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The Effect of Beach Environment and Sea Water on Nickel Corrosion Rate as a Collimator Material for the Application of Boron Neutron Capture Therapy

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ABSTRACT

The purpose of this study is to determine the value of corrosion rate influenced by coastal environment and seawater to nickel as a collimator base material for the application of boron neutron capture therapy (BNCT). In this research, the authors used 99.9% pure nickel as the reference material. Corrosion testing was carried out to determine the rate of corrosion of nickel as a base material for BNCT. After the specimens were formed, the test specimens were then corroded for 12 weeks, with various conditions such as indoor, outdoor environment, static seawater, and moving seawater. The results of this study indicated that in corrosion testing with indoor condition, the corrosion rate values are 0.61-1.00 mpy. For outdoor condition, the corrosion rate is 0.89-1.34 mpy. Meanwhile, at static seawater conditions, the corrosion rate is 0.97-1.24 mpy. Lastly, for moving seawater condition, the corrosion rate is 1.64-1.91 mpy. The results showed that corrosion resistance was relatively the same for all nickel exposed to corrosion in the coastal environment. Therefore, in regards to corrosion resistance, using nickel as a collimator base material for BNCT applications is considered as safe.

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1. INTRODUCTION

Cancer is one of the most pressing problems in the world, with a substantial and increasing burden carried by middle and lower income countries [1]. Cancer remains a leading cause of death throughout the world. In the United States, 1,735,350 new cancer

cases and 609,640 cancer-related deaths occurred in 2018 [2].

The clinical results of conventional mono-chemotherapy on cancers are usually far from satisfactory due to several problems such as tumor heterogeneity and resistance to chemotherapy drugs [2]. In Indonesia, traditional medicine is used as a herbal medicine. Anti-cancer drugs with herbal extracts are highly recommended to improve clinical outcomes in cancer chemotherapy as an

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immunotherapy agent [3]. However, herbal medicine given is not necessarily effective between one patient and another, thereby reducing its effectiveness. Other means of cancer prevention and therapy can be done by means of Boron Neutron Capture Therapy (BNCT).

BNCT is a cancer therapy technique that uses the principle of physics in nuclear reactions when stable boron (boron-10) is irradiated using low-energy (thermal) neutrons [4]. The source of neutrons can be obtained from various sources, such as radioisotopes, nuclear reactors, and accelerators [5]. The disadvantage of a radioisotope neutron source is that the neutron flux is low, causing cancer therapy to last more than an hour. This long-term therapy will cause fatigue in patients and require more boron [6].

The use of reactors as a neutron source is limited by several factors, such as high safety requirements for reactor facilities, the presence of radioactive waste, high construction costs, and difficulties in obtaining permits [7]. To overcome this problem, neutron sources from accelerators are being developed. It employs a collimator to redirect the neutron beam into the target boron, with the former is subject to corrosion. Therefore, one of the studies needed is corrosion research on collimator material, in this case nickel.

Corrosion is a physicochemical interaction between a metal and its environment which results in changes in the nature of metals and can cause significant functional damage to metals [8]. Based on this, the authors conducted a study of the influence of the coastal and seawater environment on the corrosion rate of nickel, by testing corrosion on the coastal and seawater environments. The authors chose this research because nickel is increasingly being used in various industrial fields, one of which is as a collimator-making material for BNCT applications.

2. THEORY

Boron Neutron Capture Therapy (BNCT)

Boron Neutron Capture Therapy (BNCT) is a cancer therapy method that uses interactions between thermal neutrons and boron-10 which produce boron-11, which decayed while simultaneously emit alpha, lithium, and gamma particles [9].

First, boron-10 drug carriers are injected into the blood; then the cancer accumulates the drug through the blood transport system. After that, the cancer is illuminated by thermal or epithermal neutrons, where the neutrons are extracted from the fission of uranium-235 in nuclear reactors. Furthermore, boron-10 atoms in cancer capture neutrons to produce 1.47 MeV and 0.84 MeV alpha particles along with lithium-7, the former of which are used to kill cancer cells [10].

Neutrons used in cancer therapy with the BNCT method are thermal and epithermal neutrons. Thermal neutrons can penetrate body tissue at a depth of 2-3 cm, making it suitable for use to treat skin cancer, while epithermal neutrons are able to penetrate body tissues at a depth of 8-10 cm, making them suitable for use in deeper cancer therapy [11].

Nickel is considered as the best collimator wall material, since it can reduce neutron flux but can also slightly increase neutron energy. In fact, pure nickel is able to produce epithermal neutrons without intermediaries, although it is still considered better to use intermediaries [12]. BNCT collimator design drawings can be seen in Figure 1.

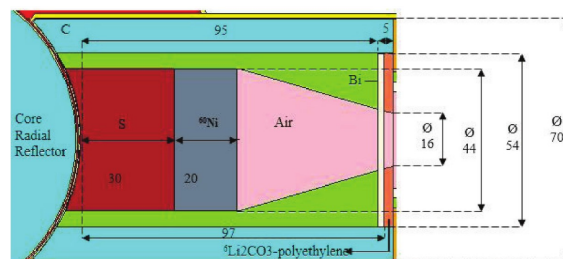


Fig. 1. BNCT Collimator Design [12].

Sketch of the collimator measurement results can be seen in Figure 2.

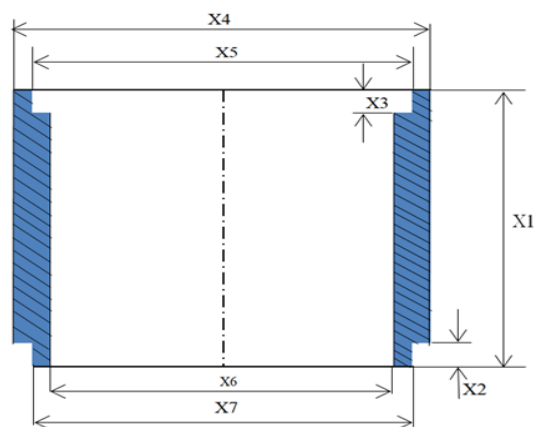


Fig. 2. Sketch Collimator.

Table 1. Shop finishing dimension inspection report for each collimator section conducted at PT. BARATA INDONESIA [4].

No	Standard	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆	X ₇
		145	15	15	Ø190	M175X3	Ø160	M175X3
1.	Realization	144.8	15.0	15.0	190.0	171.8	160.0	174.9
2.	Realization	146.6	16.0	15.0	190.5	171.9	159.3	175.0
3.	Realization	145.5	15.0	14.6	190.1	171.2	159.7	174.6
4.	Realization	145.2	15.1	14.9	190.0	171.8	159.7	174.7
5.	Realization	145.1	15.4	14.8	189.8	171.7	159.8	174.8
6.	Realization	145.0	15.3	14.9	190.0	171.6	159.7	174.6
7.	Realization	145.0	15.1	14.5	190.1	171.0	160.0	176.1
8.	Realization	145.2	15.0	14.8	189.6	171.7	160.0	174.5
9.	Realization	145.5	15.0	14.6	190.1	171.2	159.7	174.6
10.	Realization	145.1	15.4	14.8	189.8	171.7	159.8	174.8
11.	Realization	145.0	15.1	14.5	190.1	171.0	160.0	176.1
12.	Realization	145.5	15.0	14.6	190.1	171.2	159.7	174.6

Nickel

Nickel (Ni) is a hard, corrosion resistant silverish-white metal. Ni plays an important role in hard metal deposition processes in the form of metal alloys. For example, stainless steel contains 18% Ni and 8% Cr. Other example is nichrome, which contains 80% Ni and 20% Cr [13].

Nickel, with atomic number 28, is a transition metal element with a mass number of 58,71. It is located in group VIII period 4. In general, the oxidation level of Ni is +2, while at the oxidation level +3 is only little known [14].

Table 2. Density of Nickel and Alloys [15].

UNS Number	Alloy	Density
		g/cm ³
N02200	Nickel 200	8.89
N04400	Nickel copper 400	8.84
N06600	Nickel chromium iron alloy 600	8.51
N06625	Nickel chromium molybdenum alloy 625	8.44
N08825	Iron nickel chromium alloy 825	8.14
*	Iron nickel chromium cast alloy 20	8.02
N10665	Nickel molybdenum alloy B2	9.20
N06985	Nickel chromium molybdenum alloy G-3	8.30

Corrosion

Corrosion is the event of damage to a material or a decrease in the quality of material due to its

reaction with its environment. The corrosion process is unavoidable, but efforts can be made to slow it. Muis conveyed that there were 4 components of corrosion, including: anode, cathode, electrolyte, and cross metal [16].

Corrosion rate is the amount of material lost (oxidized) per unit of time. Corrosion rate can be calculated by the method of weight loss or weight gain loss (WGL). This test is in accordance with the standards (ASTM G31-72, 2004) and (ASTM G1-03, 2017).

Hadi, S., 2018 explained the formula for the corrosion rate, as seen in equation 1 [17].

$$CPR = \frac{K.W}{\rho.A.t} \quad (1)$$

where,

CPR : Corrosion rate (mpy)

W: Lost weight (gram)

P : Specimen density (g/cm³)

K: Constants (Table 3)

t : time of corrosion (hours)

A: Area of specimen affected by corrosion (cm²)

Table 3. Constant Values [15]

Corrosion Rate Unit Desired	Constant (K)
Mils per year (mpy)	3.45 x 10 ⁶
Inches per year (ipy)	3.45 x 10 ³
Inches per month (ipm)	2.87 x 10 ²
Millimetres per year (mm/y)	8.76 x 10 ⁴
Micrometres per year (µm/y)	8.76 x 10 ⁷

with K = constant 3.45 x 10⁶, W = missing mass (gram), D = density of test sample (g/cm³), A = cross-sectional area (cm²), t = test time (hour) [18]. In terms of the accuracy of mils per year, it is preferable when the corrosion rate ranges from 1-200 mpy so that the corrosion data can be shown using small numbers, avoiding decimals. The designation of inches per year and inches per month will involve the decimal point [19].

Table 4. Correlation between Corrosion Rate and Corrosion Resistance [20].

Relative Corrosion Resistance	Corrosion Rate			
	mpy	mm/yr	$\mu\text{m/yr}$	nm/hr
Outstanding	< 1	<0.02	< 25	< 2
Excellent	1 - 5	0.02 – 0.1	25 - 100	2 - 10
Good	5 - 20	0.1 – 0.5	100 - 500	10 - 50
Fair	20 - 50	0.5 – 1	500 - 1000	50 - 150
Poor	50 - 200	1 – 5	1000 - 5000	150 - 500

Micro Structure

Micro structure is the smallest structure contained in a material which cannot be seen with the naked eye, but can be observed using micro structure observers including: upright light microscope, electron microscope, ion field microscope, field emission microscope, and X-ray microscope. The benefits of observing the microstructure are namely to study the relationship between the properties of the material with the structure and defects in the material and to estimate the properties of the material if the relationship is already known [21].

3. METHODOLOGY

Formation of corrosion test and micro test specimens

Initial specimens obtained from PSTA-BATAN were square in shape with an average size of 26 x 25 x 14 mm before machining. Corrosion test and micro test specimens are made by milling lathe.

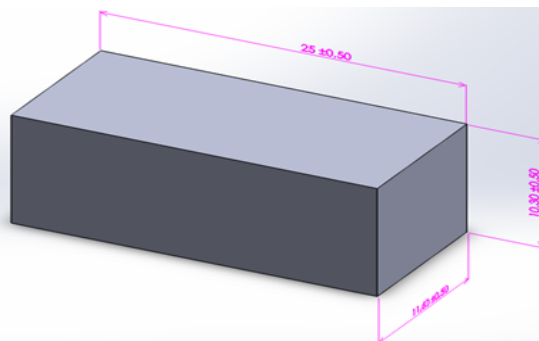


Fig. 4. Dimensions of Corrosion and Micro Test Objects, average size: 25 mm x 11.6 mm x 10.3 mm with a total of 12 specimens.

Micro Structure Testing

Micro structure testing steps:

1. The nickel specimen, etching liquid, water, and upright microscope are prepared.
2. The surface of the specimen is soaked with special etching fluid for 5-20 seconds.
3. The specimen is dipped in distilled water until it is clean, removed from the water, then wiped using a cloth rag.
4. Specimens are viewed using a microscope at 100x magnification, then photos are taken using a cellphone or screenshots using a computer.

Corrosion Testing

Corrosion testing steps:

1. The nickel specimens, digital scales, and calipers are prepared.
2. Specimens are weighed and measured to determine the initial weight before corroding.
3. Specimens are placed in each variation by hanging.
4. The aquarium is prepared for testing variations of stationary water and moving water.
5. Room temperature, salinity, pH of water, angina velocity, humidity are measured using each tool.
6. Specimens of every variation are taken every 4 weeks until it the end of 12 weeks.
7. Corrosion products are cleaned using a special cleaning fluid for nickel corrosion for 1 - 3 minutes.
8. The specimen is washed using soap, rinsed with clean water, and wiped dry.
9. The specimen is weighed; then the final result is obtained to be used as a weight loss formula.

Schematic of indoor and outdoor testing in a beach environment is shown by Figure 5.

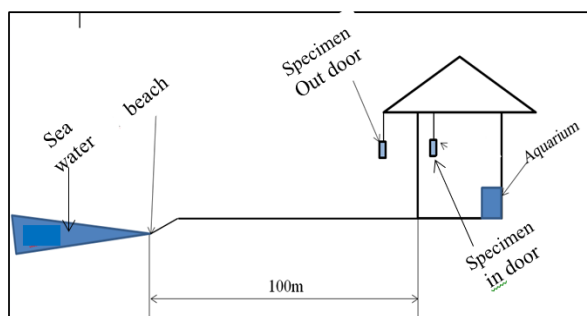


Fig. 5. Schematic of indoor and outdoor testing in the Ketawang Beach environment

Schematic testing of specimens in a State of static water and moving water is shown in Figure 6.

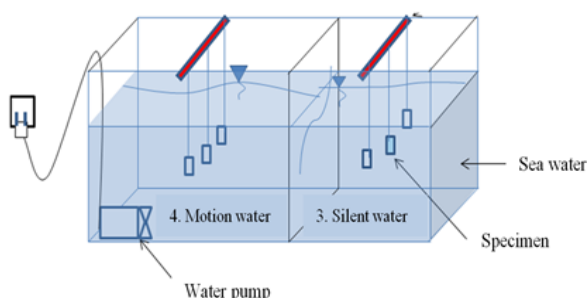


Fig. 6. Schematic of testing stationary water and moving water specimens in the aquarium

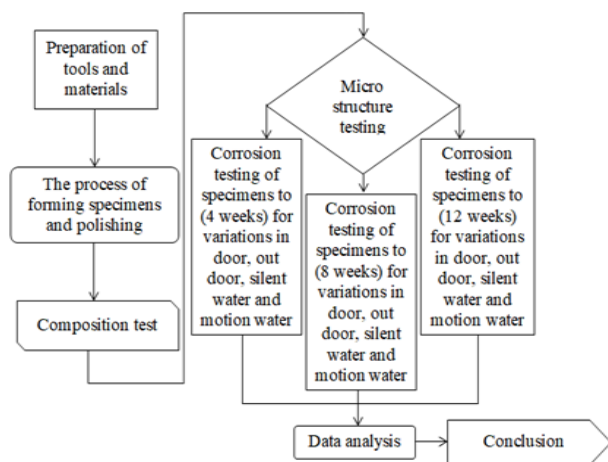


Fig. 7. Research flowchart.

4. RESULTS AND DISCUSSION

Corrosion testing on Ni specimens is aimed to compare the rate of corrosion in specimens with variations in indoor, outdoor, seawater in a stationary state, and seawater in a moving state for 4 weeks, 8 weeks, and 12 weeks. Corrosion testing was conducted using nickel material with 99.9% purity in 12 specimens. This corrosion test used the

method of weight loss or weight gain loss (WGL), where the specimens are corroded in the environment and the sea water of Ketawang Beach for the aforementioned periods. Corrosion data results are shown in Table 5.

Table 5. Data Results of Conversion to Corrosion Rate mpy (mils per year)

Name Specimen	Variation	K	t (jam)	ΔXYZ (cm ²)	ρ	Δm (gram)	Corrosion rate (mpy)
4 weeks							
Q1	In door	3450000	672	12.69	8.89	0.02	1.00
Q2	Out door	3450000	672	12.95	8.89	0.02	0.89
Q3	Silent water	3450000	672	13.93	8.89	0.03	1.24
Q4	Motion water	3450000	672	14.10	8.89	0.04	1.64
8 weeks							
Q5	In door	3450000	1344	12.69	8.89	0.03	0.68
Q6	Out door	3450000	1344	12.95	8.89	0.05	1.11
Q7	Silent water	3450000	1344	13.93	8.89	0.05	1.04
Q8	Motion water	3450000	1344	14.10	8.89	0.09	1.84
12 weeks							
Q9	In door	3450000	2016	12.69	8.89	0.04	0.61
Q10	Out door	3450000	2016	12.95	8.89	0.09	1.34
Q11	Silent water	3450000	2016	13.93	8.89	0.07	0.97
Q12	Motion water	3450000	2016	14.10	8.89	0.14	1.91

Figure 8 shows a graph comparing the value of corrosion rate with various conditions of indoor, outdoor, static seawater, and moving seawater at 4 weeks, 8 weeks, and 12 weeks. The highest value occurs in silent moving water condition by 1.91 mpy and the lowest value is on the indoor condition by 0.61 mpy. There is a significant difference between the highest and lowest values of 1.31 mpy. From the graph analysis of the nickel corrosion rate presented, it can be concluded that the outdoor environment of the Ketawang Beach and moving seawater can affect the rate of corrosion.

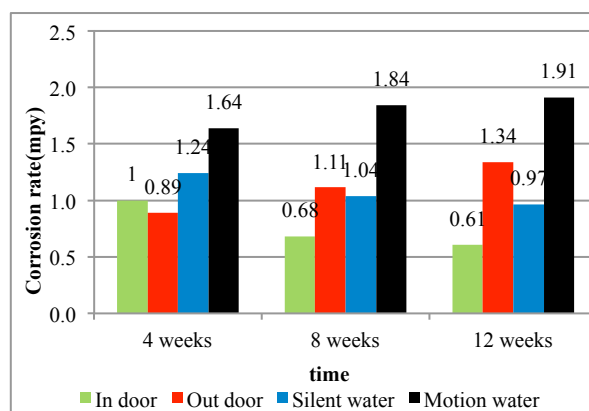


Fig. 8. Graph of Ni corrosion rate for 4 weeks, 8 weeks, and 12 weeks with variations indoor, outdoor, stationary water, and moving water.

Corrosion rate values in the condition of the outdoor environment of the Ketawang Beach and moving seawater continue to increase. The highest value occurred in the condition of moving water by 1.91 mpy at week 12. Based on corrosion standards presented in Table 4, the level of corrosion rate in nickel specimens for indoor condition is classified as outstanding because it only ranges from 0.61 mpy to 1 mpy. For outdoor condition, it is classified as excellent since the value ranges from 0.89 mpy to 1.34 mpy. Meanwhile, for static seawater condition, it is classified as excellent as the value ranges from 0.97 mpy to 1.24 mpy. Last, for moving seawater condition, it is also still classified as excellent because it ranges from 1.64 mpy to 1.91 mpy [20].

Micro Structure Test

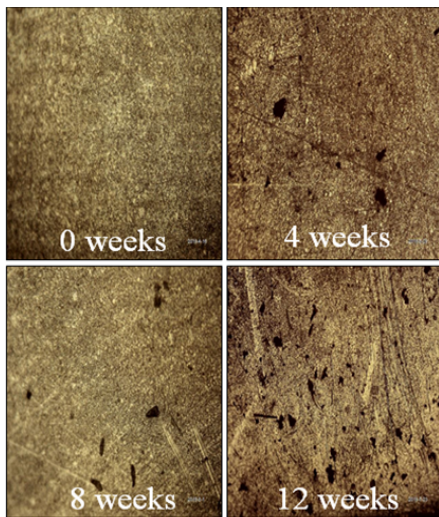


Fig. 9. Nickel surface microstructure corroded with indoor variations

Figure 9 shows that the longer the specimens are exposed to corrosion in the indoor environment, the more holes are formed due to corrosion. At week 0, there was not yet pitting corrosion. At week 4, pitting corrosion pits started to appear. Then, at week 8 until week 12, there were very significant results in pitting corrosion with the appearance of many pitting corrosion pits.

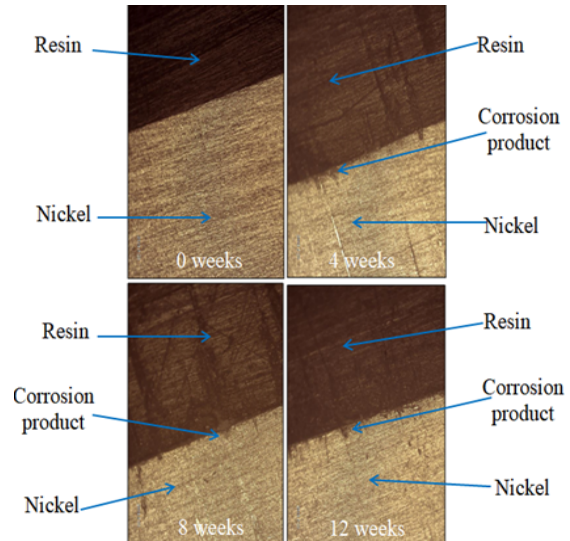


Fig. 10. Micro structure of corrosion forms with variations in door

Figure 10 shows that at week 0 pitting corrosion has not formed yet, while at week 4 pitting corrosion began to form. Between week 8 to week 12 pitting corrosion is increasing with vertical and shallow shapes.

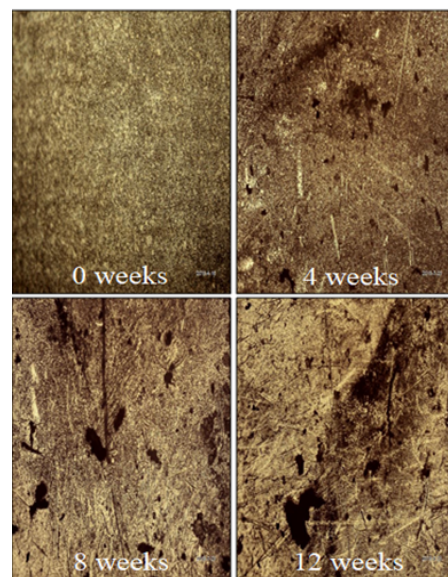


Fig. 11. Nickel surface microstructure corroded with outdoor variations

Figure 11 shows that the longer the specimens are exposed to corrosion in the outdoor environment, the more holes are formed due to pitting corrosion. It is seen that from week 0 there is no pitting corrosion, in week 4 pitting corrosion begins to appear, and week 8 to week 12 show very significant corrosion with a large amount of

corrosion well with increasingly bigger diameter. Corrosion wells are formed due to the breakdown of the protective layer on the surface of the metal by penetration of anions such as chloride.

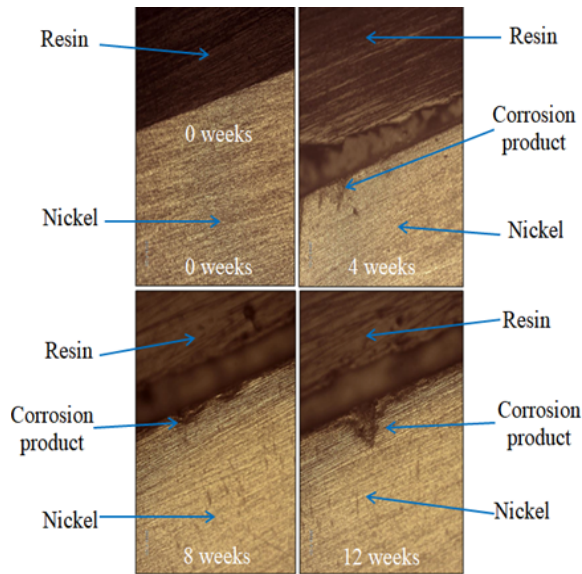


Fig. 12. Corrosion microstructure with outdoor variations

Figure 12 shows that at week 0 corrosion is not yet formed, and corrosion pitting started to appear at week 4. Between week 8 to week 12, corrosion pitting is getting more deeper with a deep conical shape.

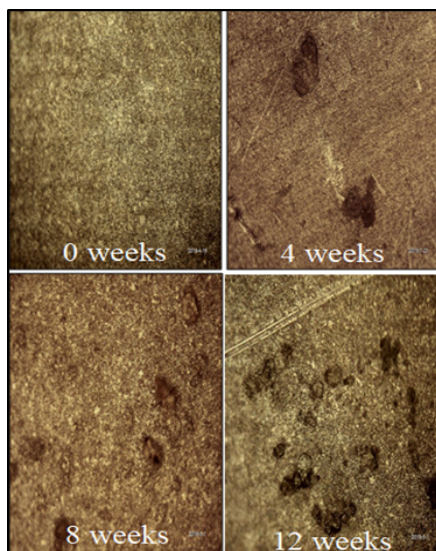


Fig. 13. Nickel surface microstructure with variations in sea water at rest

Figure 13 shows that the longer the specimens are exposed to corrosion in seawater in a stationary

state, the more corrosion is formed due to pitting corrosion. As seen from week 0, corrosion has not appeared yet. At week 4, corrosion begins to occur—pitting with smaller dots compared to the latter stage between week 8 to week 12. Very significant corrosion are shown with many large dots on the later time range.

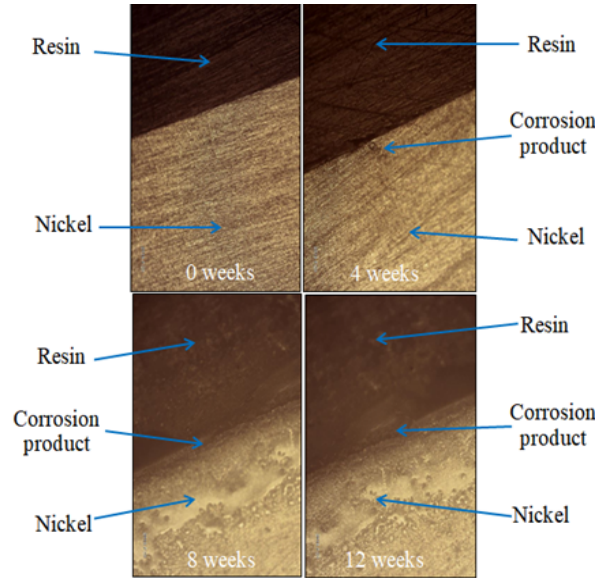


Fig. 14. Microstructure of corrosion forms with variations in deep sea water

In accordance to previous figures, Figure 14 shows that at week 0 corrosion is yet to appear, while at week 4 pitting corrosion is started to form. Between week 8 to week 12, the pitting corrosion is increasing with a widened and shallow shape.

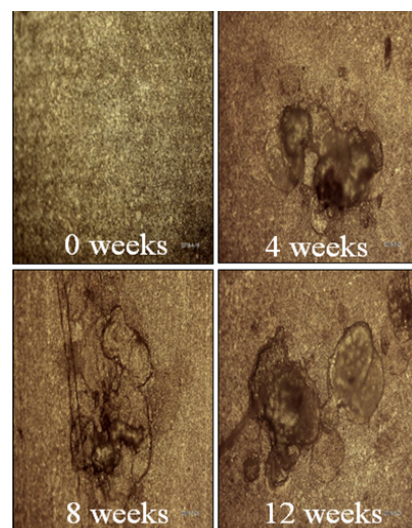


Fig. 15. Nickel surface microstructure with variations in moving water

Figure 15 shows that the longer the specimen is exposed to corrosion in seawater in a moving state, the more corrosion is formed due to erosion corrosion. Week 0 shows no erosion corrosion, but at week 4 it is occurred with a widening form. Very significant corrosion appeared between week 8 to week 12, with wide and numerous shapes. Erosion is formed because of the breakdown of the protective layer on the metal surface in line with fluid flow velocity.

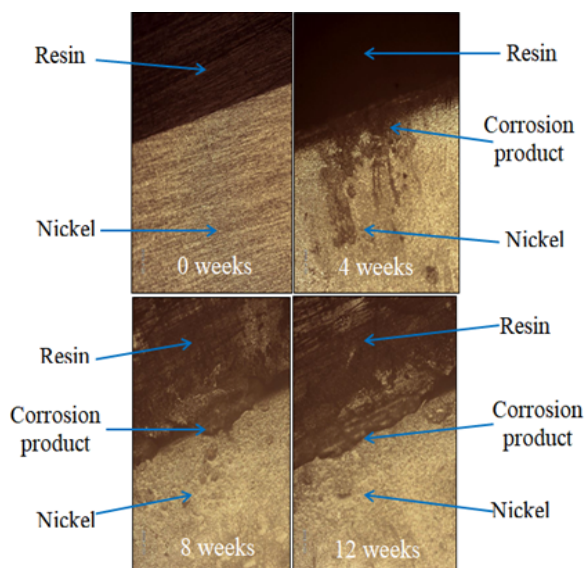


Fig. 16. Microstructure of corrosion forms with variations in sea water in a state of motion.

Figure 16 shows that at week 0 erosion corrosion has not yet formed, at week 4 erosion corrosion has begun to appear, while between week 8 through week 12 the erosion corrosion is wider and deeper.

5. CONCLUSION

Based on the results of the research that has been done on the influence of the different environmental conditions such as indoor, outdoor, static seawater, and moving seawater at Ketawang Beach, the following conclusions can be drawn:

1. The longer the specimen is suspended in an indoor environment, the rate of corrosion decreases. Corrosion rate values are 1 mpy for the first four-weeks period, 0.84 mpy for the second four-weeks period, and 0.61 mpy for the third four-weeks period.

2. The longer the specimen is suspended in an outdoor environment, the rate of corrosion increases. Corrosion rate values are 0.89 mpy for the first four weeks, 1.11 mpy for the next four weeks, and 1.34 mpy for the last four weeks.
3. The longer the test object is immersed in the seawater of Ketawang Beach in a static state, the rate of corrosion decreases. Corrosion rate values are 1.24 mpy during the first four weeks, 1.04 mpy during the second four weeks, and 0.97 mpy during the last four weeks.
4. The longer the specimen is immersed in the seawater of Ketawang Beach in a moving state, the corrosion rate increases. Corrosion rate values are 1.64 mpy for the first four-weeks period, 1.84 mpy for the second four-weeks period, and 1.91 mpy for the third four-weeks period.

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REFERENCES

1. Sarfati D. Measuring cancer in Indigenous populations. New Zealand:Elsevier; 2018.
2. Qin S.-Y., Cheng Y.-J., Lei Q., Zhang A.-Q., Zhang X.-Z. Combinational strategy for high-performance cancer chemotherapy. Wuhan:Elsevier; 2018.
3. Elfahmia, Woerdenbag H., Kasyer O. Jamu : Indonesian traditional herbal medicine towards rational phytopharmacological use. Bandung:Elsevier; 2014.
4. Sardjono Y., Harto A.W., Irhas Dosimetri Boron Neutron Capture Therapy Pada Kanker Hati (Hepatocellular Carcinoma) Menggunakan MCNP CODE Dengan Sumber Neutron dari Kolom Termal. Yogyakarta:PSTA-BATAN; 2014.
5. Savolainen S. Boron neutron capture therapy (BNCT) in Finland : Technological and physical prospects after 20 years of experiences. Helsinki:Elsevier;
6. Rasouli F.S., Masoudi S.. Design and optimization of a beam shaping assembly for BNCT based on D-T neutron generator and

- dose evaluation using a simulated head phantom. Tehran:Elsevier; 2012.
7. Kreine A.J. Present status of Accelerator-Based BNCT.Elsevier Urban and Partner Sp. z o.o.; 2014.
 8. Hilti . Corrosion Handbook. Boston:Addison-Wesley Publishing; 2015.
 9. Sardjono Y., Maysaroh A., Kusminarto, Palupi D.S. Dosimetry of In Vivo Experiment for Lung Cancer based on Boron Neutron Capture Therapy on Radial Piercing Beam Port Kartini Nuclear Reactor by MCNPX Simulation Method. ASEAN J. Sci. Technol. Dev. 35 (3):213–5.
 10. Sauerwein W.A.. Principles and Roots of Neutron Capture Therapy. Essen:Springer-Verlag Berlin Heidelberg.; 2012.
 11. Energy A. (IAEA) I.A. *Current status of neutron capture therapy*. Vienna: 2001.
 12. Warfi R., Harto A.W., Sardjono Y. Optimization of Neutron Collimator in The Thermal Column of Kartini Research Reactor for in vitro and in vivo Trials Facility of Boron Neutron Capture Therapy using MCNP-X Simulator. 2016. 1(10)
 13. Sari Y.A. Penentuan Kadar Nikel Dalam Mineral Laterit Melalui Pemekatan Dengan Metode Kopresipitasi Menggunakan Cu-Pirolidin Dithiokarbamat. Semarang:FMIPA-UNNES; 2013.
 14. Everhart J.L. Engineering Properties Of Nickel And Nickel Alloys. New York:Springer; 1971.
 15. ASTM G1-03 *Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens*. United States: 2017.
 16. Muis S. Teori Keandalan dan Mekanisme Korosi: Teknik Pembuatan Sensor Layar Sentuh. Yogyakarta:Graha Ilmu; 2015.
 17. Hadi S. Teknologi Bahan Lanjut. Yogyakarta:Andi; 2018.
 18. Kelly R.G. Electrochemical Techniques in Corrosion Science and Engineering. New York:Marcel Dekker, Inc; 2003.
 19. Fontana G.M. Corrosion Engineering. New York:McGraw Hill Book Company; 2018.
 20. Jones D.A. Principles and Prevention of Corrosion. New York:Macmillan Publishing Company; 1992.
 21. Voort G.F.V. Applied Metallography. New York:Van Nostrand Reinhold Company; 1986.