-105, 2023.
[13]Y.M. Li, et al., Analytical homogenization for stretch and bending of honeycomb sandwich plates with skin and height effects, Composite Structures, Volume 120, Pp.406-416, 2015.
[14]Rakhmad Arief Siregar, dkk, Effect of Forging Process on Impact Strength in Brass Materials, Jurnal Dinamis, Volume11, No.01, Hal. 020-028, 2023.
[15]Werner Goldsmith, and Jerome L. Sackman, An Experimental Study of Energy Absorption in impact on Sandwich Plates, International Journal of Impact Engineering, Volume 12, Issue 2, Pp.241-262, 1992.