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Research Article

The effect of time variation on the steels corrosion rate in 0.5 M H_2SO_4 solution

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Afira Ainur Rosidah[1], Vuri Ayu Setyowati[1], Suheni[1], and Rafly Rijayanto[1]

[1]Department of Mechanical Engineering, Institut Teknologi Adhi Tama Surabaya, Indonesia

Corresponding author:
Afira Ainur Rosidah
Department of Mechanical Engineering, Institut Teknologi Adhi Tama Surabaya, Indonesia
Email: afiraar@itats.ac.id

Abstract

Previous researches have carried out studying the corrosion behavior of steels, the most frequently used steels are medium carbon steel, alloy steel, and stainless steel. This is due to their wide range application. So, corrosion behavior is necessary to be analyzed for every steel type because of its wide function. This study was aimed to analyze the corrosion rate, macrostructure, and the XRD results of the AISI 1045, AISI 4140, and SS 304 which represent every steel type. Then, the steels were exposed to the 0.5M H2SO4 solution with various corrosion times. The variation of the corrosion time was 48, 96, and 144 hours. The results of this study revealed that AISI 1045 showed the highest corrosion rate with the value of 183.7 mpy at 144 hours of the time variation. All specimens obtained the increase in the corrosion rate with the increase in the corrosion time. Furthermore, for the macrostructure results, AISI 1045 and AISI 4140 gave obvious rust on the surface of the specimens for all time variation. The corrosion spots appear in the time variation of 96 and 144 hours for SS 304 specimens. XRD analysis confirmed the presence of metal oxides as corrosion products.

Keywords: *AISI 1045, AISI 4140, SS 304, corrosion time, sulfuric acid, x-ray diffraction*

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INTRODUCTION

Steels are widely used materials in every industrial field, continuous use leads the materials to experience a decrease in their function which is caused by corrosion attack, abrasive, and impact wear [1]. Corrosion is commonly found almost in every steel application, such as in pipelines and machinery parts [2]–[4].

Many researchers have carried out studying the corrosion behavior of steels, the most frequently used steels are medium carbon steel, alloy steel, and stainless steel. This is due to their wide application. For medium steels, Adoe et al. studied the temperature effect of AISI 1045 corrosion rate, additionally, Rosidah et al. examined the corrosion rate of the coated AISI 1045 in NaCl solution for 48 hours [5], [6]. Irianty et al. and Moli et al. investigated the corrosion rate of the medium alloy steel which is AISI 4140 with inhibitor and gas nitriding treatment, respectively [7], [8]. Moreover, the research on the corrosion behavior of stainless steel mostly used SS 304 as the material. The SS 304 was put in sulfuric acid and natrium hydroxide to analyze its corrosion rate with temperature and time variation [9], [10]. From the previous researches, it can be stated that corrosion medium, time, and temperature are important factors in affecting the corrosion rate.

The most convenient method to investigate corrosion attack is exposing the sample to the salt, alkaline or acidic medium, then calculating the weight loss by the time function [11], [12]. Previous studies mostly used the acidic medium to corrode the materials due to the rapid corrosion time. Medium carbon steel was exposed to the 9.8% H_2SO_4 solution was able to reach a corrosion rate of 1,900.73 mpy after one week [13]. Furthermore, SS 304 had a 1.3 mpy corrosion rate in 8% H_2SO_4 solution at 200^oC [9]. Other than the corrosion media, the corrosion time also provides a significant influence on the corrosion rate. Earlier experiments show that the longer exposing time can lead to a higher corrosion rate [14], [15].

Corrosion behavior is necessary to be analyzed for every steel type because of its wide function. The simplest way to analyze is by soaking the specimen to the acid medium using the time variation. For these reasons, this study was focused on analyzing the corrosion rate, macrostructure, and the XRD results of the AISI 1045, AISI 4140, and SS 304 representing every steel type. Then, the steels were exposed to the 0.5M H_2SO_4 solution with various corrosion times.

METHODS AND ANALYSIS

The materials used were AISI 1045, AISI 4140, and SS 304 with 25 mm in diameter and 30 mm in height. Each material was made as many as three samples as shown in Figure 1. The acid solution was prepared using 0.5M H_2SO_4 solution. Before the samples were exposed to the acid solution, all the samples were weighed to determine the initial weight, additionally, the surface area was calculated for all samples. Then, all the samples were soaked in the acid solution to analyze the corrosion behavior. The variation of the corrosion time was 48, 96, and 144 hours. After reaching the determined time, the samples were removed and weighed to obtain the final weight. These steps are illustrated in Figure 2.

The corrosion rate is calculated after obtaining the surface area, the initial and final weight of the samples. Since the corrosion experiment was carried out using the weight-loss method, so the corrosion rate was achieved using the following formula.

$$Corrosion\ rate\ (mpy) = \frac{534 \cdot W}{D \cdot A \cdot T} \qquad \dots (1)$$

Where:
W = weight loss (mg) = final weight – initial weight
D = specimen density (g/cm^3)
A = specimen area (in^2)
T = exposure time (hour)

The macrostructure analysis was done by observing the rust appearance. Furthermore, the X-Ray Diffraction (XRD) characterization was carried out using the angle range of 20-100^o.

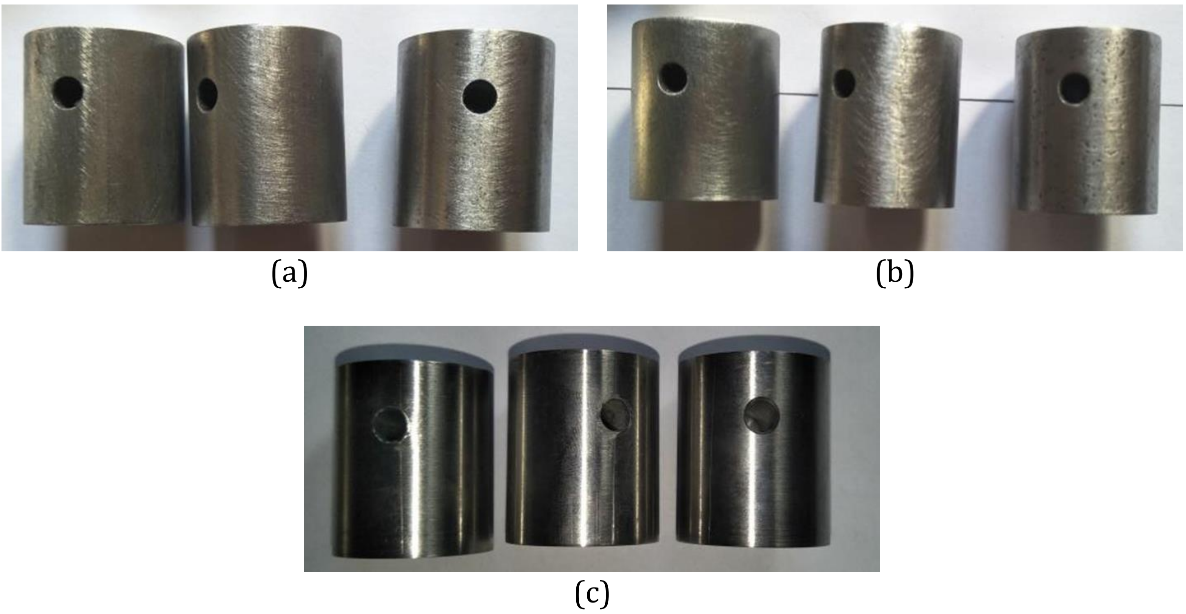

Figure 1. Corrosion testing specimens of (a) AISI 1045, (b) AISI 4140, and (C) SS 304

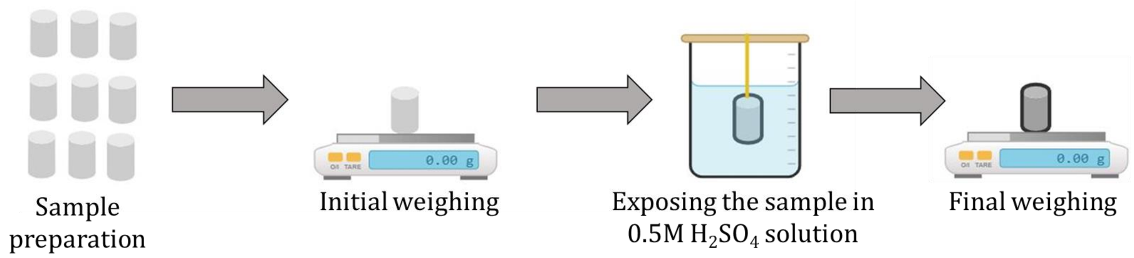

Figure 2. Illustration of corrosion immersion test mechanism

RESULTS AND DISCUSSIONS

Corrosion Rate

The corrosion rate was calculated using the formula as seen in the experimental section. From the initial and final weight for all samples, the weight changes were obtained and used to evaluate the corrosion rate with the corrosion time variation (see Table 1). The AISI 1045 shows the highest weight loss (2,500mg) that leads to the highest corrosion rate with the value of 183.7 mpy at 144 hours of the time variation. This highest result is followed by the AISI 4140 with the corrosion rate value of 176.87 mpy and SS 304 with the lowest corrosion rate value. All specimens display the increment results of the corrosion rate. The corrosion rate increases with the increase in the corrosion time as shown in Figure 3. This result is similar to the previous studies [9], [16].

Table 1. Initial weight, final weight, and corrosion rate results of AISI 1045, AISI 4140, and SS 304 with the corrosion time variation

No	Materials	Time (hour)	Mass			Corrosion rate (mpy)
			Initial weight (mg)	Final weight (mg)	Δm (mg)	
1	AISI 1045	48	4,000	3,450	550	122.3
		96	4,000	2,700	1,300	143.34
		144	4,100	1,600	2,500	183.7
2	AISI 4140	48	4,100	3,500	600	132.65
		96	4,000	2,700	1,300	143.7
		144	4,000	1,600	2,400	176.87
3	SS 304	48	4,000	4,000	0	0
		96	4,000	3,800	200	22.5
		144	4,000	3,700	300	22.63

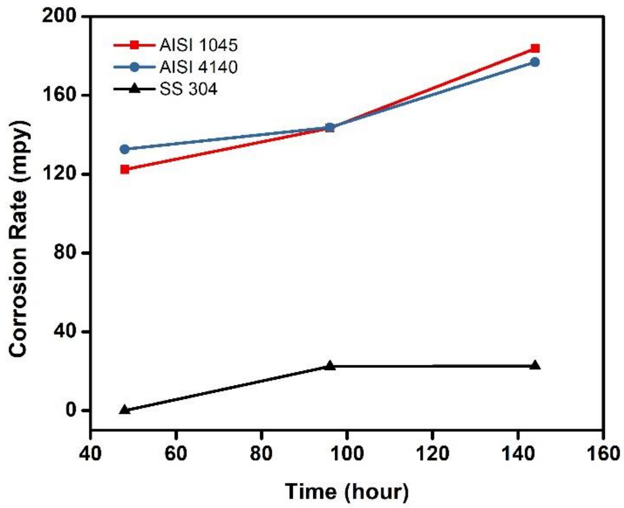

Figure 3. Corrosion rate results of AISI 1045, AISI 4140, and SS 304 with the corrosion time variation

Stainless steel has the lowest weight loss with a value of 300mg and the lowest corrosion rate of 22.63 mpy. This is because the SS 304 has a Cr_2O_3 passive layer protecting from corrosion. Moreover, the time exposure of 48 hours shows no weight loss, but with the increase of the exposure time, the weight loss escalates as well. This weight loss occurred due to the aggressive ion of SO_4^{2-} began to damage the passive layer as the time increased, additionally, this reason as revealed in previous studies [17].

Macrostructure

The visual appearance of the corroded specimens is displayed in Figure 4 – 6. AISI 1045 and AISI 4140 showed uniform corrosion patterns, obvious rust on the surface of the specimens appeared. The longer the corrosion time, the more obvious rust was seen on the surface. This was due to the formation of Fe^{2+} ions which was oxidized becoming Fe^{3+}. The deposited rust and corroded specimens were further confirmed in XRD results.

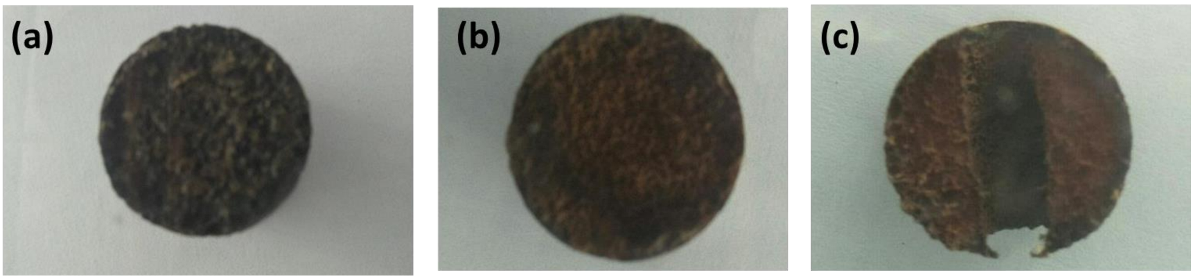

Figure 4. AISI 1045 with the corrosion time of (a) 48, (b) 96, and (c) 144 hours.

Figure 5. AISI 4140 with the corrosion time of (a) 48, (b) 96, and (c) 144 hours.

The macrostructure of the corroded SS 304 seems no obvious change for the 48 hours of the time variation. This indicates that 48 hours of the time variation had not been able to make ions from acid solution damaging the passive layer of SS 304. Moreover, the corrosion spots appear at the time variation of 96 and 144 hours (see Figure 6(b) and 6(c)). These corrosion spots indicate the intergranular corrosion attack and lead to the weight loss. This is because at the grain boundaries, there is a higher energy than the area around the grain boundaries due to the bonding forces between grains. This higher energy makes it easier for Fe elements to lose electrons and will turn into ions [18].

Figure 6. SS 304 with the corrosion time of (a) 48, (b) 96, and (c) 144 hours.

X-Ray Diffraction (XRD)

The diffraction peaks of raw materials and the corroded materials showed in figure 7. Similar patterns of AISI 1040 and 4140 indicate the presence of austenite, Fe_2O_3, and metallic Fe. Another iron compound in low intensity shows as iron oxide. Regarding peak shape, the board peak of AISI 4140 indicates low crystallinity instead of AISI 1045. Besides, new compounds exist in the XRD pattern of SS 304, such as Fe_3C (JCPDF 34-0001), Cr_2O_3, and Fe, Ni (Cr_2O_4) [19]. For corroded samples, the XRD pattern shows no significant differences for AISI 1040 and 4140 in Figure 7(b). Both materials have peak pattern as austenite, Fe, and Fe_2O_3 due to similar compositions of carbon and iron. However, the increasing peak intensity of Fe_3C appear in corroded SS 304 indicates more amount of iron carbide than raw materials.

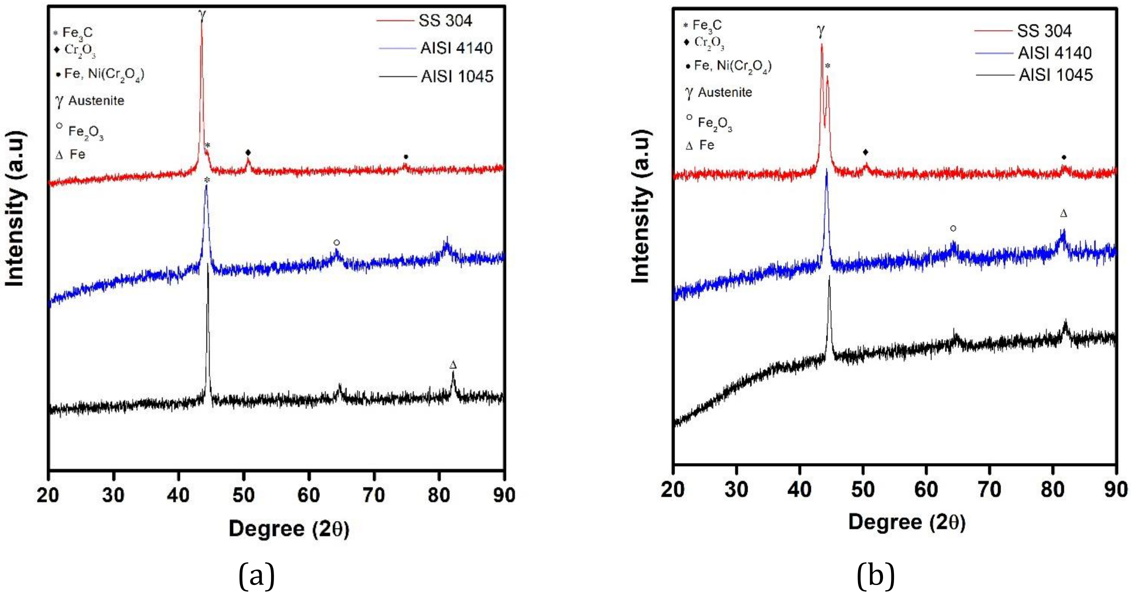

Figure 7. XRD resluts of (a) the raw materials and (b) the specimens after the corrosion time variation of 144 hours

CONCLUSIONS

AISI 1045 provided the highest corrosion rate with the value of 183.7 mpy at 144 hours of the time variation. Stainless steel has the lowest weight corrosion rate of 22.63 mpy. This is because the SS 304 has a Cr_2O_3 passive layer protecting from corrosion. AISI 1045 and AISI 4140 revealed uniform corrosion patterns, additionally, SS 304 showed the corrosion spots at the time variation of 96 and 144 hours. XRD confirmed the corrosion product including Fe_2O_3 for AISI 1045 and AISI 4140. Passive layer such as Cr_2O_3 and $Fe(Cr_2O_4)$ also showed in the SS 304 after corrosion occurred.

DECLARATION OF CONFLICTING INTERESTS

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REFERENCES

[1] S. Yin, D. Y. Li, and R. Bouchard, “Effects of strain rate of prior deformation on corrosion and corrosive wear of AISI 1045 steel in a 3.5 Pct NacI solution,” *Metall. Mater. Trans. A Phys. Metall. Mater. Sci.*, vol. 38, no. 5, pp. 1032–1040, 2007, doi: 10.1007/s11661-007-9107-8.

[2] E. B. Ramlee, P. B. Hussain, and N. B. Shaik, “Enhancing the lifetime and corrosion resistance of gears made of carbon steel,” *Materwiss. Werksttech.*, vol. 51, no. 6, pp. 774–779, Jun. 2020, doi: https://doi.org/10.1002/mawe.201900254.

[3] A. Rajabipour and R. E. Melchers, “Service life of corrosion pitted pipes subject to fatigue loading and hydrogen embrittlement,” *Int. J. Hydrogen Energy*, vol. 43, no. 17, pp. 8440–8450, 2018, doi: https://doi.org/10.1016/j.ijhydene.2018.03.063.

[4] W. Witoni, “KOROSI PADA PEREDAM SUARA (MUFFLER) TOYOTA KIJANG GRAND 94,” *J. Tek. Mesin*, vol. 6, no. April, pp. 16–21, 2019.

[5] D. G. H. Adoe, W. Bunganaen, B. K. A. Mandala, P. Studi, and T. Mesin, "Analisis Pengaruh Temperatur Dan Perlakuan Korosi Terhadap Ketahanan Putus Tabung Silinder Asetilin Bermaterial Drum Besi Bekas (Baja AISI 1045)," *Lontar J. Tek. Mesin Undana*, vol. 07, no. 02, pp. 22–27, 2020.

[6] A. A. Rosidah, V. A. Setyowati, and M. Choir, "Effect of Current and Coating Time on the Layer Thickness and Corrosion Rate of Electroplated AISI 1045," *SPECTA J. Technol.*, vol. 5, no. 1, pp. 99–104, 2021.

[7] R. S. Irianty and Khairat, "Ekstrak Daun Pepaya sebagai Inhibitor Korosi pada Baja AISI 4140 dalam Medium Air Laut," *J. Teknobiologi*, vol. IV, no. 2, pp. 77–82, 2013.

[8] L. T. Moli, N. Wahab, M. Gopinathan, K. Karmegam, and M. Maniyarasi, "Effects of gaseous nitriding AISI4140 alloy steel on corrosion and hardness properties," in *IOP Conference Series: Materials Science and Engineering*, 2016, vol. 152, no. 1, pp. 1–6, doi: 10.1088/1757-899X/152/1/012059.

[9] F. Bahar, "ANALISIS LAJU KOROSI MATERIAL BEJANA TEKAN PWR DALAM BERBAGAI KONSENTRASI H2SO4 DAN TEMPERATUR," *Sigma Epsil.*, vol. 14, no. 1, pp. 10–13, 2010.

[10] M. Meryanalinda, A. S. Umartono, and D. Setiawan, "Analisa Laju Korosi Material Stainless Steel Grade SS304 dan Alloy UNS N08020 Terhadap Asam Sulfat dan Natrium Hidroksida," *Wahana Tek.*, vol. 09, no. 01, pp. 39–43, 2020.

[11] S. R. Kumar, S. D. Krishnaa, M. D. Krishna, N. T. Gokulkumar, and A. R. Akilesh, "Investigation on corrosion behaviour of aluminium 6061-T6 alloy in acidic, alkaline and salt medium," in *Materials Today: Proceedings*, 2021, vol. 45, pp. 1878–1881, doi: 10.1016/j.matpr.2020.09.079.

[12] D. Clover, B. Kinsella, B. Pejcic, and R. De Marco, "The influence of microstructure on the corrosion rate of various carbon steels," *J. Appl. Electrochem.*, vol. 35, no. 2, pp. 139–149, 2005, doi: 10.1007/s10800-004-6207-7.

[13] M. Tampubolon, R. G. Gultom, L. Siagian, P. Lumbangaol, and C. Manurung, "Laju Korosi Pada Baja Karbon Sedang Akibat Proses Pencelupan Pada Larutan Asam Sulfat (H2SO4) dan Asam Klorida (HCl) dengan Waktu Bervariasi," *Sprocket J. Mech. Eng.*, vol. 2, no. 1, pp. 13–21, 2020, doi: 10.36655/sproket.v2i1.294.

[14] E. Febriyanti, A. Suhadi, and J. Wahyuady, "Pengaruh Waktu Perendaman dan Penambahan Konsentrasi Nacl (PPM) terhadap Laju Korosi Baja Laterit," *SINTEK J.*, vol. 11, no. 2, pp. 79–87, 2017, [Online]. Available: https://jurnal.umj.ac.id/index.php/sintek/article/view/2092.

[15] A. J. Sinaga and C. Manurung, "Analisa Laju Korosi dan Kekerasan Pada Stainless Steel 316 L Dalam Larutan 10 % NaCl Dengan Variasi Waktu Perendaman," *Sprocket J. Mech. Eng.*, vol. 1, no. 2, pp. 92–99, 2020, doi: 10.36655/sprocket.v1i2.186.

[16] I. Y. Suleiman, O. B. Oloche, and S. A. Yaro, "The Development of a Mathematical Model for the Prediction of Corrosion Rate Behaviour for Mild Steel in 0.5 M Sulphuric Acid," *ISRN Corros.*, vol. 2013, pp. 1–9, 2013, doi: 10.1155/2013/710579.

[17] M. N. Muhsinin and B. A. Kurniawan, "Pengaruh Polutan Terhadap Karakteristik dan Laju Korosi pada Baja AISI 1045 dan Stainless Steel 304 di Lingkungan Muara Sungai," *J. Tek. POMITS*, vol. 1, no. 1, pp. 1–5, 2012.

[18] H. Jodi, "Karakterisasi Korosi Baja SS-430 pada lingkungan NaCl," *Pus. Teknol. Bahan Ind.*, vol. 13, no. 3, pp. 149–155, 2007.

[19] A. P. S. Jasbir Singh, Sandeep Sharma, "Oxidation Effects on wear Resistance of SS-304 and SS-316 Austenitic Stainless Steels," *Int. J. Innov. Technol. Explor. Eng.*, vol. 8, no. 10, pp. 2353–2357, 2019.