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Corrosion Behavior of Steel Sleeve Joint in Different Concentration of Sodium Chloride (NaCl)

Umie Nadiatul Nadzirah Mohd Sohami[1], Muhammad Faisal Mahmod[1,2*]

[1]Faculty of Mechanical and Manufacturing Engineering,
University Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

[2]Structural Integrity and Monitoring Research Group (SIMReG), Faculty of Mechanical and Manufacturing Engineering, University Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

*Corresponding Author

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Abstract: A steel sleeve joint is a common way to fix a pipeline that has corroded, however even this type of repair is not immune to corrosion. To understand and increase the effectiveness of the steel sleeve joint, the corrosion behavior of the steel sleeve joint in various sodium chloride concentrations has been examined in this study. Carbon steel sleeve joints in weld and pipe areas were examined using a Scanning Electron Microscope (SEM) and Energy Dispersive Spectroscopy (EDS), which were utilized to determine the surface morphologies and element composition. The sample's parameters include sodium chloride concentrations of 15% and 33% and immersion times of 24, 48, and 72 hours. A Vickers hardness test is also done on the steel sleeve joint sample to compare the hardness of the weld and the pipe part. Results showed that the sample submerged in a 15% sodium chloride concentration corroded by more than 33%, and the corrosion product form increased with immersion time. The Vickers hardness number ranged from 216.4 to 284.8 HV for welds and 132.8 to 182.1 HV for pipe areas, respectively. The different values prove different corrosion behavior happen on both areas of the sample when compared by the results of surface morphologies and the Vickers hardness test.

Keywords: Steel sleeve joint, corrosion behavior, surface morphologies

1. Introduction

The oil and gas sector is one of the key global industries that has a significant impact on the world's economy. The oil and gas industries are divided into upstream, midstream, and downstream [1]. The most effective and secure method for moving oil and gas to the processing facilities during the midstream and downstream phases is through an offshore pipeline system. The offshore pipeline could be corroded along its length due to the presence of highly corrosive media such as carbon dioxide (CO2), hydrogen sulfide (H2S), and free water [2]. Millions of dollars are wasted annually due to downtime, lost production, and damaged pipes as a result of corrosion-related issues in oil-gas production and processing processes [3]. Many offshore pipeline systems have corrosion-related concerns due to their operation, and this is often regarded as a major problem that can lead to catastrophic failure and damage to the environment. As a general repair method for pipeline issues, full-encirclement steel sleeves have historically been used in oil and gas pipeline maintenance and repair. Steel sleeve joints are a typical repair method, however for a variety of reasons, corrosion can still happen at the steel sleeve joint. To better understand the materials and their corrosion behavior, it is crucial to identify the corrosion behavior of sleeve joints in pipelines.

**Corresponding author: mfaisal@uthm.edu.my*

The increasing usage of natural gas and oil in the industry has raised concerns over the availability of primary resources for long-term applications. To ensure the sustainability of oil and gas, researchers have started considering avoiding any corrosion, thus avoiding any pipeline failure or leakage in transporting the oil and gas to consumers. An alternative solution is to identify the possible corrosion in the offshore pipeline that includes steel sleeve joints. Hence, it is crucial to analyze the surface morphologies of the sleeve to identify the corrosion behavior of steel sleeve joints in two areas: the weld and pipe section. However, some research has been done focusing on experimentation for corrosion of the pipeline, so there is less research on corrosion for steel sleeve joints [4]. Therefore, this research aims to study the corrosion behavior of steel sleeve joints in different concentrations of sodium chloride and analyze surface morphologies for steel sleeve joints.

2. Materials and Research Method

The material utilized in this study was low carbon steel pipe, and the sample preparation will undergo four processes: cutting, grinding, filing, and Metal Inert Gas welding. The type of weld material used in MIG welding is stainless steel. The sectioning method was performed on the steel sleeve joint to produce a cross-section of the specimen. The element compositions of the materials are shown in Table 1.

Table 1 - Element compositions of low carbon steel sample

Material	C	Fe
Composition (%weight)	4.18	95.82

The SEM image was captured with a set magnification of x1.50k and 30.0um. Besides that, the corrosion rate by mass loss where all the samples have been weighed before and after immersion by following ASTM G1. Lastly, a Vickers hardness test has been conducted to investigate the welding hardness and corrosion behavior respectively after the sample has been immersed in NaCl. In addition, the Microhardness Number (HV) was measured on two different areas for each sample to compare the weld area and the pipe area of the steel sleeve.

2.1 Immersion Corrosion Test

Corrosion rates are computed with a uniform metal loss assumption. Therefore, when specimens are attacked unevenly, the estimated corrosion rate shows only the relative severity of the assault and could not be used to forecast carbon steel performance in the test solution [5]. The equation has been referred to as ASTM G1 (Standard Practice for Preparing, Cleaning, and Evaluation of Corrosion Test Specimens). The following equation represents the technique in millimeters each year [6]. The corrosion rate equation is as below:

$$\text{Corrosion Rate}, CR = \frac{(K)x(W)}{(A)x(T)x(D)} \tag{1}$$

where K is the constant for mm/yr, T is the time of exposure (h), A is the area of surface sample, W indicates mass loss (gram) and D is the density of sample ($\mathrm{g/cm^3}$). The immersion test used different sodium chloride concentrations and different immersion time, as shown in Table 2.

Table 2 - Sample with different NaCl concentration and immersion time

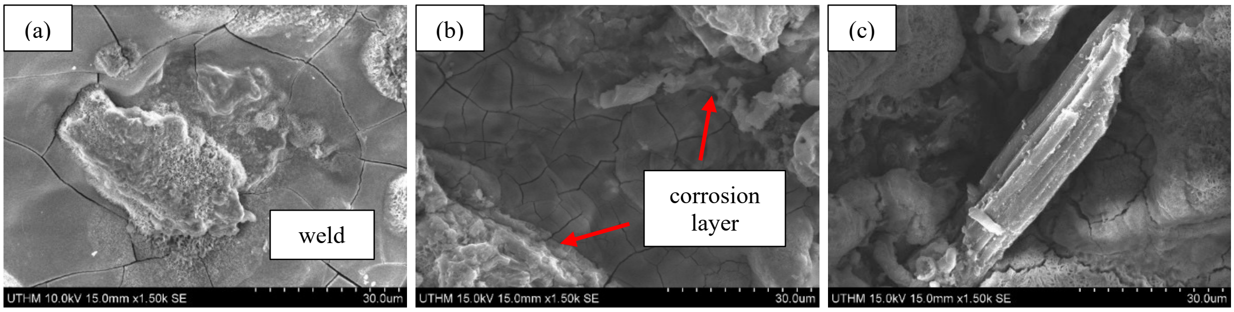
Concentration	24 hours	48 hours	72 hours
15% of NaCl	S151	S152	S153
33% of NaCl	S331	S332	S333

3. Result and Discussion

The results and discussion are focused more on corrosion behavior at different concentrations of Sodium Chloride (NaCl) and immersion time for each sample of steel sleeve. A total of 6 samples have been welded by using MIG welding with the different parameters of the concentration of NaCl, which are 15% and 33% and immersion times of 24, 48, and 72 hours respectively. The elements of corrosion products and corrosion surface morphologies were determined using a Scanning Electron Microscope (SEM) and Energy Dispersive Spectroscopy (EDS), with two areas for each sample: pipe and weld.

3.1 Surface Morphologies Weld Area

Fig. 1 shows the SEM images collected and analyzed on the weld area of the sample immersed in 15% NaCl concentration, and the immersion times are 24 hours, 48 hours, and 72 hours, respectively. Based on the SEM image, S151 developed a spot of corrosion products on the weld surface, and the layer of corrosion on S152 started to appear more. In contrast, S153 developed more corrosion products, with almost all of the weld surface being covered with a corrosion layer. In addition, the surface morphologies indicated that as the immersion time increased, the corrosion products and inconsistent oxide layer became denser and increased. The EDS results revealed that the main components of each sample are silicon, ferum, oxygen, and carbon.By comparing the oxygen percentage, the percentage of S152 and S153 increases by 15.32% and 22.35% from S151. It can be seen that the corrosion products formed at the weld are not consistent as the immersion time increases because the weight percentage of the sample is not consistent and other elements such as silicon exist in the weld area [7].



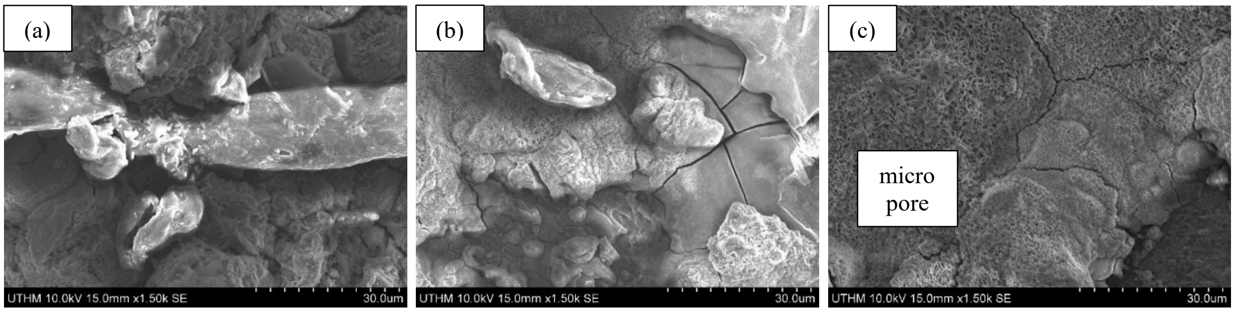
Element	Weight%	Atomic%
C K	44.00	66.90
O K	15.54	17.74
Si K	6.56	4.26
Fe L	33.90	11.09
Totals	100.00	

Element	Weight%	Atomic%
C K	22.69	40.26
O K	30.86	41.10
Si K	1.18	0.90
Cl K	2.10	1.26
Fe L	43.17	16.48
Totals	100.00	

Element	Weight%	Atomic%
C K	4.43	9.62
O K	37.89	61.76
Na K	1.53	1.73
Si K	1.46	1.35
Fe L	54.70	25.54
Totals	100.00	

Fig. 1 - Surface morphologies of weld area for 15% concentration of NaCl (a) S151, 24 hours; (b) S152, 48 hours; (c) S153, 72 hours of immersion time

Fig. 2 shows the SEM images collected and analyzed samples' weld area surfaces immersed in 33% NaCl concentration with immersion time of 24 hours, 48 hours, and 72 hours, respectively. Based on the images captured by the SEM, a corrosion layer formed on the weld area, and it shows that as the immersion time increased, the layer became inconsistent, and more significant spots developed. The weld area also shows the sample has micro pores and pits as a sign of corrosion. In contrast, it can be observed that the sample surface was intensively affected by the NaCl solution where Cl and Na exist in the element percentage of the sample immersed in 33% NaCl [8]. The corrosion product formed on the sample's surface after the immersion time test was iron oxides, called rust, and it developed in a consistent manner with the formation of corrosion products. S331 shows a pitting defect after NaCl immersion as shown in Fig. 2. In welding, pits are usually found at specific microstructural features in the weld deposit [9]. In comparison between 15% and 33% concentrations of NaCl for weld area, the image indicated similarity in surface morphologies under SEM. However, through EDS, the value of oxygen percentage in 15% NaCl is higher than the sample in 33%, which is the higher oxide form during the immersion test.



Element	Weight%	Atomic%
C K	36.84	69.35
O K	4.75	6.71
Cl K	1.23	0.79
Fe L	57.18	23.15
Totals	100.00	

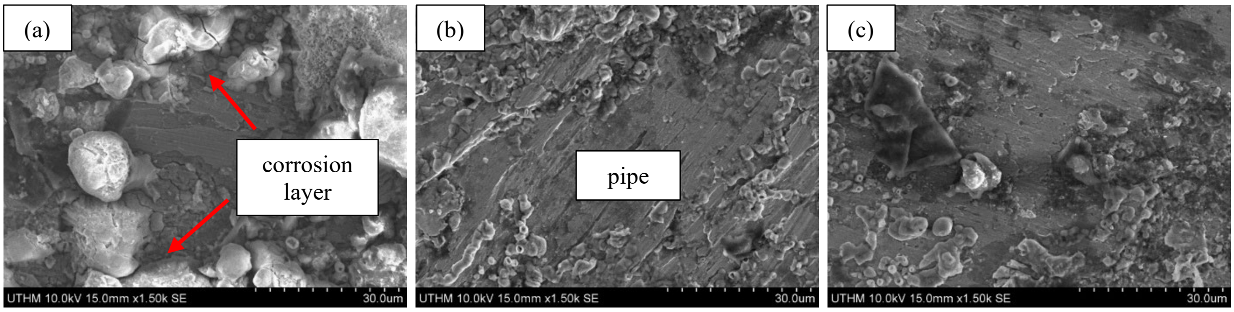
Element	Weight%	Atomic%
C K	40.60	59.67
O K	26.97	29.76
Si K	1.05	0.66
Fe L	31.38	9.92
Totals	100.00	

Element	Weight%	Atomic%
C K	6.53	14.74
O K	31.82	53.91
Na K	2.05	2.42
Fe L	59.60	28.93
Totals	100.00	

Fig. 2 - Surface morphologies of weld area for 33% concentration of NaCl (a) S331, 24 hours; (b) S332, 48 hours; (c) S333, 72 hours of immersion time

3.2 Surface Morphologies Pipe Area

Fig. 3 shows all the SEM images of the pipe part surface at the immersion time of 24, 48, and 72 hours with 15% concentrations of NaCl. SEM pictures of the sample have been collected and analyzed according to 24 hours, 48 hours, and 72 hours of immersion times. A thick and inconsistent layer of corrosion product was formed on the sample surface of S151 as the sample had been immersed for 24 hours. Based on the element percentages conducted by EDS, it shows that oxygen weight percentages are more significant at the thick spot layer compared to the center area of the sample surface. For S152, the layer appears to be a small and regular spot compared with S151. SEM image shows a uniform corrosion layer on the sample as the immersion time increased to 48 hours. This can be proven as the oxygen weight percentage in S152 increases by about 2.64% in weight percentage compared to S151. However, S153 shows that the sample develops a larger spot and less layer on the sample surface even with 72 hours of immersion time. Based on the element percentage, the weight of ferum is almost similar to S152 where the oxygen percentage increases with a 3.26% difference.



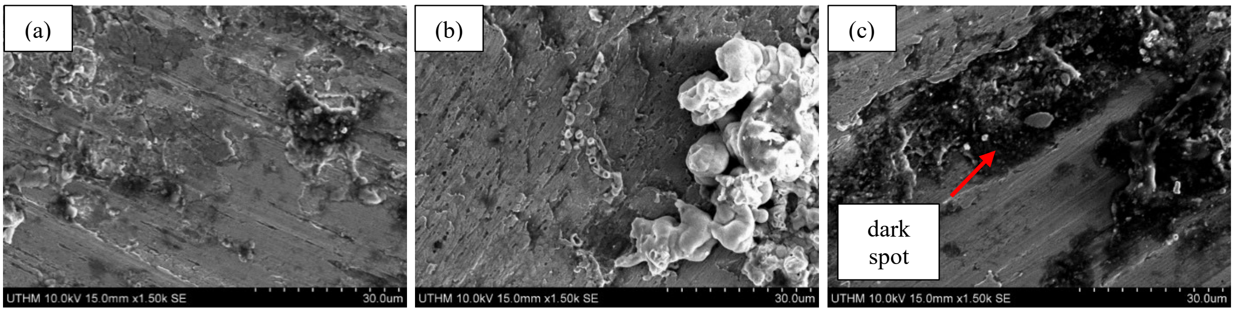
Element	Weight%	Atomic%
C K	15.78	31.74
O K	29.52	44.58
Fe L	54.70	23.67
Totals	100.00	

Element	Weight%	Atomic%
C K	10.00	21.47
O K	32.16	51.83
Fe L	57.84	26.70
Totals	100.00	

Element	Weight%	Atomic%
C K	7.70	16.55
O K	35.42	57.16
Fe L	56.88	26.30
Totals	100.00	

Fig. 3 - Surface morphologies of pipe area for 15% concentration of NaCl (a) S151, 24 hours; (b) S152, 48 hours; (c) S153, 72 hours of immersion time

Fig. 4 indicated a barely thin corrosion layer formed on the sample surface S331 as the sample had been immersed for 24 hours compared to the other samples. EDS data shows that carbon, oxygen, and ferum are the main components of the thin layer. While for S332, compared with S331, the layer appears to be thicker, and it can be seen on the rightside of the sample surface that more corrosion products have developed as the immersion time increased to 48 hours. This can be proven as the element percentage of oxygen on S332 increases with a difference of 10.63% in weight percentage compared to S331. However, S333 shows that the sample develops a dark spot and a thin layer on the sample surface. Based on the element percentage, the weight of oxygen is at the highest, 32.00% compared to S331 and S332 where the spectrum has been detected in the dark spot area. In comparison between 15% and 33% of the NaCl concentrations for the pipe area, the image indicates a significant difference in surface morphologies under SEM. The samples with 15% NaCl concentration show larger corrosion products formed on the sample surface. Through EDS, the value of oxygen percentage in 15% NaCl is higher than the sample in 33% NaCl, which presents the higher oxide form during the immersion test.



Element	Weight%	Atomic%
C K	29.29	56.79
O K	13.22	19.24
Fe L	57.49	23.97
Totals	100.00	

Element	Weight%	Atomic%
C K	51.92	69.20
O K	23.85	23.86
Fe L	24.23	6.94
Totals	100.00	

Element	Weight%	Atomic%
C K	12.12	25.16
O K	32.00	49.89
Fe L	55.88	24.95
Totals	100.00	

Fig. 4 - Surface morphologies of pipe area for 33% concentration of NaCl (a) S331, 24 hours; (b) S332, 48 hours; (c) S333, 72 hours of immersion time

3.3 Corrosion Rate by Mass Loss

The immersion corrosion testing was used to identify the corrosion rate and corrosion behavior for each sample. All samples were taken out from the corrosion media, washed with distilled water, and removed the corrosion product or rust before being weighted. Each sample's corrosion rate is calculated by following ASTM G1 (Standard Practice for Preparing, Cleaning, and Evaluation Corrosion Test Specimens), where the corrosion rates are calculated from mass losses.

Fig. 5 shows a graph of corrosion rate against immersion time, where it can be seen that the corrosion rate of the sample immersed in a 15% NaCl concentration is higher than that of a 33% NaCl. Thus, the higher the concentration, the lower the corrosion rate of the sample [10]. When the concentration is higher, the oxygen solubility will be reduced and more oxygen dissolved, thus increasing the corrosion rate [11]. From Fig. 5, it can also be seen that the changes in corrosion rate correspond with immersion time. As the immersion time increased, the weight loss also increased as more corrosion products developed on the sample surface. All the samples show an increase in corrosion rate for both NaCl concentrations with the increase of immersion time in the NaCl solution. However, sample S153 shows a decrease in corrosion rate with the increase of immersion time. The low corrosion rates observed suggest that a protective iron oxide coating formed rapidly on the metal surface [12].

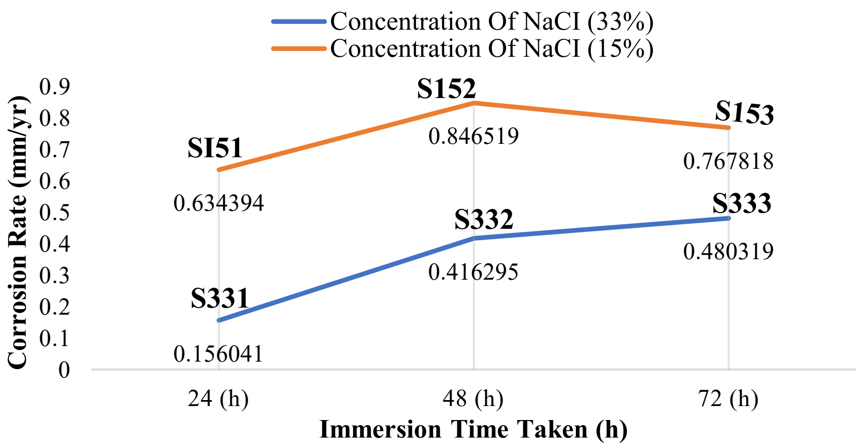


Fig. 5 - Graph corrosion rate against immersion time taken

3.4 Vicker's Hardness Test

The hardness analysis was conducted using a Vickers Hardness Tester on the sample to investigate the hardness value (HV) for a different area of the sample, divided by weld and pipe area. The load applied is constant for each indentation, which is 50 kg. Fig. 6 shows the average hardness number (HV) graph against the immersion time for the weld area. The graph shows an inconsistent line graph for all samples at two different concentrations of NaCl. This condition is caused by the MIG welding process, whereby the weld area is inconsistent during the welding process to create the steel sleeve.

However, both line graphs show the value of the average hardness number, HV, in the range of 216.4 to 284.8, which is still in a similar range. The results show an inconsistent value due to the element that exists in each of the samples itself [13]. Based on the SEM and EDS results discussed in Section 3.1, the sample shows the addition of elements such as silicon in the weld area of the sample. These different elements in the weld area of the sample affect the average hardness number (HV) of samples where the value is inconsistent with the immersion time and NaCl concentration. For example, samples S333 and S153 show the approximate value with an immersion of 72 hours in the NaCl solution.

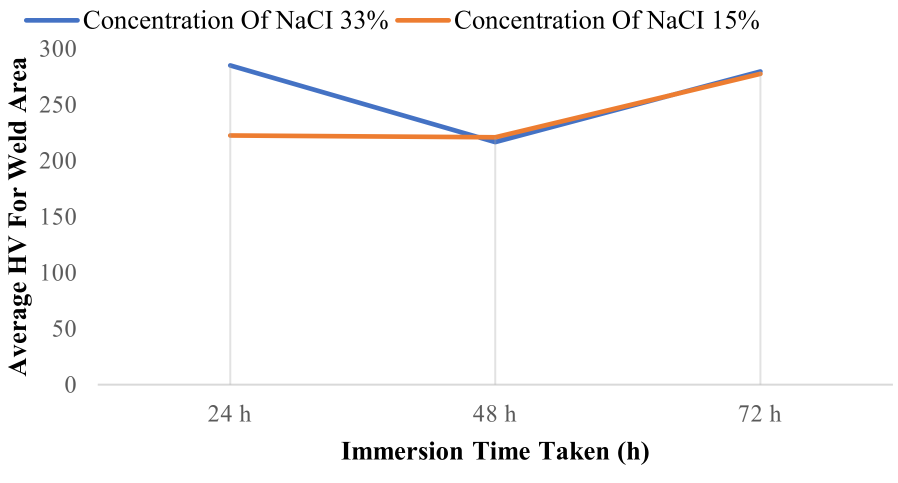


Fig. 6 - Graph average HV against immersion time taken for weld area

Fig. 7 shows the graph of the average hardness number (HV) against the immersion time for the pipe area. The graph shows an approximately consistent line graph for all samples at two different NaCl concentrations. This condition is caused by the corrosion products formed on the sample, whereby the corrosion on the pipe area is consistent with the immersion time. Both line graphs show an almost similar value of the average hardness number, HV, at 48 hours and 72 hours of immersion time. The average hardness number (HV) for all the samples is 132.8 to 182.1, which is still in a similar range. The results show a consistent value due to the main element that exists in each of the samples itself [13]. Based on the SEM and EDS results discussed in Section 3.2, the sample shows the main elements of carbon, oxygen, and ferum in the pipe area of the sample. However, different weight percentages for each element on the sample surface affect the sample's average hardness number (HV) for the pipe area. In addition, the different weight percentages for the elements are also in a similar range, so the effects on hardness are minor and almost similar.

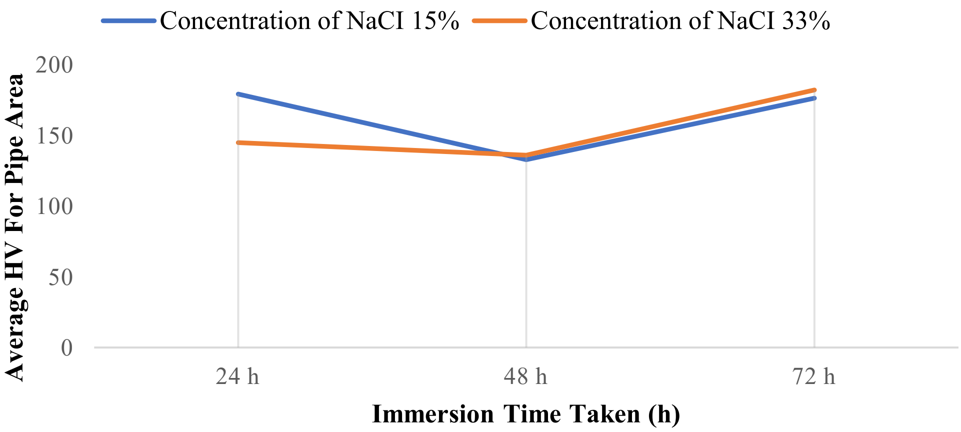


Fig. 7 - Graph average HV against immersion time taken for pipe area

4. Conclusion

The results obtained by SEM and EDS illustrate that the surface morphologies in the weld area have a thick layer of corrosion product and that the layer of oxide seems higher in the weld area compared with the pipe area. In comparison, the samples at 15% NaCl concentration corroded more than the samples at 33% NaCl. These results can be observed through visual inspection of the color changes and could be proven by the element composition and surface morphology images. Thus, the higher the NaCl concentration, the lower the corrosion rate of the sample.

The mass loss of the sample reflects the corrosion rate when calculated by using the equation from ASTM G1. Results of the corrosion rate indicate that the corrosion rate will increase as the immersion time increases. Other than that, the element composition shows that the weld area consists of additional elements such as silicon, sodium, and chloride, which affect the hardness value of the weld area [14]. As a result, the hardness number at the weld area is higher than in the pipe area due to the additional elements, even though significant corrosion occurred in the weld area.

As a consequence of the overall results, the corrosion behavior of the carbon steel sleeve joint may be analyzed primarily by comparing the weld and pipe area, where it can be seen that varied concentrations and immersion times considerably affect the sample. Thus, all research objectives have been accomplished, and the findings can contribute to future studies.

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